The performance of irrigated mixtures of tall fescue, ryegrass and white clover in subtropical Australia. 1. The effects of sowing mixture combinations, nitrogen and oversowing on establishment, productivity, botanical composition and persistence

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Abstract

In the subtropics of Australia, the ryegrass component of irrigated perennial ryegrass (*Lolium perenne*) — white clover (*Trifolium repens*) pastures declines by approximately 40% in the summer following establishment, being replaced by summer-active C_4 grasses. Tall fescue (*Festuca arundinacea*) is more persistent than perennial ryegrass and might resist this invasion, although tall fescue does not compete vigorously as a seedling. This series of experiments investigated the influence of ryegrass and tall fescue genotype, sowing time and sowing mixture as a means of improving tall fescue establishment and the productivity and persistence of tall fescue, ryegrass and white clover-based mixtures in a subtropical environment.

Tall fescue frequency at the end of the establishment year decreased as the number of companion species sown in the mixture increased. Neither sowing mixture combinations nor sowing rates influenced overall pasture yield (of around 14 t/ha) in the establishment year but had a significant effect on botanical composition and component yields. Perennial ryegrass was less competitive than short-rotation ryegrass, increasing first-year yields of tall fescue by 40% in one experiment and by 10% in another but total yield was unaffected. The higher establishment-year yield (3.5 t/ha) allowed Dovey tall fescue to compete more successfully with the remaining pasture components than Vulcan (1.4 t/ha). Sowing 2 ryegrass cultivars in the mixture reduced tall fescue yields by 30% compared with a single ryegrass (1.6 t/ha), although tall fescue alone achieved higher yields (7.1 t/ha). Component sowing rate had little influence on composition or yield. Oversowing the ryegrass component into a 6-week-old sward of tall fescue and white clover improved tall fescue, white clover and overall yields in the establishment year by 83, 17 and 11%, respectively, but reduced ryegrass yields by 40%. The inclusion of red (*T. pratense*) and Persian (*T. resupinatum*) clovers and chicory (*Cichorium intybus*) increased first-year yields by 25% but suppressed perennial grass and clover components.

Yields were generally maintained at around 12 t/ha/yr in the second and third years, with tall fescue becoming dominant in all 3 experiments. The lower tall fescue seeding rate used in the first experiment resulted in tall fescue dominance in the second year following establishment, whereas in Experiments 2 and 3 dominance occurred by the end of the first year. Invasion by the C_4 grasses was relatively minor (< 10%) even in the third year. As ryegrass plants died, tall fescue and, to a lesser extent, white clover increased as a proportion of the total sward. Treatment effects continued into the second, but rarely the third, year and mostly affected the yield of one of the components rather than total cumulative yield. Once tall fescue became dominant, it was difficult to re-introduce other pasture components, even following removal of foliage and moderate renovation. Severe renovation (reducing the tall fescue population by at least 30%) seems a possible option for redressing this situation.

Introduction

In the temperate regions of Australia, dairy farmers sow perennial ryegrass (*Lolium perenne*) and white clover (*Trifolium repens*) pastures, which are highly productive, produce high quality

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feed for most of the year and persist for at least 5 years if management and environmental conditions are appropriate (Read *et al.* 1990). However, in the subtropical environment of southern Queensland and northern New South Wales, hot humid summers reduce the growth and persistence of perennial ryegrass (Lowe *et al.* 1999a). During summer, less-desirable, faster-growing C_4 grasses tend to invade these pastures. To maintain cool season production, many dairy farmers in the subtropics sow vigorous, winter-growing annual or short-rotation ryegrasses (*L. multiflorum*) and then in early summer either oversow with a forage crop or allow natural pasture to re-establish (Lowe and Hamilton 1985; Kelly *et al.* 1990). These approaches, although productive, are costly and leave gaps in the supply of forage during the establishment periods for both the winter pasture and the forage crop.

Cultivar screening experiments in southern Queensland (Lowe and Bowdler 1984; 1995) showed that alternative temperate perennial grasses, including tall fescue (*Festuca arundinacea*), were more persistent during the warmer months and produced higher yields than the more seasonally variable perennial ryegrass. However, a grazing experiment conducted in the same environment demonstrated that milk production from tall fescue was less efficient (*i.e.*, lower milk production per unit of forage on offer) than from perennial ryegrass (Lowe *et al.* 1999b). We hypothesised that a planting mixture of tall fescue, ryegrass and white clover might produce a pasture which established quickly after germination, produced high yields (with high forage quality) and persisted longer than perennial ryegrass-white clover mixtures.

If ryegrass plants are lost, C_4 grasses, including rhodes grass (*Chloris gayana*) and paspalum (*Paspalum dilatatum*), tend to invade (Lowe and Hamilton 1985; Lawson *et al.* 2002), reducing the productive period of the cool season species (Cameron 1969). Tall fescue has demonstrated an ability to replace ryegrass and to resist the ingress of C_4 grasses under subtropical conditions (Lowe and Bowdler 1995) and can become dominant (Lowe *et al.* 1999a). Methods of re-introducing other components need to be identified.

This study aimed to identify methods of establishing combinations of tall fescue, ryegrass and white clover in a subtropical environment, which would ensure satisfactory establishment of all components and long-term pasture productivity. Factors investigated included: the types of tall fescue cultivar and ryegrass species sown; time of sowing of the ryegrass component; sowing rates for ryegrass and tall fescue; the number of grasses and other species sown with tall fescue; and the use of nitrogen applications at establishment. The 2 papers in the series cover the establishment of these mixtures, their yield, botanical composition and persistence over 3 years and a comparison of their performance under fixed-defoliation or tall fescue-specific management regimes. This first paper of the series presents data on establishment and performance over 3 years.

Materials and methods

Site

Field sowings were made in 1997, 1998 and 1999 into fully prepared seedbeds in adjacent sites at Gatton Research Station in south-east Queensland (27°34′S, 152°20′E; elevation 95 m). The soil type was an alluvial black clay (black earth, Stace *et al.* 1972; Ug 5.15, Northcote 1971) with a soil analysis of 128 mg/kg phosphorus (Colwell extraction) and 1.0 cmole/kg potassium (K) and a pH of 8.3 (H_2O). Gatton experiences a subtropical climate with 60% of its rainfall in summer; up to 30 frosts can occur during winter.

Treatments and design

Experiment 1. Fourteen temperate pasture mixtures (Table 1) were sown by hand in April 1997 into forty-two 10 m^2 plots in a randomised block design, giving 3 replications. Haifa white clover (*Trifolium repens*), the most adapted white clover cultivar in south-east Queensland (Jones and Lowe 1992), was included in all mixtures at 10 kg/ha. Two tall fescue cultivars (Dovey and Vulcan) and 2 ryegrasses (Dobson and Flanker) were sown alone or in various combinations, *i.e.*, each of the fescues with 1 or 2 companion ryegrasses. Ryegrass was sown at either 5 or 10 kg/ha and tall fescue at 10 kg/ha. The cultivars were chosen because they contributed specific characteristics to the mixtures. Dovey is high-yielding and has good seedling vigour, while Vulcan is a comparatively high-quality selection but with less vigorous seedling growth (Stewart and Charlton 2003). Dobson (*L. perenne*), a perennial cultivar with an upright habit, contrasts

Table 1. Sowing combinations included in Experiments 1–3. Seeding rates (kg/ha) are in brackets.

Treatment No	Treatment combination
Experiment 1	
1	Dovey[1] (10), Dobson (10), Haifa (10)
2	Dovey (10), Flanker (10), Haifa (10)
3	Vulcan (10), Dobson (10), Haifa (10)
4	Vulcan (10), Flanker (10), Haifa (10)
5	Dovey (10), Dobson (5), Haifa (10)
6	Dovey (10), Flanker (5), Haifa (10)
7	Vulcan (10), Dobson (5), Haifa (10)
8	Vulcan (10), Flanker (5), Haifa (10)
9	Dobson (10), Haifa (10)
10	Flanker (10), Haifa (10)
11	Dovey (10), Haifa (10)
12	Vulcan (10), Haifa (10)
13	Dovey (10), Flanker (5), Dobson (5), Haifa (10)
14	Vulcan (10), Flanker (5), Dobson (5), Haifa (10)
Experiment 2	
1	Dovey (10), Tetila (5), Haifa (5), ryegrass sown with other components
2	Dovey (25), Tetila (5), Haifa (5), ryegrass sown with other components
3	Dovey (10), Flanker (5), Haifa (5), ryegrass sown with other components
4	Dovey (25), Flanker (5), Haifa (5), ryegrass sown with other components
5	Dovey (10), Dobson (5), Haifa (5), ryegrass sown with other components
6	Dovey (25), Dobson (5), Haifa (5), ryegrass sown with other components
7	Dovey (10), Tetila (5), Haifa (5), ryegrass sown 6 wks later
8	Dovey (25), Tetila (5), Haifa (5), ryegrass sown 6 wks later
9	Dovey (10), Flanker (5), Haifa (5), ryegrass sown 6 wks later
10	Dovey (25), Flanker (5), Haifa (5), ryegrass sown 6 wks later
11	Dovey (10), Dobson (5), Haifa (5), ryegrass sown 6 wks later
12	Dovey (25), Dobson (5), Haifa (5), ryegrass sown 6 wks later
Experiment 3[2]	
1	Dovey (25), Haifa (5), 0N at sowing
2	Quantum (25), Haifa (5), 0N at sowing
3	Dovey (5), Impact (10), Aran (1), Sustain (1), Renegade (6), Maral (1), Puna (0.5), 0N at sowing
4	Dovey (25), Haifa (5), 60N at sowing
5	Quantum (25), Haifa (5), 60N at sowing
6	Dovey (5), Impact (10), Aran (1), Sustain (1), Renegade (6), Maral (1), Puna (0.5), 60N at sowing

[1] Dovey and Vulcan = tall fescue; Flanker = short-rotation ryegrass; Dobson and Impact = perennial ryegrass; Tetila = annual ryegrass; Haifa, Aran and Sustain = white clover; Renegade = red clover; Maral = Persian clover; and Puna = chicory.
[2] Each initial treatment subdivided in Year 2 to include oversowing treatments.

with Flanker, a vigorous, long-season Italian ryegrass (*L. multiflorum*) type (Stewart and Charlton 2003). Their contrasting seasonal growth characteristics were expected to provide different competition levels for tall fescue seedlings. Flanker was sown only at establishment, with no additional sowings in Years 2 and 3.

Experiment 2. Pasture mixtures of ryegrass and tall fescue (Table 1) were sown by hand in April 1998 into thirty-six 10 m^2 plots in a randomised block design with 3 replications. Twelve treatments were compared: combinations of 3 ryegrass cultivars (Dobson perennial, Flanker short-rotation and Tetila annual), 2 sowing times for the ryegrass component (sown with the other components or 6 weeks later) and 2 seeding rates for the tall fescue component (10 and 25 kg/ha). Again, the cultivars were chosen because they contributed specific characteristics to the mixtures. Dovey was chosen as Vulcan performed poorly in Experiment 1. Tetila is a quick-growing, short-season annual which was expected to provide less competition in the first year for the tall fescue component than Flanker. Ryegrasses were either sown at the same time as other components into a prepared seedbed or oversown 6 weeks later without soil disturbance to allow the tall fescue to establish without ryegrass competition. All ryegrasses and white clover were sown at 5 kg/ha. The higher tall fescue seeding rate was the recommended rate in areas of New Zealand where tall fescue was the dominant species (McCallum *et al*. 1992).

Experiment 3. Eighteen plots of 30 m^2 were sown by hand in April 1999 with one of 3 temperate pasture mixtures: (i) Dovey tall fescue (25 kg/ha) and Haifa white clover (5 kg/ha), (ii) Quantum tall fescue (25) and Haifa (5) and

(iii) Dovey (5), Impact ryegrass (10), Aran white clover (1), Sustain white clover (1), Renegade red clover (*T. pratense*) (6), Maral Persian clover (*T. resupinatum*) (1) and Puna chicory (*Cichorium intybus*) (0.5) (complex mixture) (Table 1). The experiment was a split-plot design, with 3 replications. Two nitrogen (N) treatments (nil or 60 kg N/ha) were applied as urea at sowing to the 3 pasture mixtures. Cultivars were again chosen because they contributed specific characteristics to the mixture combinations. Quantum was another tall fescue with high seedling vigour. The complex mixture contained other adapted cultivars of ryegrass, white, red and Persian clovers and chicory which had performed well in previous studies (Lowe *et al*. 1996).

At the end of the first year, each of the main plots was split into three 10 m^2 plots. Three oversowing treatments were imposed on these swards in April 2000, and were re-imposed on the same plots in April 2001. All swards were defoliated to 5 cm, ripped to a depth of 5 cm with a tyned implement (0.3 m between tynes) in order to create soil disturbance without major loss of established plants. After ripping, the swards were oversown with Surrey annual ryegrass at 20 kg/ha or Impact perennial ryegrass at 10 kg/ha or left as a control with no extra seed added. Seed was broadcast on to the surface and irrigation was applied to provide coverage.

Techniques

Harvesting of each experiment commenced in June after early April sowings and regrowth was assessed at 4-week intervals for 36 months. Dry matter (DM) yield was measured by cutting, to 5 cm, a quadrat of 5.9 m^2 using a self-propelled harvester with a reciprocating blade that defoliated, collected and weighed the samples in one operation, from the central section of each plot. A sample of the cut material was taken to determine the DM content of the fresh material and botanical composition. Botanical composition was determined by hand-sorting a sub-sample into ryegrass, tall fescue, clover and weeds (and chicory in Experiment 3). Samples were dried in a forced-draught oven at 80°C for 24 h. After sampling harvests, pasture residues were removed using a forage harvester.

Plant frequency of tall fescue and ryegrass was determined in autumn each year, using a fixed 1 m × 0.25 m quadrat, divided into a 100-square grid. The presence or absence of plant tillers was recorded in each square and frequency was expressed as a percentage as suggested by Tothill (1978). Plant frequency was not assessed at the end of the establishment year for Experiment 3 because of the need to cultivate swards prior to oversowing.

Seasonal yields were calculated by summing the DM yields measured within the following periods: autumn – March 1 to May 31, winter – June 1 to August 31, spring – September 1 to November 30 and summer – December 1 to February 28/29. A harvest was included in a seasonal yield if more than half the growth period occurred in that season.

Plots received 50 mm of irrigation every 2 weeks using hand-shift, overhead sprinklers to ensure yields were not limited by soil moisture stress (Anon 1995). Irrigation schedules were maintained unless more than 25 mm of rainfall was received in the week prior to scheduled application.

Statistical analyses

Data for DM yields and plant frequency were subjected to analysis of variance using the statistical package 'Genstat' (Payne *et al*. 2007). In Experiment 1, fescue, ryegrass, clover, total grass, grass plus clover and total DM yield data were normally distributed and did not require transformation. Weed data were log transformed using (DM+0.0001). Plant frequency needed angular transformation using (180/pi)*arcsin(sqrt(p/100)). Treatments (Table 1) were combined as indicated below for the following factorial analyses:

Dovey (1, 2, 5, 6, 11, 13) *vs* Vulcan (3, 4, 7, 8, 12, 14)
Dobson (1, 3, 5, 7, 9) *vs* Flanker (2, 4, 6, 8, 10)
1 ryegrass in mixture (1, 2, 3, 4, 5, 6, 7, 8) *vs* 2 ryegrasses (13, 14)
no ryegrass in mixture (11, 12) *vs* 2 ryegrasses (13, 14)
no ryegrass in mixture (11, 12) *vs* 1 ryegrass (1, 2, 3, 4, 5, 6, 7, 8)
ryegrass seeding rate; 5 kg/ha (5, 6, 7, 8) *vs* 10 kg/ha (1, 2, 3, 4).

DM data for all components and total yield were normally distributed in Experiments 2 and

3 and did not require transformation. Interactions between factors were generally non-significant or, when present, were small relative to the main effects. Therefore, only main effect results have been presented for all 3 experiments. In Experiment 3, 2 N treatments were applied at sowing but, as significant differences were demonstrated only in the cut immediately following sowing, second- and third-year data have been presented as averages.

Climate

Rainfall, A-pan evaporation and temperature recorded at Gatton from 1997 to 2002 are presented in Figure 1. The 1998–99 summer was hotter and wetter than those in 1997–98 and 1999–2000, while a severe drought with extreme temperatures prevailed in the 2001–02 summer. Evaporation rates were very high in the 2000–01 and 2001–02 summers, and the 2001 winter was colder and drier than the other winters.

Results

DM yield

Experiment 1. Choice of ryegrass cultivar, the number of grass species included and ryegrass seeding rate had no effect (P>0.05) on total sown species yields of the mixtures in any year of the study (Table 2). Over the 3-year period, yields increased by only 0.3, 3.1 and 0.3% as a result of changing ryegrass cultivar, modifying the number of ryegrass cultivars sown in the mixture and modifying the ryegrass seeding rate, respectively. Varying the tall fescue cultivar affected (P<0.05) total sown species yield only in the third year and over the 3 years; Dovey increased it by 8.6% over the 3-year period compared with Vulcan.

In the establishment year, clover yield was lower (P<0.05) when grown with Dovey tall fescue than with Vulcan. Including ryegrass in the sowing mixture depressed yields of tall fescue, in particular, as well as white clover (P<0.05). Ryegrass yields were higher (P<0.05) when 2 ryegrasses were sown compared with only 1. Flanker ryegrass yielded more (P<0.05) than Dobson perennial ryegrass, but associated yields of tall fescue and clover were reduced (P<0.05). The higher ryegrass sowing rate significantly (P<0.05) reduced tall fescue yields.

In the second and third years and in the accumulated 3-year total, ryegrass and white clover yields were higher (P<0.05) when Vulcan was used instead of Dovey (Table 2). Including ryegrass in the mixture reduced tall fescue and white clover yields (P<0.05) independent of the number of ryegrass cultivars sown. Sowing 2 ryegrass cultivars increased (P<0.05) ryegrass yield compared with sowing only 1 ryegrass but only in the second year. The higher ryegrass seeding rate increased (P<0.05) ryegrass yields, had no effect on white clover or total sown yields but depressed tall fescue yields. Weed yields were low, occurring mainly in the third year and only 3-year yields are presented.

Experiment 2. While ryegrass yields were very good in the establishment year (about 6.3 t/ha), yields were poor (0–0.4 t/ha) in Years 2 and 3. Sowing the ryegrass component at the same time as the other components increased ryegrass yield by 66% in the establishment year compared with delayed sowing but almost halved that of tall fescue (Table 3). There was a smaller, but significant increase (P<0.05) in clover (Table 3) and weed (data not presented) yields with delayed sowing of ryegrass. The overall result was that total yield was significantly (P<0.05) increased (about 11%) by delayed sowing of ryegrass. In the second and third years, there was no significant effect of ryegrass sowing time on total sown species yield. Over the 3 years, total sown yields and yields of fescue and white clover were increased by delayed sowing of ryegrass.

In all 3 years, ryegrass and weed yields (data not presented) were significantly (P<0.05) reduced when tall fescue was sown at 25 kg/ha compared with 10 kg/ha, while tall fescue yield was higher at the higher sowing rate in the establishment year. Total yields were unaffected (P>0.05).

Overall, choice of ryegrass cultivar had little effect on yields, although tall fescue yield was highest (P<0.05) in association with Tetila. All 3 ryegrass cultivars yielded poorly in the second and third years, with Tetila showing no regeneration after the establishment year. White clover and total sown yields were unaffected by ryegrass cultivar.

Experiment 3. Sowing mixture affected total pasture yield, with the complex mixture yielding 25% more (P<0.05) than the simple mixtures in the establishment year (Table 4). However in

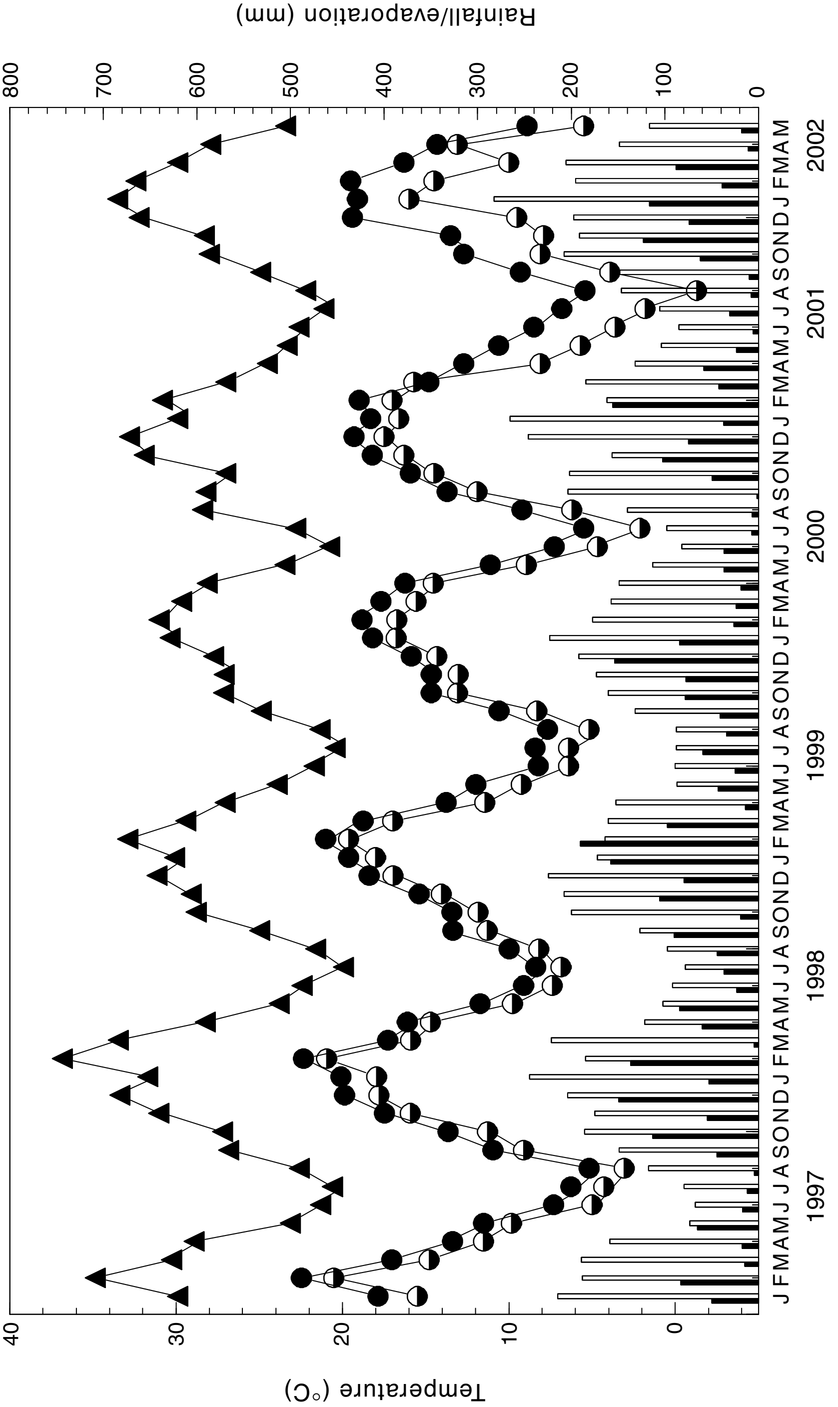

Figure 1. Mean monthly maximum (▲), minimum (●) and terrestrial minimum (◐) temperatures (°C) and rainfall (▬) and A-pan evaporation (▭)(mm) at Gatton Research Station from January 1997 to May 2002.

Table 2. Component and total dry matter yields (t/ha) of ryegrass-tall fescue-clover mixtures, sown in 1997 at Gatton, for the 3 years following sowing (Experiment 1).

Treatment	Establishment year (1997–1998)				Second year (1998–1999)				Third year (1999–2000)				3-year total				
	Ryegrass	Tall fescue	White clover	Total sown species	Ryegrass	Tall fescue	White clover	Total sown species	Ryegrass	Tall fescue	White clover	Total sown species	Ryegrass	Tall fescue	White clover	Total sown species	Weeds
Effect of tall fescue cultivar																	
Dovey	6.0	3.5	5.6	15.1	2.5	5.5	6.2	14.1	0.2	4.9	7.3	12.8	8.0	12.6	17.4	38.0	0.9
Vulcan	6.3	1.4	6.2	13.9	4.1	1.1	8.0	13.2	1.1	1.3	8.7	12.0	10.6	3.5	20.9	35.0	2.0
LSD (P=0.05)[1]	NS[2]	0.6	0.6	NS	0.5	0.6	0.4	NS	0.2	0.5	0.6	0.8	0.8	1.0	0.7	1.2	0.5
Effect of ryegrass cultivar																	
Dobson	5.3	2.0	6.3	13.6	3.3	3.2	7.3	13.6	0.8	2.8	8.0	12.0	8.7	7.3	19.7	35.7	1.6
Flanker	7.1	1.2	5.0	13.3	3.7	3.0	6.9	13.5	0.7	3.2	8.4	12.6	10.6	6.7	18.5	35.8	1.6
LSD (P=0.05)	0.6	0.7	0.6	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.8	NS	0.8	NS	NS
When tall fescue is sown with:																	
No ryegrass cvv.	—[3]	7.1	7.5	14.6	—	5.5	7.8	13.7	—	4.0	8.0	12.6	—	15.2	21.2	36.4	1.5
1 ryegrass cv.	6.0	1.6	5.5	13.1	3.1	3.0	6.9	13.6	0.6	3.0	8.0	12.4	8.9	7.0	18.6	34.6	1.6
2 ryegrass cvv.	6.8	1.1	5.9	13.8	4.0	2.3	7.1	13.7	0.8	2.6	7.9	12.0	10.7	5.5	19.1	35.3	1.2
LSD (0 *vs* 1) (P=0.05)	na[4]	0.8	0.8	1.4	na	0.8	0.6	NS	na	0.6	NS	NS	na	1.4	1.0	NS	NS
LSD (0 *vs* 2) (P=0.05)	na	1.0	1.0	NS	na	1.1	0.8	NS	na	0.8	NS	NS	na	1.8	1.3	NS	NS
LSD (1 *vs* 2) (P=0.05)	0.8	NS	NS	NS	0.7	NS	0.8	NS	NS	NS	NS	NS	1.1	1.4	1.0	NS	NS
Effect of ryegrass seeding rate																	
5 kg/ha	6.1	2.0	5.1	13.2	2.8	3.6	6.8	13.6	0.5	3.2	7.9	12.2	8.6	8.0	18.0	34.6	1.4
10 kg/ha	5.9	1.1	5.9	12.9	3.5	2.5	7.2	13.6	0.7	2.9	8.2	12.7	9.3	5.9	19.3	34.5	1.6
LSD (P=0.05)	NS	0.7	0.7	NS	0.6	0.8	NS	NS	0.2	NS	NS	NS	NS	1.3	0.9	NS	NS

[1] Within columns, LSD (P=0.05) values are provided for detecting differences between means.
[2] NS — non-significant differences.
[3] — not sown.
[4] na — no statistical analysis possible.

Table 3. Component and total dry matter yields (t/ha) of ryegrass-tall fescue-clover mixtures, sown in 1998 at Gatton, in the 3 years after sowing (Experiment 2).

Treatment	Establishment year (1998–1999)				Second year (1999–2000)				Third year (2000–2001)				3-year total				
	Ryegrass	Tall fescue	White clover	Total sown species	Ryegrass	Tall fescue	White clover	Total sown species	Ryegrass	Tall fescue	White clover	Total sown species	Ryegrass	Tall fescue	White clover	Total sown species	Weeds
Tall fescue sowing rate																	
10 kg/ha	6.6	6.6	5.9	19.0	0.4	7.1	11.1	18.5	0.1	6.9	3.7	10.6	7.1	20.5	20.6	48.2	2.1
25 kg/ha	6.0	8.2	4.5	18.6	0.1	7.4	10.4	18.0	0.0	6.6	3.7	10.3	6.1	22.1	18.6	46.9	2.5
LSD (P=0.05)[1]	0.5	0.7	0.4	NS[2]	0.1	NS	NS	NS	0.1	NS	NS	NS	0.6	0.9	1.7	NS	0.3
Ryegrass cultivar																	
Dobson	5.9	7.7	5.3	18.9	0.4	6.8	10.7	17.9	0.0	6.6	3.7	10.3	6.3	21.5	19.7	47.1	2.0
Tetila	6.4	7.4	5.5	19.2	0.1	7.8	10.4	18.2	0.0	7.1	3.6	10.7	6.4	22.3	19.4	48.0	2.3
Flanker	6.6	7.0	4.9	18.4	0.4	7.0	11.1	18.5	0.1	6.5	3.7	10.3	7.0	21.1	19.7	47.3	2.5
LSD (P=0.05)	NS	NS	0.5	NS	0.2	0.6	NS	NS	NS	0.4	NS	NS	NS	1.2	NS	NS	0.4
Ryegrass sowing time																	
Week 0	7.8	5.2	4.8	17.8	0.4	7.3	10.2	17.9	0.1	6.6	3.6	10.2	8.3	19.1	18.5	45.9	2.2
Week 6	4.7	9.5	5.6	19.8	0.1	7.2	11.3	18.6	0.0	6.8	3.8	10.7	4.9	23.5	20.7	49.1	2.4
LSD (P=0.05)	0.5	0.7	0.4	0.6	0.1	NS	NS	NS	NS	NS	NS	NS	0.6	0.9	1.7	1.5	NS

[1] Within columns, LSD (P=0.05) values are provided for detecting differences between means.
[2] NS — non-significant differences.

subsequent years, it yielded about 20% less than the simple mixtures as components were lost (Table 5). Tall fescue and white clover yields in the simple mixture were higher (P<0.05) than in the complex mixture, especially in the second and third years. Dovey outyielded (P<0.05) Quantum in the first year but not subsequently (P>0.05). The application of nitrogen at sowing had no effect (P>0.05) on component or total yields at any stage.

Table 4. The effect of sowing mixture and nitrogen application at sowing on first-year DM yields (t/ha) of mixtures at Gatton (Experiment 3, 1999).

Treatment	Pasture component			
	Tall fescue	Legumes	Chicory	Total sown species
Mixture				
Dovey-Haifa (D)	13.5	6.9	—[3]	20.4
Complex mixture (M)	1.5	9.2	12.2	25.5
Quantum-Haifa (Q)	11.5	7.9	—	19.5
LSD (P=0.05)	1.9[1]	1.3	na[4]	1.8
Nitrogen at sowing				
60 kg/ha (60)	8.6	7.9	4.4	21.7
Nil (0)	9.0	8.1	3.7	21.9
LSD (P=0.05)	NS[2]	NS	NS	NS

[1] Within columns, LSD (P=0.05) values are provided for detecting differences between means.
[2] NS — non-significant differences.
[3] — not sown.
[4] na — no statistical analysis possible.

Oversowing with annual or perennial ryegrasses failed to increase (P>0.05) ryegrass yield in any mixture compared with ripping alone in either year after sowing (data not presented); ryegrass averaged less than 100 kg/ha in the second year and less than 30 kg/ha in the third. Weed yields were low (<1%) and unaffected by treatment (Table 5).

Seasonal yields

Experiment 1. In the establishment year, pastures were grass-dominant in winter, slightly grass dominant in spring and clover-dominant in summer and autumn (Figure 2.1A). Ryegrass was the dominant grass in mixtures in winter and spring. Dovey outyielded Vulcan (P<0.05) in spring, summer and autumn, but total yields of Dovey and Vulcan mixtures were similar (P>0.05) in all seasons.

While Flanker produced (P<0.05) higher yields in the first winter than Dobson, there was more clover in the Dobson mixture (Figure 2.1B). Total yield was higher (P<0.05) in the Dobson mixture but only in spring.

When no companion ryegrass was sown, tall fescue yields were higher (P<0.05) in all seasons in the establishment year (Figure 2.1C) and clover yields were higher in winter and spring. Ryegrass yield in spring was significantly higher

Table 5. Total and component DM yields (t/ha) of simple and complex mixtures sown at Gatton in 1999 in the second and third years (Experiment 3).

Mixture	Ryegrass	Tall fescue	White clover	Chicory	Total sown species	Weeds
Second year after establishment (2000–01)						
Dovey simple mixtures	0.0	6.8	6.1	—[3]	12.9	0.02
Complex mixture	0.1	2.3	1.6	6.0	10.0	0.04
Quantum simple mixtures	0.1	7.4	5.9	—	13.4	0.06
LSD (P=0.05)[1]	NS[2]	0.4	0.4	na[4]	0.6	NS
Third year after establishment (2001–02)						
Dovey simple mixtures	0.0	7.2	3.4	—	10.6	0.03
Complex mixture	0.0	3.9	2.3	2.3	8.5	0.06
Quantum simple mixtures	0.0	6.8	3.2	—	10.0	0.11
LSD (P=0.05)	NS	0.5	0.6	na	1.0	NS
Two-year total						
Dovey simple mixtures	0.0	14.0	9.5	—	23.5	0.06
Complex mixture	0.1	6.2	3.9	8.3	18.5	0.10
Quantum simple mixtures	0.1	14.2	9.2	—	23.5	0.17
LSD (P=0.05)	NS	0.6	0.9	na	1.3	NS

[1] Within columns, LSD (P=0.05) values are provided for detecting differences between means.
[2] NS — non-significant differences.
[3] — not sown.
[4] na — no statistical analysis possible.

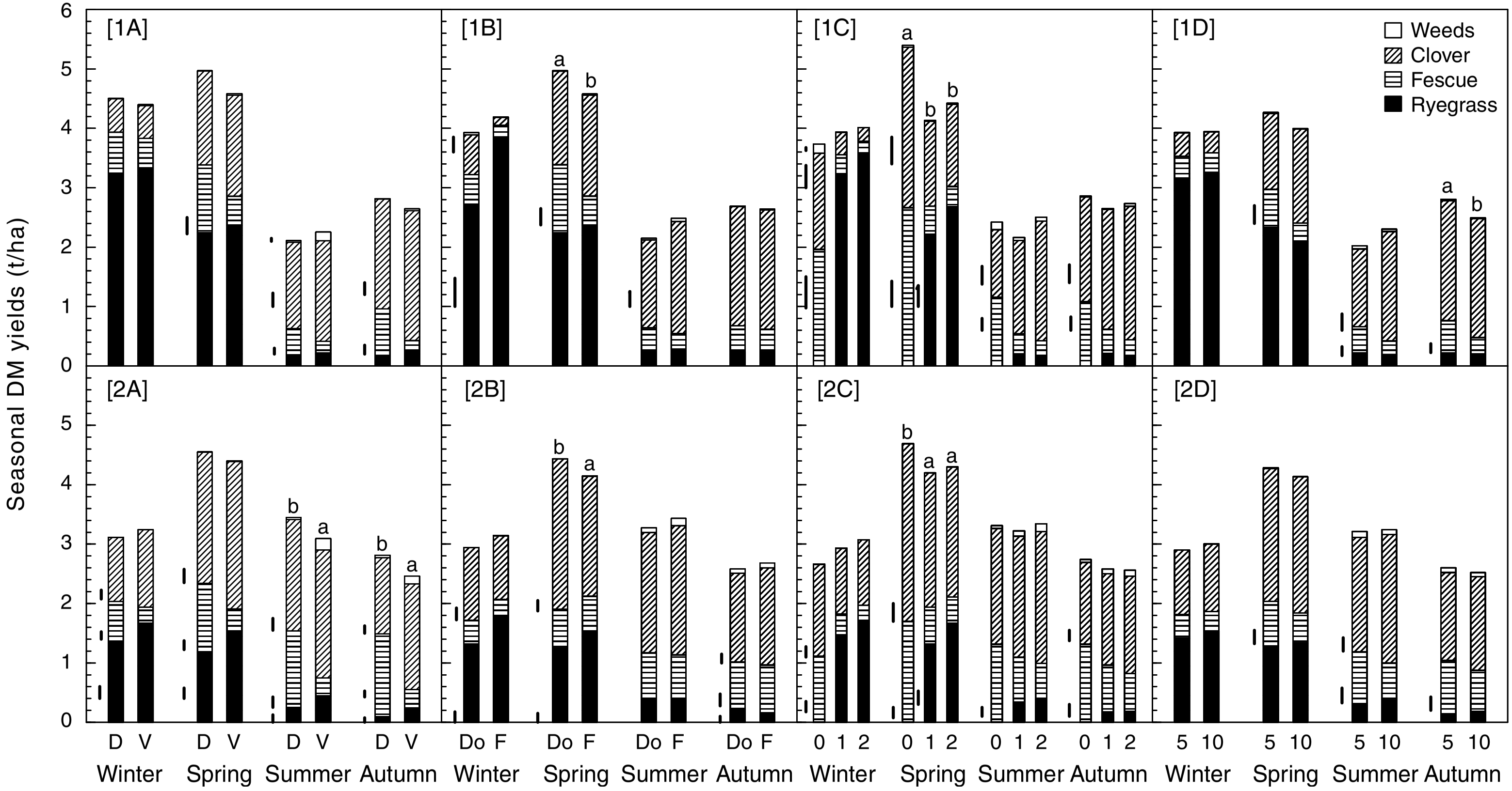

Figure 2. The effects of: [A] tall fescue cultivar (D — Dovey, V — Vulcan); [B] ryegrass cultivar (Do — Dobson perennial ryegrass, F — Flanker short-rotation ryegrass); [C] number of ryegrass cultivars sown (0, 1, 2); and [D] ryegrass sowing rate (5 kg/ha, 10 kg/ha) on the seasonal yield and botanical composition of pasture mixtures in the establishment year (Graph 1) and averaged over the 3 years (Graph 2) (1997, Experiment 1).
Vertical bars alongside each component indicate significance at P=0.05. Column totals, within seasons, headed by different letters are significantly different at P=0.05.

($P<0.05$) when 2 ryegrass cultivars were sown with tall fescue compared with only 1. Ryegrass sowing rate had no effect on any pasture component in the first winter (Figure 2.1D). However in the other 3 seasons, tall fescue yields were higher ($P<0.05$) at the lower ryegrass seeding rate.

Over the 3-year period, pastures were slightly grass-dominant in winter, changing slowly to legume dominance in summer and autumn, especially with Vulcan. Tall fescue cultivar had a substantial effect on pasture composition in all seasons (Figure 2.2A). Dovey outyielded Vulcan ($P<0.05$) so that ryegrass and white clover yields were consistently higher ($P<0.05$) with Vulcan than with Dovey. Total pasture yields were higher ($P<0.05$) in Dovey-based swards during summer and autumn. Choice of ryegrass cultivar affected seasonal component yields with Dobson outyielding Flanker in autumn and Flanker being superior ($P<0.05$) in winter and spring (Figure 2.2B). Ryegrass cultivar influenced ($P<0.05$) total yields in spring with Dobson superior to Flanker.

Including ryegrass in the mixture reduced tall fescue yields ($P<0.05$) in all seasons and the effect was generally worse when 2 ryegrasses were sown, but total yields were influenced only in spring (Figure 2.2C). Sowing ryegrass in the mixture also reduced ($P<0.05$) clover yields in all seasons except summer. Sowing ryegrass at 10 rather than 5 kg/ha in the mixture reduced ($P<0.05$) tall fescue yields in all seasons except winter and white clover yields in summer but had no effect ($P>0.05$) on seasonal ryegrass yields (Figure 2.2D). Weeds were present only during summer and autumn, and yields were unaffected by treatment.

Experiment 2. Pastures were very weedy in the autumn following sowing, and were grass-dominant through winter, spring and summer but were legume-dominant by the second autumn (Figure 3.1A). Sowing tall fescue at 25 kg/ha rather than 10 kg/ha increased ($P<0.05$) fescue yield in the autumn and winter after sowing but reduced clover yields until summer. Effects on total yield were significant in autumn and spring but differences were not great.

Ryegrass cultivar had little effect on production in the establishment year or overall, although tall fescue yield in the first spring was highest ($P<0.05$) in combination with Dobson. Tetila was the highest ($P<0.05$) yielding ryegrass in the first autumn (Figure 3.1B) but by the second autumn, Dobson was the only ryegrass still surviving. Weed yields were highest in association with Dobson. Delayed sowing of the ryegrass component reduced ($P<0.05$) total yield in the first autumn compared with sowing all components at the same time but increased spring and summer yields (Figure 3.1D). While autumn, winter and spring yields of ryegrass in the establishment year were lower ($P<0.05$) with delayed sowing, yields of tall fescue and clover were increased ($P<0.05$) and this effect persisted throughout most of the first year.

Over the 3-year period, sowing time of the ryegrass component was the most influential factor on seasonal yields (Figure 3.2C). Sowing ryegrass 6 weeks after the other components reduced ($P<0.05$) ryegrass yield in all seasons, while white clover and tall fescue yields were increased, significantly ($P<0.05$) so in winter and spring for tall fescue and in winter and summer for white clover. Total yields were increased ($P<0.05$) in spring and summer if sowing was delayed.

Overall, sowing the tall fescue component at 25 rather than 10 kg/ha had little effect on yields although fescue yields were increased and white clover yields reduced ($P<0.05$) in winter (Figure 3.2A). However, total yield in summer was higher ($P<0.05$) at the lower seeding rate of tall fescue. Choice of ryegrass cultivar in the mixture had minimal effect on the pasture (Figure 3.2B). Weeds were most prominent in summer and were unaffected by treatment.

Experiment 3. In the establishment year, the complex mixture produced the highest yields ($P<0.05$) in every season except winter (Figure 4A). However, composition of the forage differed greatly between mixtures. While the 2 simple mixtures were grass-dominant from autumn to spring and generally balanced between grass and clover in summer and the second autumn, the complex mixture was predominantly chicory and clover with ryegrass contributing significant amounts in winter only and disappearing by summer. Clover yields were highest in the complex mixture in winter and spring, declining into summer and the second autumn. Nitrogen application increased ($P<0.05$) ryegrass, tall fescue, clover and total yields in the first autumn but had no subsequent effect (Figure 4B).

Over the 3-year period, choice of mixture had a substantial effect on the seasonal yields of components (Figure 5). Total yields of the simple mixtures were higher ($P<0.05$) than those of the complex mixture in autumn and more than double

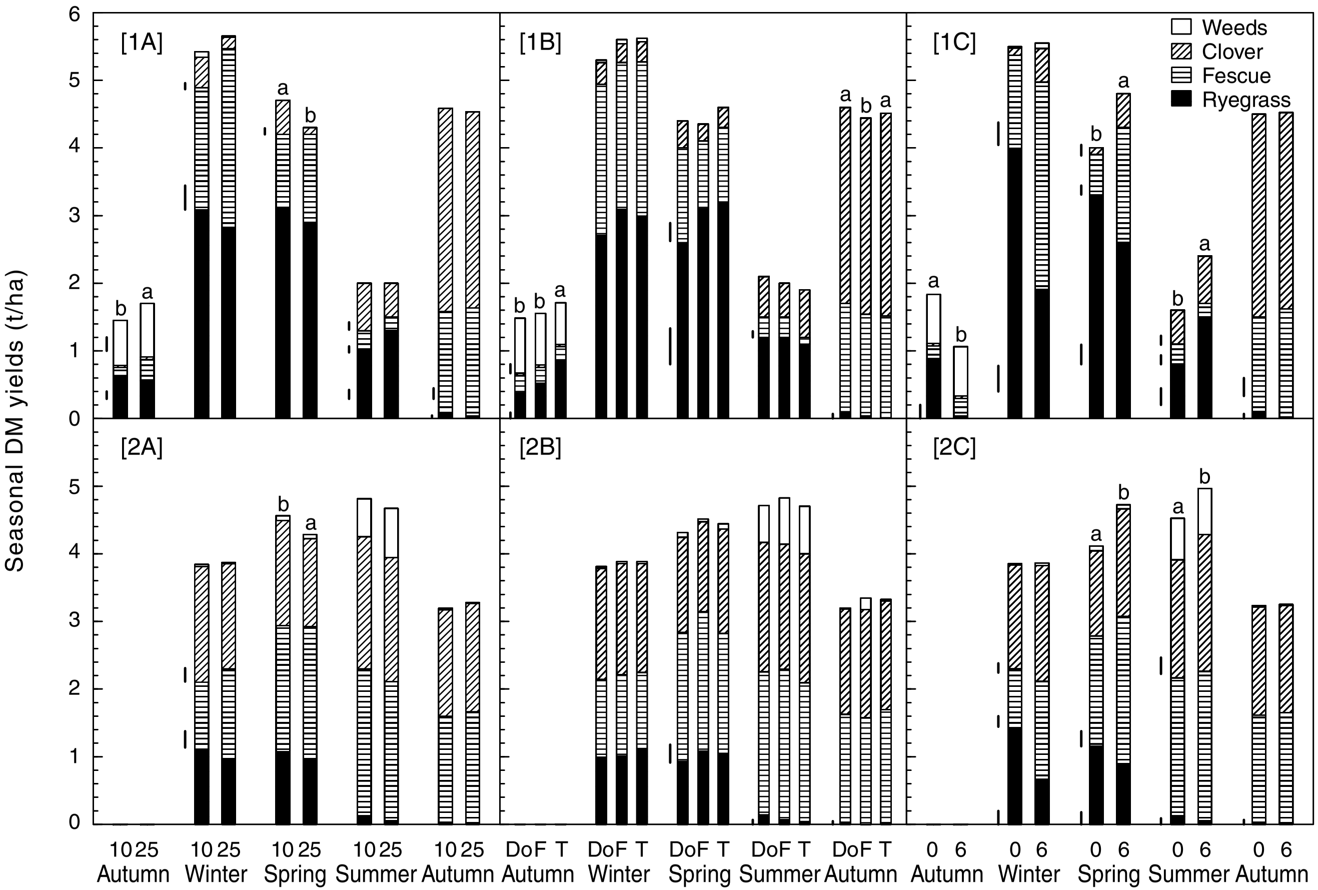

Figure 3. The effects of: [A] tall fescue sowing rate (10 kg/ha, 25 kg/ha); [B] ryegrass cultivar (Do — Dobson, F — Flanker, T — Tetila); and [C] ryegrass sowing time (0 – week 0, 6 – week 6) on the seasonal yield and botanical composition of pasture mixtures in the establishment year (Graph 1) and averaged over the 3 years (Graph 2) (1998, Experiment 2). In the establishment year, data for autumn 1998 encompassed the period from April 15 (sowing) to May 31 and autumn 1999 from March 1 to May 31.
Vertical bars alongside each component indicate significance at P=0.05. Column totals, within seasons, headed by different letters are significantly different at P=0.05.

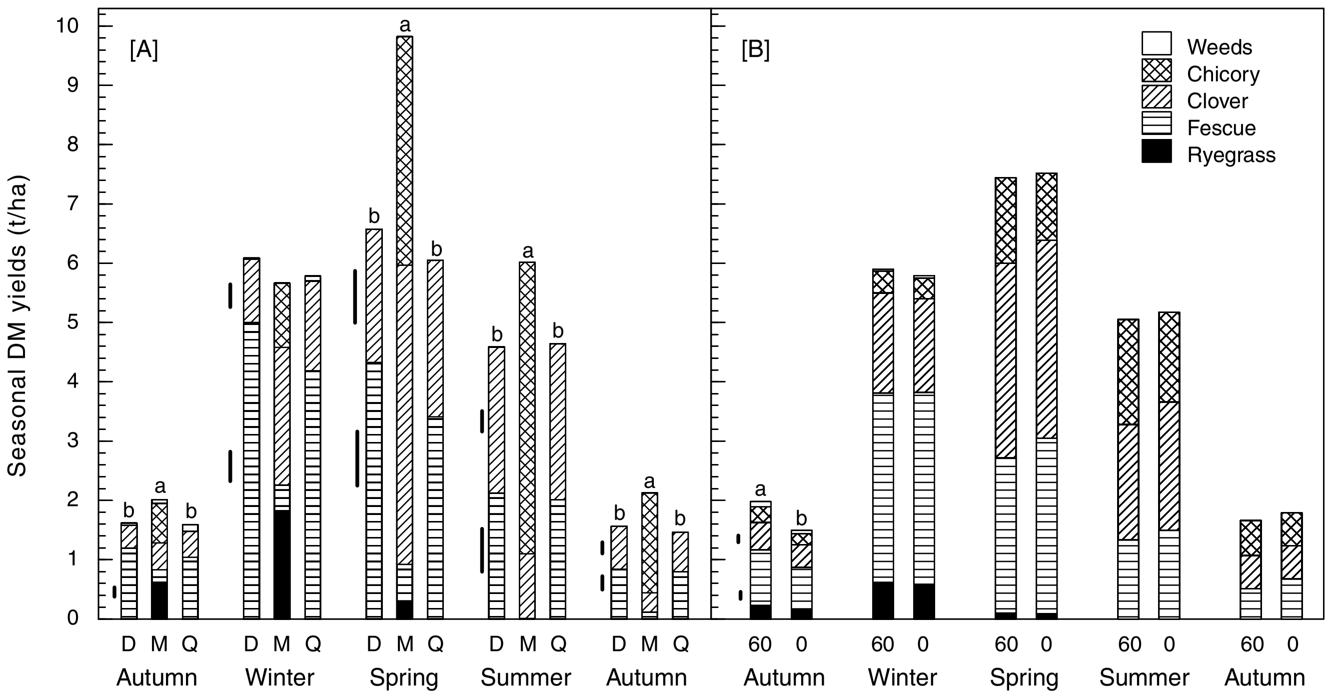

Figure 4. The effects of: [A] sowing mixture (D — Dovey-Haifa, M — complex mixture, Q — Quantum-Haifa); and [B] nitrogen at sowing (0, 60 kg/ha) on the seasonal yield and botanical composition of pasture mixtures in the establishment year (1999, Experiment 3). Data for autumn 1999 encompassed the period from April 15 (sowing) to May 31 and autumn 2000 from March 1 to March 27 (oversowing).
Vertical bars alongside component in left hand column indicate significant difference at P=0.05. Columns, within seasons, headed by different letters are significantly different at P=0.05.

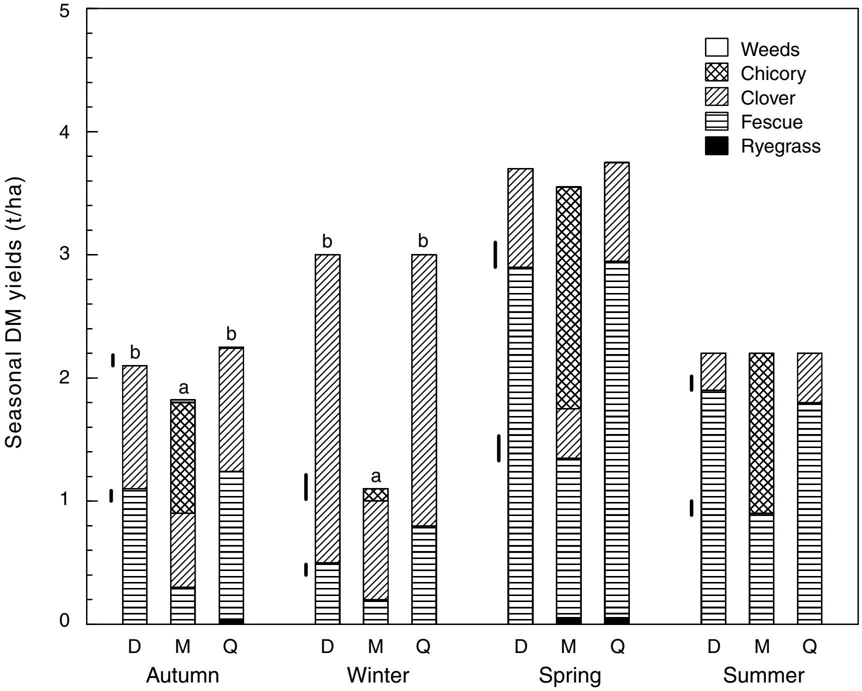

Figure 5. The effects of sowing mixture (D — Dovey-Haifa, M — complex mixture, Q — Quantum-Haifa) on the average seasonal yield and botanical composition of pasture mixtures over 3 years (Experiment 3).
Vertical bars alongside each component indicate significance at P=0.05. Column totals, within seasons, headed by different letters are significantly different at P=0.05.

in winter, while clover and tall fescue yields were higher in all seasons. All pastures were heavily clover-dominant in winter. Chicory produced about half the total yield of the complex mixture in all seasons except winter. Tall fescue cultivar had little overall effect, although Quantum out-yielded (P<0.05) Dovey in the simple mixtures in winter.

Persistence

Experiment 1. Planting ryegrass with tall fescue reduced tall fescue frequency at the end of the first summer (P<0.05) and this effect persisted throughout the study (Table 6). There was a small but significant (P<0.05) increase in ryegrass density at the end of Year 1, and a halving of tall fescue numbers by doubling the sowing rate of ryegrass. This effect was reduced as the study progressed. Dobson ryegrass survived better than Flanker. Tall fescue survival was 9% higher (P<0.05) when sown with Dobson than with Flanker. More (P<0.05) ryegrass persisted if Vulcan was sown as Vulcan survival was only half that of Dovey.

Tall fescue populations, especially Vulcan, increased over the 3 years (Table 6) while ryegrass numbers were much lower. As expected, there was a greater frequency of the perennial, compared with the annual, ryegrass in the second and third years of the experiment.

Experiment 2. The higher tall fescue sowing rate increased (P<0.05) the tall fescue frequency at the end of Year 1 without affecting ryegrass frequency (Table 7) but this effect had disappeared by the end of Year 3. Sowing the ryegrass component 6 weeks later than the remaining components increased (P<0.05) tall fescue frequency at the end of the first year but differences were not significant by the end of Year 3. Ryegrass cultivar affected the frequency of ryegrass at the end of the first year, with Dobson>Flanker>Tetila.

Within 2 years of establishment, tall fescue density increased until it dominated swards, while that of ryegrass fell to negligible levels (data not

Table 6. The persistence (% frequency) of perennial ryegrass and tall fescue plants at the end of each of the 3 years at Gatton (Experiment 1, 1997).

Treatment	Frequency (%)					
	Year 1		Year 2		Year 3	
	Ryegrass	Tall fescue	Ryegrass	Tall fescue	Ryegrass	Tall fescue
Tall fescue cultivar						
Dovey	4.4 (0.6)[1]	7.4 (1.7)	7.1 (1.5)	29.7 (24.6)	6.5 (1.3)	40.9 (42.9)
Vulcan	1.8 (0.1)	17.2 (8.7)	17.2 (8.7)	8.7 (2.3)	10.8 (3.5)	15.4 (7.1)
LSD (P=0.05)	0.7	0.5	1.6	1.9	1.8	2.0
Ryegrass cultivar						
Dobson	7.9 (1.9)	11.4 (3.9)	15.3 (7.0)	17.8 (9.3)	13.2 (5.2)	29.8 (24.7)
Flanker	1.7 (0.1)	10.5 (3.3)	11.6 (4.0)	17.1 (8.7)	4.5 (0.6)	26.0 (19.2)
LSD (P=0.05)[2]	0.7	0.8	1.6	NS[3]	1.8	2.5
No. of ryegrass cultivars sown						
0	—[4]	19.1 (10.7)	—	27.4 (21.2)	—	34.1 (31.4)
1	3.0 (0.3)	11.0 (3.6)	12.3 (4.5)	17.4 (8.9)	8.1 (2.0)	27.9 (21.9)
2	2.7 (0.2)	8.9 (2.4)	11.6 (4.0)	17.8 (9.3)	10.8 (3.5)	23.5
LSD (0 *vs* 1)(P=0.05)	na[5]	1.0	na	2.6	na	2.8
LSD (0 *vs* 2)(P=0.05)	na	1.6	na	3.3	na	3.5
LSD (1 *vs* 2)(P=0.05)	1.1	1.0	NS	NS	NS	NS
Ryegrass sowing rate						
5 kg/ha	2.5 (0.2)	15.0 (6.7)	10.7 (3.5)	20.2 (11.9)	8.6 (2.2)	30.2 (25.3)
10 kg/ha	3.5 (0.4)	7.6 (1.8)	13.9 (5.8)	14.7 (6.4)	7.6 (1.8)	25.7 (18.8)
LSD (P=0.05)	0.9	0.8	NS	2.3	NS	2.5

[1] Angular transformation of % frequency presented (back transformed data in brackets).
[2] Within columns, LSD (P=0.05) values are provided for detecting differences between means.
[3] NS — non-significant differences.
[4] — ryegrass not sown.
[5] na — no statistical analysis possible.

presented). By the end of the study, white clover density also fell to a low level (< 5%) (data not presented).

Experiment 3. Oversowing with either ryegrass cultivar had little effect in increasing ryegrass density in the second and third years (< 5% frequency) and had no effect (P>0.05) on either tall fescue or white clover frequency (Figure 6). There were significant interactions between species mixture and oversowing treatment, with more perennial ryegrass in the ripped-only, complex mixture in Year 2 and when perennial ryegrass seed was oversown into the complex mixture in Year 3, but these effects were small compared with the main effects. The frequency of tall fescue and white clover was always lower (P<0.05) in the complex mixture. The density of tall fescue increased in the complex mixture by the end of the third year but white clover and chicory densities had fallen.

Table 7. The persistence (% frequency) of ryegrass and tall fescue sown in mixtures at Gatton at the end of the establishment and final years (Experiment 2, 1998).

Treatment	% frequency			
	Year 1		Year 3	
	Ryegrass	Tall fescue	Ryegrass	Tall fescue
Tall fescue sowing rate				
10 kg/ha	9.1 (5.4)[1]	38.8 (39.7)	9.1 (2.5)	49.7 (58.2)
25 kg/ha	8.4 (4.9)	48.8 (56.1)	6.0 (1.1)	55.6 (68.1)
LSD (P=0.05)[2]	NS[3]	5.4	NS	NS
Ryegrass cultivar				
Tetila	0.0 (0.0)	43.2 (46.7)	8.3 (2.1)	52.0 (62.1)
Flanker	9.5 (3.8)	47.9 (54.6)	0.0 (0.0)	58.4 (72.5)
Dobson	16.7 (11.7)	40.3 (42.3)	14.3 (6.1)	47.6 (54.5)
LSD (P=0.05)	6.9	NS	5.7	7.6
Ryegrass sowing time				
Week 0	10.8 (6.1)	39.4 (40.8)	9.2 (2.6)	52.2 (62.4)
Week 6	6.7 (4.2)	48.2 (54.9)	5.9 (1.1)	53.1 (64.0)
LSD (P=0.05)	NS	5.4	NS	NS

[1] Angular transformation of % frequency presented (back transformed data in brackets).
[2] Within columns, LSD (P=0.05) values are provided for detecting differences between means.
[3] NS — non-significant differences.

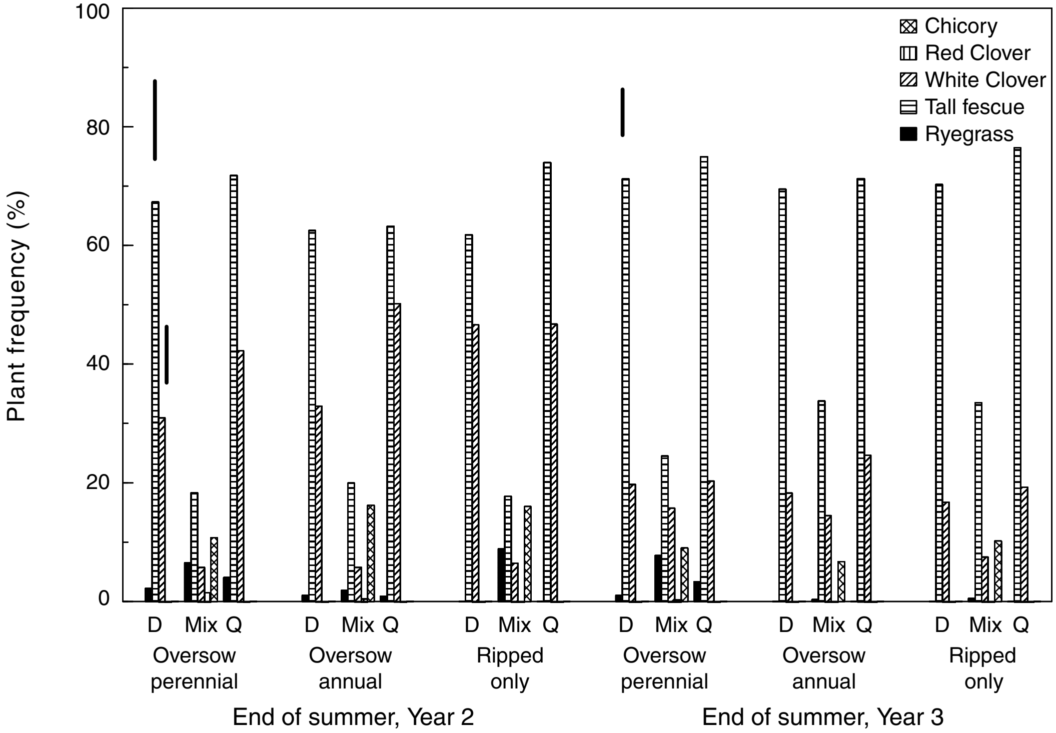

Figure 6. The effects of oversowing treatments (imposed in April of the second and third years following sowing) on the persistence (% frequency) of 3 temperate species mixtures (D — Dovey tall fescue; Mix — complex mixture; Q — Quantum tall fescue) sown in 1999 (Experiment 3).
Vertical bars above components indicate significant differences (P=0.05) between the respective components in mixtures and oversowing treatments within any year.

Discussion

This series of experiments has demonstrated that tall fescue can be established successfully in combination with ryegrass and white clover in a subtropical environment. This contrasts with the experience in temperate environments such as New Zealand where vigorous ryegrass seedlings out-compete the slower-establishing tall fescue seedlings during the establishment phase (Milne *et al*. 1989; Easton *et al*. 1994). While our results confirm that tall fescue is susceptible to competition, as shown by the much lower yields when sown with ryegrass, it seems that, under sub-tropical conditions, the competitiveness of ryegrass is reduced and that of the tall fescue component improved, allowing tall fescue to establish successfully. This reasoning is consistent with previous work (Charlton *et al*. 1986; Charles *et al*. 1991), which demonstrated that tall fescue was more affected by low temperatures than other temperate grass species, particularly affecting root development (Brock 1983).

The inclusion of tall fescue in mixtures to reduce the invasion of C_4 grasses proved successful, with the tall fescue component remaining vigorous for 3 years. Sanderson *et al*. (2005) employed a similar strategy in north-eastern USA using complex mixtures containing up to 9 species to reduce weed invasion. However, minimal C_4 grass invasion occurred in our experiments, in contrast to the experience with perennial ryegrass mixtures (Kleinschmidt 1964; Cameron 1969; Lowe and Bowdler 1984), where up to 90% of the third-year yields came from C_4 grasses. This may, in part, be related to the intensive grass weed control strategy on Gatton Research Station, which concentrates on horticultural research. On the other hand, C_4 grasses invaded adjacent areas used for ryegrass cultivar screening experiments over the same period (Lowe *et al*. 2008), suggesting that inclusion of tall fescue in mixtures was a successful strategy to counter invasion by C_4 grasses. Tall fescue density increased, colonising bare areas caused by a reduction in the size or death of perennial ryegrass crowns during late spring and summer, thus preventing or restricting a similar establishment or expansion of C_4 grasses. This contribution maintained the productivity of the temperate-based swards, ensuring a substantial cool season growth component from our irrigated pastures, which is a concern not only for subtropical conditions but also for cooler, temperate regions of Australia (Lawson *et al*. 2002).

The failure of composition of the pasture mixture to influence total pasture yield agreed with the results of Sanderson *et al*. (2005), who found no differences between mixtures containing 2, 3, 6 or 9 species, and Sugiyama and Nakashima (1991), who found that total yield of tall fescue-cocksfoot (*Dactylis glomerata*)-white clover pastures was unaffected by sowing mixture. While weeds played little role in the establishment and composition of mixtures in any of our 3 experiments, this might not be the case under commercial conditions where seedbed preparation would probably be inferior to that used in these experiments (Read *et al*. 1990; McCallum *et al*. 1992; Easton *et al*. 1994).

In contrast to the lack of yield differences, we demonstrated that sowing mixture can substantially influence botanical composition of the resulting pasture. To ensure good tall fescue establishment and persistence over 3 years, it should be sown alone or the ryegrass component of a mixture should be sown later than the fescue, *e.g*. 6 weeks. As tall fescue is not aggressive, its contribution to total yield decreases as the competition from other grasses increases, as found by Sugiyama and Nakashima (1991) with tall fescue and cocksfoot mixtures and Sanderson *et al*. (2005) with complex mixtures. Reducing sowing rate of ryegrass to 5 rather than 10 kg/ha increased the tall fescue contribution to first-year yields without any marked effect on ryegrass yields. Since increasing the tall fescue seeding rate from 10 to 25 kg/ha had little effect on total yield but decreased the contribution of ryegrass and clover, there seems little merit in incurring the additional cost for seed.

The productivity of our mixed tall fescue swards was consistent throughout the 3-year life of the stands. The only exception was in Experiment 3 and in a complementary experiment (Lowe *et al*. 2009), where tall fescue (simple mixtures) or chicory (complex mixtures) dominated by the end of the establishment year. Poor legume production during the second and third years would have reduced the nitrogen supply and therefore, presumably, potential DM production. Legume components decreased substantially in the second year from complex mixtures in a temperate environment (Sanderson *et al*. 2005) as they did in our experiment. Our other 2 experiments maintained a better legume component for longer and did not experience the same third-year yield depression. However, third-year yield depressions have been reported in other environments with tall fescue-dominant pastures (Keane 1982; McCallum *et al*. 1992). Generally, the yield depression in these experiments was smaller than that demonstrated by other temperate grasses under subtropical conditions (Lowe and Bowdler 1984; 1995).

We also showed that sowing a complex mixture had the greatest effect on seasonality of production. The contribution of chicory and Persian clover boosted spring, summer and autumn yields over those of the simple mixtures in Experiment 3, a time when ryegrass and white clover yields normally decrease substantially. Similarly, delaying the sowing of ryegrass improved spring and summer yields in Experiment 2. A similar result was obtained by Sanderson *et al*. (2005) in a temperate environment in north-eastern USA, where complex mixtures improved productivity in dry seasons although the abundance of individual species fluctuated substantially.

The cultivar of ryegrass or tall fescue which is sown is obviously important in terms of establishment and botanical composition, and thereby component yields, as shown by Sugiyama and Nakashima (1991) with cocksfoot and Pederson and Brink (1991) with clovers. Ryegrass species with high competitive advantage (*i.e*., annual > perennial) can increase the ryegrass contribution and reduce the tall fescue yield as demonstrated in both artificial and natural swards (Harper 1978). On the other hand, tall fescue cultivars with higher establishment vigour (Dovey and Quantum) can reduce ryegrass production and increase tall fescue contribution more than less vigorous types (Vulcan), as we have shown. The treatment with the greatest impact on cumulative yields throughout the study was the type of tall fescue cultivar sown. Cultivar differences were also important in determining yield of tall fescue swards in Japan (Sugiyama and Nakashima 1991).

Most of the establishment treatments investigated in these experiments continued to affect component yields throughout the 3-year life of the swards, although the significant effects generally dissipated by the third year. The majority of the treatments affected the yield of one or more pasture components but rarely affected total yields. Previous research has highlighted the poor competitive ability of tall fescue when sown in association with ryegrass in temperate environments (Bell 1985; McCallum *et al*. 1992; Easton *et al*. 1994). After investigating the competition between tall fescue and perennial ryegrass in simulated swards, Bell (1985) concluded that, once tall fescue had become established, it should be possible to maintain it in swards with ryegrass. Our findings lend weight to this hypothesis as delaying the sowing of the ryegrass component until the tall fescue plants were well established significantly improved yield of tall fescue until the end of the second year. The extreme dominance of tall fescue in mixed swards, as recorded in our experiments by the end of the third year, is unusual in temperate areas (McCallum *et al*. 1992; Easton *et al*. 1994), although it does appear to be more likely in subtropical areas (Fitzgerald *et al*. 1992; Lowe and Bowdler 1995; Lowe *et al*. 1999a; Staley and Belesky 2004). This is related to differential responses of the species to temperature and to tall fescue's inability to compete with more adapted species, particularly perennial ryegrass (McCallum *et al*. 1992; Easton *et al*. 1994). The more adapted summer-active tall fescue cultivars appear to be better able to resist invasion by tropical species (Callow *et al*. 2003).

In response to this dominance, Experiment 3 investigated ways of re-establishing other components into the stand by some form of sward disturbance. Ripping with narrow tipped tynes to a depth of 5 cm was designed to provide some soil disturbance and provide a setback for the tall fescue plants without causing major damage. However, the tall fescue plants recovered more rapidly than expected. As a result, very little ryegrass established after oversowing in autumn in either the second or third years, even though sowing annual ryegrass into slashed C_4 pasture is normally successful in the subtropics (Anon 1995). Similar results have been demonstrated in other areas of Australia where any improvements achieved by renovating degenerated perennial ryegrass pasture were generally small unless competition was reduced (Callow *et al*. 2005; Lawson and Kelly 2007). While we mowed the sward to 5 cm at monthly intervals before and after oversowing, competition for light, nutrients and space by the established tall fescue plants, both in the above- and below-ground environment, was most likely the reason for the poor ryegrass establishment. Staley and Belesky (2004) attributed difficulties in establishing legumes into a dominant tall fescue sward to inhibition of root growth by detrimental physical or chemical conditions associated with the tall fescue sward.

Our data would suggest that, to successfully establish other components into tall fescue-dominant swards, more severe renovation methods which reduce the vigour of the tall fescue component, such as the removal of around 30% of the stand, mowing to 3–4 cm or treatment with a chemical to suppress growth, combined with high seeding rates, will be required. Further testing of these strategies seems warranted. The difference in success rates with oversowing ryegrass into tall fescue, as opposed to C_4 grass, swards appears to be related to differences in dormancy (and therefore competition) in autumn.

A further significant outcome of the study was the substantial contribution to yield of chicory in the complex mixture used in Experiment 3, especially in the first and second years, at the cost of yields of the other components (perennial ryegrass, tall fescue and white clover). Similar findings were reported by Hume *et al*. (1995), who found yields of sown grass were inversely related to chicory yields in chicory-based pasture mixtures. The 25% yield increase achieved in the first year by the complex mixture over the simple mixtures was balanced by a loss of 21% over the next 2 years and suggests that maintenance of the other components is essential if these mixtures are to prove useful. Care will be needed by adjusting the seeding rates, particularly of chicory and Persian clover, and by attention to early defoliation management so that competition from these components is reduced.

Conclusions

There are opportunities to exploit the superior persistence of tall fescue (Lowe and Bowdler 1995) by including it in mixtures with other temperate species under subtropical conditions. Sowing the ryegrass once the tall fescue and white clover components have established was the most successful sowing option for establishing ryegrass-tall fescue mixtures. On the other hand, if all components were to be sown together, a combination of sowing only a single ryegrass cultivar, choosing a perennial rather than an annual ryegrass and limiting the ryegrass sowing rate to 5 kg/ha is most likely to achieve a balanced mixture of components in the establishment year. Including an annual clover species and chicory will create even greater competition, resulting in poor establishment of all perennial components except chicory. However, the extra 25% yield in the first year is a strong argument for the inclusion of these species. The combination may increase the complexity of management of such mixtures, as the species require different management to achieve optimum utilisation (Lowe *et al*. 2009). Further evaluation of these options would seem warranted.

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