Evaluating temperate species in the subtropics. 2. Perennial grasses

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Abstract

A series of 3-year experiments, spanning the period 1993–2006, evaluated the performance of commercially available cultivars and breeders' lines of perennial ryegrass (*Lolium perenne*), tall fescue (*Festuca arundinacea*), brome grass (*Bromus* spp.) and phalaris (*Phalaris aquatica*) and the herbs, chicory (*Cichorium intybus*) and plantain (*Plantago lanceolata*) under irrigation in a subtropical environment. Measurements included annual and total dry matter (DM) yields, seasonal yields, persistence and resistance to rust in pure, nitrogen-fertilised swards.

Summer-active tall fescue cultivars averaged around 50 (range 40–70) t/ha DM over 3 years, except at Mutdapilly where the average was 25 (range 11–34) t/ha DM. This was 30% more than perennial ryegrass cultivars (38 t/ha DM), with the prairie grasses (45 t /ha DM) intermediate between these extremes. About 45% of this total yield from all species occurred in the first year. The most productive cultivars were AU Triumph, Dovey, Quantum, Jesup and Jesup MaxP. Grasslands Matua and Atom produced the highest yields for brome grass and Tolosa, Fitzroy, Dobson, Bronsyn, Cannon and Quartet were the highest-yielding of the perennial ryegrasses, along with the hybrid ryegrass, Horizon. Tall fescue produced higher spring, summer and autumn yields than the perennial ryegrasses in this environment, with perennial ryegrasses superior in winter.

Differences in persistence were of even greater magnitude; tall fescue cultivars were around twice as persistent as the perennial ryegrasses, while the bromes were less persistent than the perennial ryegrasses under a cut-and-carry regime.

Incidence of crown rust was generally lower in tall fescue than in perennial ryegrass. However, the newer ryegrass cultivars and some experimental lines showed higher resistance than the older cultivars. Phalaris and the brome grasses were not infected by rust.

First-year yields explained 67% of the variation in 3-year total yields and 50% of the variation in persistence after 3 years. The possibility of using detailed sampling in the first year and persistence over 3 years as a method of predicting cultivar performance is discussed.

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Introduction

Over the last 40 years, annual sowings of Italian ryegrasses (*Lolium multiflorum*) have proven a more reliable source of cool-season forage than perennial-based pastures for subtropical dairy production (Lowe and Hamilton 1985). Perennial (*L. perenne*) and short-rotation (*L. multiflorum*) ryegrasses have historically failed to persist in the subtropical environment of central and southern Queensland (Kleinschmidt 1964; Cameron 1967) and this still remains a problem (Lowe *et al.* 1999a). On the other hand, milk production from these pastures, at least in the first year, is higher than from other temperate grasses (Lowe *et al.* 1999b). Of the older cultivars evaluated, Kangaroo Valley was the most persistent (Lowe and Bowdler 1984); grass dry matter (DM) yields were high in the first year but a high proportion of the grass population was lost in the first summer (Kleinschmidt 1964; Cameron 1967; Lowe *et al.* 1999a). The identification of more persistent perennial ryegrass cultivars is essential if these pastures are to fulfil the potential in the subtropics that they deliver in temperate environments (Read *et al.* 1990).

Tall fescue (*Festuca arundinacea*) and prairie grass (*Bromus willdenowii*) display better production and persistence than perennial ryegrass under subtropical conditions (Lowe and Bowdler 1995) but quality and acceptability, particularly of tall fescue, limit their productive potential (Easton *et al.* 1994). Once management is optimised (Callow *et al.* 2003), milk production from them can be similar to that from perennial ryegrass, particularly in the second and third years (Lowe *et al.* 1999b).

At high temperatures, perennial ryegrasses have reduced growth rates and their *in vitro* digestibilities and soluble carbohydrate concentrations are lower as temperatures increase (Wilson and Ford 1971). Most temperate species cease growth when temperatures exceed 30°C (Mitchell 1956). Daytime temperatures in the subtropical environment of south-east Queensland regularly exceed this critical value in summer. None of the older cultivars has been selected to grow under the combination of high summer temperatures and high humidity experienced in the subtropics. However, with the current concerns about global warming, ryegrass breeders are selecting perennial ryegrass to tolerate higher temperatures (Cunningham *et al.* 1994) and this provides an opportunity to find better-adapted cultivars for the subtropics.

The most significant disease of perennial ryegrass and tall fescue is crown rust (*Puccinia coronata*) and this seems to be most prevalent in warmer, more humid environments (Prine 1991; Cunningham *et al.* 1994). Animal acceptance of temperate grasses is affected by rust infection (Easton *et al.* 1994), so selection of cultivars with improved resistance is essential. Otherwise, utilisation can be severely reduced.

The first paper in this series reported the evaluation of short-term ryegrasses in south-east Queensland (Lowe *et al.* 2007). This paper summarises the evaluation, in terms of DM production, seasonal yield distribution, persistence and rust resistance, of about 100 commercial cultivars and breeding lines of perennial and hybrid ryegrass, tall fescue, prairie grass and phalaris, along with 2 types of herbs, over a 13-year period.

Materials and methods

Site

Seventeen field studies were conducted at Gatton Research Station (27°34′S, 152°20′E; elevation 95 m) in south-east Queensland between 1993 and 2005 and 1 experiment was conducted at Mutdapilly Research Station (27°46′S, 152°40′E; elevation 40 m) in 1997. The soils are deep, alluvial black clays (black earth, Stace *et al.* 1972; Ug 5.15 and 5.16, Northcote 1971). Those at Gatton had a pH of 7.8–8.3 (H_2O) and a clay content of 67–70%, and contained 128–134 mg/kg P (Colwell extraction) and 0.87–1.0 mmol/100 g K, while that at Mutdapilly had a pH of 6.7 (H_2O) and a clay content of 87%, with 84 mg/kg P and 0.83 mmol/100g K.

Treatments and design

Experiments were laid out in randomised block designs with 3 or 4 replicates. The number of treatments varied from 5 to 26, with the lower treatment numbers associated with 4 replicates. Treatments included elite breeders' lines of perennial ryegrass (*Lolium perenne*), hybrid ryegrass [*Lolium hybridum* (syn. *L. x boucheanum*)], tall fescue (*Festuca arundinacea*), festulolium (*x Festulolium* spp.), brome grasses (*Bromus* spp.) and phalaris (*Phalaris aquatica*), selected by commercial plant breeders from their programs, together with newly-released and standard cultivars, and the herbs, chicory (*Cichorium intybus*) and plantain (*Plantago lanceolata*).

Generally, the standards included Ellett, Yatsyn 1 or Dobson (perennial ryegrass), Dovey, Advance or AU Triumph (tall fescue) and Grasslands Matua (prairie grass), which had been shown to be superior in this environment (Lowe and Bowdler 1995). Other standards were included when requested by seed companies. Cultivars developed by AgResearch Grasslands in New Zealand (Impact, Samson, Supreme Plus, Matua, Gala and Puna) are marketed with the prefix 'Grasslands' and those developed by Pyne Gould Guinness Ltd (Cannon, Horizon, Typhoon and Atom) are marketed with the prefix 'Ceres' (Stewart and Charlton 2003). They will subsequently be referred to without these prefixes for ease of presentation.

Techniques

Seed of ryegrass (20 and 30 kg/ha for diploid and tetraploid cultivars, respectively), tall fescue (25 kg/ha), brome grass (40 kg/ha) and herbs (5 kg/ha) was sown by hand into weed-free seedbeds in early April, rolled and irrigated (12.5 mm) weekly for 4 weeks. Previous research has shown that establishment and production are optimised if ryegrass is sown in early April (Lowe *et al.* 1986). Actual sowing dates in early April varied from year to year.

Harvesting of each experiment commenced in late May or early June and regrowth was assessed at 4-weekly intervals over a 3-year period. DM yield was measured by cutting, to 5 cm above ground level from the central section of each plot, a quadrat of 2.25 (before 1997) or 5.85 (1997–2005) m^2 using a reciprocating mower. The botanical composition was determined by sorting a sub-sample of the harvested herbage into grass and weed components. Samples were dried in a forced-draught oven at 80°C for 24 h. The remaining pasture residues on each plot were removed using a forage harvester.

In late summer (mid-late February) of each year and at the end of the experiment, presence of grass crowns was measured in a fixed, 1 × 0.25 m quadrat, divided into a 100-square grid. Persistence was assessed as the percentage of squares containing grass crowns.

Seasonal yields were calculated by summing harvests from the sampling periods that fell 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 sampling was deemed to fall into a season if more than half the growth period occurred in that season.

The incidence of crown rust (*Puccinia coronata*) was visually assessed on each plot prior to each harvest. A 1–9 scale of decreasing damage to the leaf surface in increments of 10% was used, where 1 = greater than 80% of the leaf area within the plot affected by rust pustules and 9 = no damage. While rust was assessed throughout the 3-year experimental periods, damage was more consistently recorded in spring. Data presented here are the averages of all harvests where rust was recorded in the spring of the first year, as loss of plant density may have influenced relative infection levels in later years.

Plots received 50 mm of irrigation every 2 weeks using a fixed, solid-set layout with overhead sprinklers to ensure DM yields were not limited by soil moisture stress. Irrigation schedules were maintained unless more than 25 mm of rainfall was received in the week prior to application. Urea was applied at sowing and following each defoliation at 60 kg/ha N. Superphosphate, providing 18 kg/ha P and 22 kg/ha sulphur (S), was applied during the second and third spring periods to satisfy a known S deficiency at the sites.

Statistical analyses

Data for DM yields, persistence and rust damage were subjected to analysis of variance using the statistical package 'GenStat' (Payne *et al.* 2007). Weighted, modified joint regression analyses (Digby 1979) were undertaken on total yields over 3 years, yield in Year 1, seasonal yields and percent of yield produced in summer, final persistence and average spring rust score. The technique has been described in Lowe *et al.* (2007); however, in this instance, environment was defined as different 3-year periods. A similar application of this technique was used by McLaughlin *et al.* (1994) in evaluating the effects of environment on the ability of potato cultivars to accumulate cadmium. Any cultivar, which appeared in only 1 environment (3-year period), was discarded. For some cultivars, the iterative process did not converge and it was necessary to drop those, which appeared only a few times, to attain convergence. Different cultivars/lines were dropped from different attribute analyses. The sensitivities of each cultivar to environmental effects were plotted against the final estimates of the cultivar means. A high mean and a sensitivity of around 1.0 should indicate a reliable cultivar under variable conditions, as proposed by Findlay and Wilkinson (1963). Cultivars with a high sensitivity have below average stability and are specifically adapted to favourable environments, while those with sensitivities below 1.0 are specifically adapted to unfavourable environments (Findlay and Wilkinson 1963).

Pairwise differences between cultivar means were tested using a protected least significant difference procedure (P=0.05). The range of standard errors for cultivars varied, with large values for experimental lines; hence only average standard errors for perennial ryegrass, tall fescue and experimental lines are given in Figures 1–6 to indicate this variability.

To assess the potential for reducing the assessment period for perennial temperate grasses in this environment, correlations were calculated between yield attribute means over 3 years and yields in the first year and between persistence and total yields and yields in the first year for each group of species individually and in combination.

General

In the subtropics, establishment of perennial temperate pastures is most critical, dictating their long-term performance. In the case of perennial ryegrass, no seedling recruitment is possible in future years because, with the exception of the cultivar Kangaroo Valley and its derivatives, little seed production occurs. The other temperate grass species do produce seed but, with the exception of prairie grass, much of the seed is lost by false germinations. Temperate grasses perform poorly in summer because temperatures can be well above their optimum levels, while restrictions on the availability of irrigation require improvement in summer yields to increase water use efficiency. For these reasons, we deal specifically with the above attributes in this paper.

In Tables 2–6, the quoted year indicates the sowing year and cumulative 3-year totals are the sum of that year and the following 2 years. Best and worst experimental lines provide the range of performance of breeding lines within species for each experiment and these differ between years and attributes.

Climate

Seasonal rainfall and temperatures varied considerably between years, with winter the most variable season (Table 1). Over the 13-year period, rainfall in autumn, winter and summer and total rainfall were below the long-term averages. Maximum and minimum temperatures for all seasons were above the long-term averages. Maximum temperatures in autumn, spring and summer showed the greatest increases above average. There was greater variation between seasons for minimum, compared with maximum, relative humidity.

Rainfall was very low in 1993, 2001 and 2002 and these years were characterised by low relative humidity in summer. Summer temperatures were highest in 1997, 2001 and 2003, while winter temperatures were lowest in 1994, 2000 and 2002.

Results

Total yields

Overall performance. The more fibrous-leaved, summer-active tall fescue cultivars, such as AU Triumph, Cajan, Dovey and Quantum, were the highest-yielding temperate grasses. Yields of AU Triumph were significantly ($P<0.05$) higher than those of Vulcan, Jesup and Advance plus all ryegrass cultivars except some experimental lines. Most experimental lines were rarely sown and had high standard errors. Most tall fescue cultivars performed well under all conditions, with sensitivities around 1 (Figure 1). The exception was Typhoon, which had a similar performance to Advance but favoured better conditions (*i.e.,* high positive sensitivity). Tolosa was the best performing perennial ryegrass, although this result must be tempered by the fact that it occurred in only 2 experiments. It yielded significantly ($P<0.05$) better than all except Bronsyn, Dobson, Fitzroy, Horizon, Quartet and a number of experimental ryegrasses. Its performance was similar ($P>0.05$) to that of Matua prairie grass and all the tall fescue cultivars except AU Triumph. The older ryegrass cultivars such as Embassy, Yatsyn 1, Banks and Ellet had generally lower ($P<0.05$) yields than the ryegrasses listed above, but a number of the newer cultivars, such as Meridian, Impact and Arrow, did not outyield these older cultivars. The other *Bromus* species generally performed poorly compared with Matua.

Individual experiment performance. The tall fescue cultivars, AU Triumph, Dovey and Quantum, outyielded ($P<0.05$) the perennial ryegrass cultivars in all experiments in which they were included (Table 2). Exceptions occurred where other cultivars/lines had equivalent ($P>0.05$) yields: 1994 (Dobson perennial ryegrass and the experimental brome), 1993 and 1994 (Superstrike Matua prairie grass) and 2000 Exp 1 (best experimental ryegrass). Generally, the other tall fescue cultivars and experimental lines yielded less than AU Triumph, Dovey and

Table 1. Seasonal and total rainfall (mm), seasonal average maximum and minimum temperatures (°C) and relative humidity (%) and seasonal daily radiation received (MJ/m^2) at Gatton Research Station from 1993 to 2005 and long-term averages for temperature (66 years) and rainfall (98 years). Averages for relative humidity and radiation not available.

	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	Mean (±s.e.)	Long-term average
Rainfall															
Autumn	42	149	80	515	96	148	151	78	123	127	97	102	57	136±33	178
Winter	62	29	47	92	30	101	117	49	45	57	70	14	84	61±9	111
Spring	94	53	285	130	208	212	192	153	194	68	138	188	321	172±22	176
Summer	234	337	399	202	317	413	258	267	129	219	400	259	331	290±24	313
Annual	345	486	852	1037	619	695	948	459	629	387	565	700	628	642±58	778
Maximum temperature															
Autumn	27.6	26.0	27.2	26.8	27.0	28.1	26.5	26.6	26.9	27.5	26.2	26.7	28.1	27.0±0.2	26.9
Winter	22.2	21.8	21.4	21.1	21.3	21.0	20.8	21.4	22.0	22.0	21.6	22.7	22.1	21.7±0.6	21.2
Spring	27.5	28.8	28.2	28.0	28.0	27.2	25.9	28.1	27.1	30.2	28.4	28.8	28.6	28.1±0.3	28.0
Summer	31.6	31.0	30.3	30.7	32.6	30.3	29.0	31.6	32.8	31.6	32.4	31.5	33.3	31.4±0.3	31.2
Minimum temperature															
Autumn	13.6	12.7	13.9	14.0	13.8	14.9	14.5	14.8	14.8	13.6	13.7	13.9	13.6	14.0±0.2	13.8
Winter	8.4	5.1	7.0	7.8	6.1	9.0	8.0	5.8	6.8	5.8	7.3	6.1	7.8	7.0±0.3	6.6
Spring	13.3	12.2	13.8	12.0	13.7	13.7	13.1	12.9	12.5	13.1	12.2	13.1	14.7	13.1±0.2	12.7
Summer	19.6	18.9	18.9	18.7	20.1	19.0	17.2	18.6	19.3	18.6	20.1	19.1	20.4	19.1±0.2	18.8
Maximum relative humidity															
Autumn	97.0	96.9	96.0	94.6	97.7	95.7	96.3	96.3	96.8	96.9	98.3	98.4	96.4	96.7±0.3	—
Winter	97.0	97.5	93.3	95.9	97.6	95.3	97.0	97.3	96.9	95.1	98.6	93.8	97.7	96.4±0.4	—
Spring	93.9	86.7	94.0	93.1	95.5	94.0	96.5	94.0	94.4	91.6	95.6	96.3	95.4	93.9±0.7	—
Summer	89.1	93.2	94.5	94.3	95.6	94.6	94.2	95.1	91.5	89.0	95.3	96.2	95.6	93.7±0.7	
Minimum relative humidity															
Autumn	46.8	49.2	47.9	49.2	49.3	48.5	50.7	51.6	51.0	46.2	51.4	51.3	43.9	49.0±0.7	—
Winter	48.1	40.4	43.6	47.4	44.8	51.2	50.2	42.2	44.7	40.3	49.7	37.9	47.3	45.2±1.2	—
Spring	45.3	35.1	43.7	39.1	45.0	46.0	49.9	41.8	42.5	35.4	41.7	42.1	45.9	42.6±1.2	—
Summer	47.0	47.4	51.3	48.6	48.8	50.5	48.9	47.0	43.8	43.1	49.0	49.2	50.3	48.1±0.7	
Radiation															
Autumn	17.5	17.0	17.2	16.5	17.5	16.8	16.4	15.7	17.3	17.6	16.7	16.9	17.4	17.0±0.2	—
Winter	13.7	15.3	14.6	14.1	14.6	13.3	13.6	14.5	14.8	14.8	14.0	15.5	14.0	14.4±0.2	—
Spring	20.5	23.1	21.0	23.0	21.4	20.6	20.8	21.2	21.5	23.3	23.1	22.6	21.4	21.8±0.3	—
Summer	22.9	22.7	23.7	22.9	22.9	22.5	22.5	23.5	23.4	23.3	22.7	23.1	22.8	23.0±0.1	

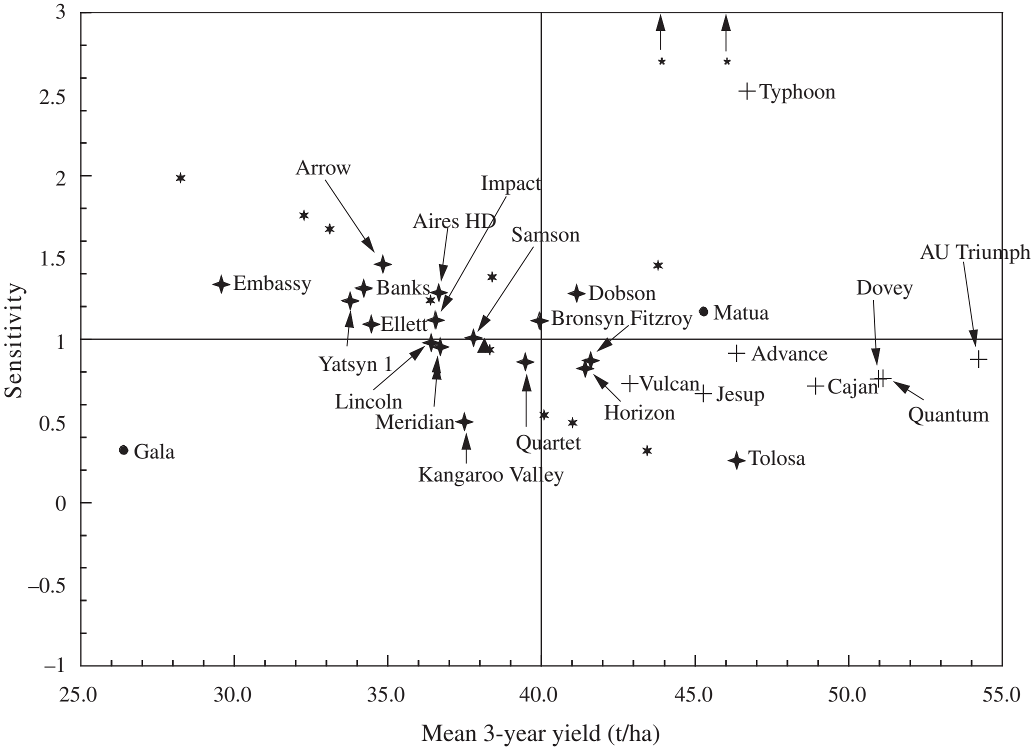

Figure 1. The relationship between cultivar adaptation (regression coefficient = sensitivity) and cultivar mean total DM yield over 3-year evaluation periods for tall fescue (+), perennial or hybrid ryegrass (✦) and brome (•) cultivars and perennial ryegrass (✱) and tall fescue (▲) experimental lines. A new experiment was sown annually over the period 1993 to 2003 at Gatton in south-east Queensland. Average s.e. values — perennial ryegrass (2.3), tall fescue (2.2), experimental lines (8.7) and brome (2.8).

Quantum ($P<0.05$). While the relative performance of the tall fescue cultivars in the only experiment conducted at Mutdapilly was similar to that demonstrated at Gatton, yields were substantially lower (average of 25 t/ha DM compared with 50 t/ha). The Phalaris cultivars produced equivalent ($P>0.05$) yields to the best ryegrass cultivars in the only year they were included.

Dobson was the highest- or equally highest-yielding commercial perennial ryegrass cultivar in all experiments in which it was included. Bronsyn and Impact were among the highest-yielding ryegrass cultivars as were Cannon, Fitzroy, Horizon, Tolosa, Quartet and Barberia on the limited occasions they were included in experiments. The best performing experimental ryegrass yielded as well as the best cultivar in 4 experiments. Mixtures of ryegrass and tall fescue performed better than the ryegrass alone but below that of the tall fescue alone (when these comparisons were available).

First-year yields

Overall performance. Jesup Max P, AU Triumph and Dovey yielded significantly ($P<0.05$) more than nearly all the ryegrass cultivars, ryegrass experimental lines and Advance, Jesup, Quantum and Vulcan tall fescues. There were no significant ($P>0.05$) differences between Quartet, Fitzroy, Dobson, Lincoln and Tolosa in first-year yields. Quartet performed less consistently than the other ryegrasses over all conditions (sensitivity <0).

Individual experiment performance. Experiments sown in 2004 and 2005, although not completed at the time of printing (2007), were included in the first-year analyses with a number of grass cultivars and herbs appearing only in these analyses. While the best indication of the potential of perennial ryegrass cultivars to perform in the subtropics occurs in the first year, before plant population losses take effect, the order of performance was generally similar in both

Table 2. Total DM yields of perennial ryegrass cultivars, cultivar mixtures and other temperate grasses over 3-year periods from sowings made annually from 1993 to 2003. Best and worst experimental lines provide the range of performance of breeding lines and differ from year to year.

Cultivar	Source	Species/ Ploidy/ Endophyte[2,3]	DM yields (t/ha)																	
			1993	1994	1995	1996[4]	1996[5]	1997[4]	1997[5,7]	1998	1999	2000[4]	2000[5]	2001[4]	2001[5]	2001[6]	2002[4]	2002[5]	2002[6,8]	2003
Ryegrass																				
Aires HD	NZ	Lp,d		62.0		35.2		35.1												
Alto	NZ	Lp,d												22.1			41.1			
Arrow	NZ	Lp,d						34.3			52.0						38.1			
Banks	NZ	Lp,d	42.8	60.2	43.9	34.3		29.9												
Barberia	Fra	Lp,d															42.3			
Boomer	Aust	Lp,d	40.1																	
Bronsyn	NZ	Lp,d		62.6	48.3	36.3				50.4	48.6			20.1		24.0	38.8		30.6	
Cannon	NZ	Lp,d										41.8								
Cobber	Aust	Lp,d												19.6						
Dobson	NZ	Lp,d	45.3	72.5		39.0	41.6	42.1	10.1	49.1	58.1	39.0					40.5			
Ellett	NZ	Lp,d	43.2	53.4	48.5	30.3		33.2												
Embassy	NZ	Lp,d	38.3	56.1	38.7															
Fitzroy	Aust	Lp,d								49.7	51.5	41.9								
Horizon	NZ/Arg	Lh,t															40.0			42.8
Impact	NZ	Lh,d	40.2	55.7	47.1			44.5		48.1	51.1	37.4	40.8	23.4			34.3		25.9	38.8
Kangaroo Valley	Aust	Lp,d				36.2		38.1		41.7										
Lincoln	NZ	Lp,d,E		55.7		34.8														
Maverick Gold	NZ	Lh,d		52.8																
Meridian	NZ	Lp,d				32.8				47.7	45.8	38.1		20.8			34.4		30.0	
Nevis	NZ	Lp,t			41.9															
Quartet	NZ	Lh,t				38.0					49.6									
Roper	Aust	Lp,d	36.5																	
Royce	Sth Afr	Lp,u																		38.9
Samson	NZ	Lp,d								44.7	52.9	40.1		24.0			33.8		30.0	
Skippy	Aust	Lp,d			51.2															
Supreme Plus	Sth Afr	Lh,d										41.7								
Tolosa	NZ	Lp,d						46.3			49.4									
Yatsyn 1	NZ	Lp,d	37.2	60.5	40.3	34.2		34.0												
Best exp. line			43.2	63.3	48.6	40.0		49.3		50.3	54.7	45.4		26.0			40.6			
Worst exp. line			30.4	56.0	36.0	34.1		37.9		45.6	49.4	37.6		21.9			34.5			
Mixtures																				
Bronsyn-Dovey		Lp,d/Fa												32.1						
Meridian-Dobson		Lp,d/Lp,d						46.2												
Impact-Dobson		Lh,d/Lp,d						46.8												
Impact-Dovey		Lh,d/Fa						57.0												
Supreme-Advance		Lh,d/Fa										43.7								
Samson-Jesup		Lp,d/Fa																43.2		

continued

Cultivar	Source	Species/ Ploidy/ Endophyte[2,3]	DM yields (t/ha)																	
			1993	1994	1995	1996[4]	1996[5]	1997[4]	1997[5,7]	1998	1999	2000[4]	2000[5]	2001[4]	2001[5]	2001[6]	2002[4]	2002[5]	2002[6,8]	2003
Tall fescue																				
Advance	NZ/Braz	Fa	53.0	59.1	50.6		44.3		22.1			50.5	47.4							
Advance MaxP	NZ	Fa,e													40.2			49.5		
AU Triumph	USA	Fa	59.9	69.7			58.9		31.8											
AU Triumph[1]	USA	Fa	58.9																	
Cajan	USA	Fa	53.1						31.1											
Dovey	Neth	Fa		70.3	61.1		57.2		33.6			51.0	49.5		51.9			51.6		52.2
Georgia 5	USA	Fa,E							32.5											
Jesup	USA	Fa							28.5									46.0		
Jesup MaxP	USA	Fa,e													47.8			50.5		
Melik	Aust	Fa		57.7																
Maxamise	USA	Fa							28.1											
Prosper	Fra	Fa					49.0													
Quantum	NZ	Fa	59.0				57.8		32.6			47.4	52.0		52.9			51.7		
Resolute	NZ	Fa											43.7							
Typhoon	NZ	Fa													46.6			49.5		51.0
Vulcan	NZ	Fa					45.0		24.8											
Best exp. line			54.9	61.9	49.6		50.6		10.5						56.8			49.8		
Worst exp. line			43.4	54.9	—		47.6		—						47.2			46.7		
Brome																				
Atom	unknown	Bw														32.0				
Bareno	NZ	Bv						35.1								27.2				
Gala	NZ	Bs						26.3								22.0				
Matua	NZ	Bw	50.7					40.4								29.7				
Matua[1]	NZ	Bw	56.1	68.4																
Best exp. line				67.5												31.8				
Phalaris																				
Atlas	Aust	Pa									56.2									
Holdfast	Aust	Pa									56.3									
General mean			45.2	60.5	45.5	36.1	49.9	40.6	22.6	47.3	52.1	42.0	48.4	23.3	49.3	27.8	38.2	48.7	31.6	44.7
LSD (P=0.05)			4.2	4.3	5.1	3.8	3.8	4.5	3.0	ns	4.8	3.8	2.2	4.4	ns	3.2	2.3	2.5	2.2	3.2

[1] Superstrike seed treatment.
[2] Lp *Lolium perenne*, Lh *Lolium hybridum* (syn. *L. x boucheanum*), Fa *Festuca arundinacea*, Bw, *Bromus willdenowii* (syn. *B. catharticus* syn. *B unioloides*), Bs *Bromus stamineus*, Bv *Bromus valdivianus*, Pa *Phalaris aquatica*; d diploid, t tetraploid, u unknown.
[3] E — Endophyte present — wild-type, e — Endophyte present — AR542 endophyte.
[4,5,6] Different experiments conducted in the same year.
[7] Data reproduced from Callow *et al.* (2003).
[8] Data reproduced from Lowe *et al.* (2008a).

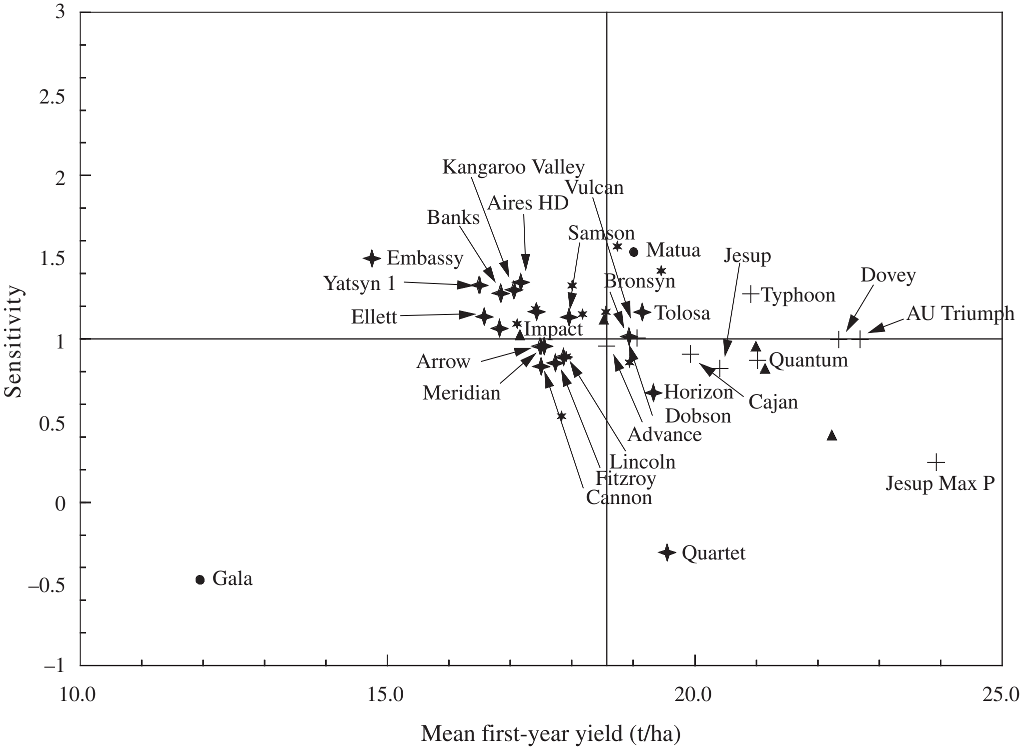

Figure 2. The relationship between cultivar adaptation (regression coefficient = sensitivity) and cultivar mean first-year DM yield for tall fescue (+), perennial or hybrid ryegrass (✦) and brome (•) cultivars and perennial ryegrass (✶) and tall fescue (▲) experimental lines. A new experiment was sown annually over the period 1993 to 2005 at Gatton in south-east Queensland. Average s.e. values — perennial ryegrass (0.7), tall fescue (1.0), experimental lines (1.5) and brome (1.3).

first-year and total yields (compare Tables 2 and 3) although first-year differences were smaller.

The tall fescue cultivars, AU Triumph, Dovey and Quantum, outyielded (P<0.05) the best of the perennial ryegrasses (Table 3), although in 1994 Dobson and an experimental line were not significantly different from AU Triumph and Dovey. Only in 2002 Exp. 1 (Barberia) and 2005 (best experimental) did a ryegrass cultivar produce significantly (P<0.05) higher first-year yields than the rest of the cultivars. Bareno and Atom bromes produced equivalent first-year yields to Matua prairie grass but Gala was always lower (P<0.05) yielding. Grouse chicory outyielded the best of the perennial ryegrasses by more than 50% in the only year it was assessed. On the other hand, Tonic plantain was lower-yielding (P<0.05) than Bronsyn and Horizon ryegrasses.

While experiment-to-experiment variation in first-year yields was generally small, extremes were recorded over the 13 years; in 1994, all species produced very high yields (GM of the combined species experiment being 25.9 t/ha DM), and in 2001, a severe summer affected all species (GM of ryegrass, tall fescue and brome experiments being 13.3, 16.7 and 16.0 t/ha, respectively). Yields of the tall fescue cultivars in the 1997 experiment at Mutdapilly were only half those from most experiments at Gatton.

Seasonal yields

Overall performance. The differences in seasonal growth of the perennial grasses are demonstrated in Figure 3. Perennial ryegrasses were superior to tall fescue in winter (Figure 3A), with Tolosa, 1 experimental ryegrass, Samson, Dobson and Bronsyn significantly (P<0.05) so. Quartet, Meridian and Impact yielded significantly more than all except AU Triumph. AU Triumph, Dovey, Quantum and Typhoon were the highest-yielding tall fescues in winter in this environment.

Table 3. First-year grass DM yields of perennial ryegrass cultivars, cultivar mixtures and other temperate grasses from sowings made annually from 1993 to 2005. Best and worst experimental lines provide the range of performance of breeding lines and differ from year to year.

Cultivar	DM yields (t/ha)																			
	1993	1994	1995	1996[2]	1996[3]	1997[2]	1997[3,5]	1998	1999	2000[2]	2000[3]	2001[2]	2001[3]	2001[4]	2002[2]	2002[3]	2002[4,6]	2003	2004	2005
Ryegrass																				
Aires HD		27.0		18.6		15.5														
Alto												13.3			18.7					
Arrow						16.7			19.4						16.8					
Banks	17.9	26.7	19.5	17.5		15.8														
Barberia															20.4					
Boomer	17.8																			
Bronsyn		26.3	19.7	17.2				13.8	18.0			12.4		12.9	17.3		17.6		19.4	19.8
Cannon										16.5									19.3	
Cobber												12.1								
Dobson	19.5	29.5		19.6	23.5	18.7	7.6	15.1	20.9	16.5					17.6					
Ellett	18.3	25.0	19.9	16.1		15.8														
Embassy	18.2	25.9	17.4																	
Fitzroy								15.2	19.6	16.6										
Horizon															19.1			19.3	21.9	20.5
Impact	19.0	24.7	19.3			16.8		13.8	19.7	15.8	16.7	11.9			16.0		16.5	17.8	19.2	19.0
Kangaroo Valley				17.2		16.2		12.6												
Lincoln		24.5		18.1																
Maverick Gold		24.8																		
Meridian				17.0				14.5	19.2	16.3		13.1			17.7		18.0			
Nevis			17.8																	
Quartet				19.4					18.9											
Roper	16.8																			
Royce																		18.8		
Samson								13.4	20.1	16.6		13.6			17.0		19.1		18.7	
Skippy			19.7																	
Supreme Plus										16.3										
Tolosa						18.1			21.4											
Yatsyn 1	17.7	27.0	18.4	17.3		15.5														
Best exp. line	19.0	27.4	20.5	20.5		18.0	10.4	14.7	21.8	17.4		15.0			17.7				21.0	21.7
Worst exp. line	17.0	23.9	15.7	17.2		17.1		12.9	19.3	14.7		12.7			16.3				20.0	
Mixtures																				
Bronsyn-Dovey												14.7								
Meridian-Dobson						18.2														
Impact-Dobson						17.8														
Impact-Dovey						18.7														
Supreme-Advance										17.3										
Samson-Jesup																20.1				

continued

Cultivar	DM yields (t/ha)																			
	1993	1994	1995	1996[2]	1996[3]	1997[2]	1997[3,5]	1998	1999	2000[2]	2000[3]	2001[2]	2001[3]	2001[4]	2002[2]	2002[3]	2002[4,6]	2003	2004	2005
Tall fescue																				
Advance	21.2	23.2	18.6		22.5		6.3			19.5	19.2									
Advance MaxP													13.5			21.9				
AU Triumph	26.0	29.4			27.4		10.9													
AU Triumph[1]	24.8																			
Cajan	22.3						10.8													
Dovey		30.2	23.6		26.8		10.6			22.0	21.5		17.9			25.8		23.6		
Georgia 5							10.2													
Jesup							9.2									22.1			22.3	
Jesup MaxP													16.2			24.6			24.4	
Malik		24.7																		
Prosper					24.3															
Quantum	25.3				26.0		11.0			19.4	19.8		17.6			23.6				
Resolute											17.0									
Typhoon													14.8			24.7		23.7	23.3	
Vulcan					22.9		7.3													
Best exp. line	22.5	26.3	20.8		24.9		6.1						20.3			23.8			23.6	
Worst exp. line	19.2	22.5	—		21.3		—						16.2			23.4			—	
Festulolium																				
Duo																			21.1	
Matrix																			20.5	
Best exp. line																			21.9	
Brome																				
Atom														17.7						
Bareno						17.1								17.0						
Gala						12.3								12.8						
Matua	24.5					16.5								17.9						
Matua[1]	24.4	29.6																		
Best exp. line		27.9												18.0						
Phalaris																				
Atlas									20.5											
Holdfast									21.2											
Herbs																				
Grouse Chicory																				32.3
Tonic Plantain																				18.9
General mean	20.2	25.9	19.0	18.2	24.3	16.9	8.4	14.0	20.1	16.9	19.0	13.3	16.7	16.0	17.5	23.4	18.2	20.6	21.1	22.0
LSD (P=0.05)	2.5	2.1	1.9	1.6	1.8	1.2	1.1	ns	ns	1.2	0.9	1.6	2.9	2.5	1.0	1.4	1.6	1.9	1.2	0.5

[1] Superstrike seed treatment. [2,3,4] Different experiments conducted in the same year. [5] Data reproduced from Callow *et al.* (2003). [6] Data reproduced from Lowe *et al.* (2008a).

Winter-active tall fescues were not included in the analysis because none appeared in more than 1 experiment.

AU Triumph and Cajan tall fescues were the best performing cultivars in spring along with Matua prairie grass (Figure 3B). AU Triumph yielded significantly more (P<0.05) than the remaining cultivars except for Tolosa and those poorly defined with large standard errors (some experimental cultivars, Arrow, Lincoln and Quartet). In addition, Matua was not significantly different from Quantum (P>0.05) and Cajan was not different from Advance, Dovey, Quantum and Typhoon.

All tall fescue cultivars yielded well in summer, with AU Triumph, Dovey and Quantum yielding significantly (P<0.05) more than Advance, while AU Triumph and Dovey yielded more (P<0.05) than Vulcan. All tall fescue cultivars significantly outyielded (P<0.05) the commercial ryegrass cultivars but not a number of the experimental lines (Figure 3C). The older ryegrass cultivars (Embassy, Ellett, Banks, Yatsyn 1) yielded less (P<0.05) than the newer cultivars (Tolosa, Bronsyn, Dobson, Impact) in summer.

Tall fescue cultivars produced high autumn yields (Figure 3D) with AU Triumph, Dovey, Quantum and Typhoon yielding significantly (P<0.05) more than Advance and Cajan; Dovey outyielded Jesup. Horizon and Fitzroy produced similar (P>0.05) yields to the tall fescues, while many other perennial ryegrasses produced significantly less. A number of the experimental ryegrasses produced similar (P>0.05) autumn yields to the best tall fescue cultivars.

Percent of yield produced in summer

Overall performance. The tall fescue cultivars produced a significantly (P<0.05) greater proportion of their DM in summer than the perennial

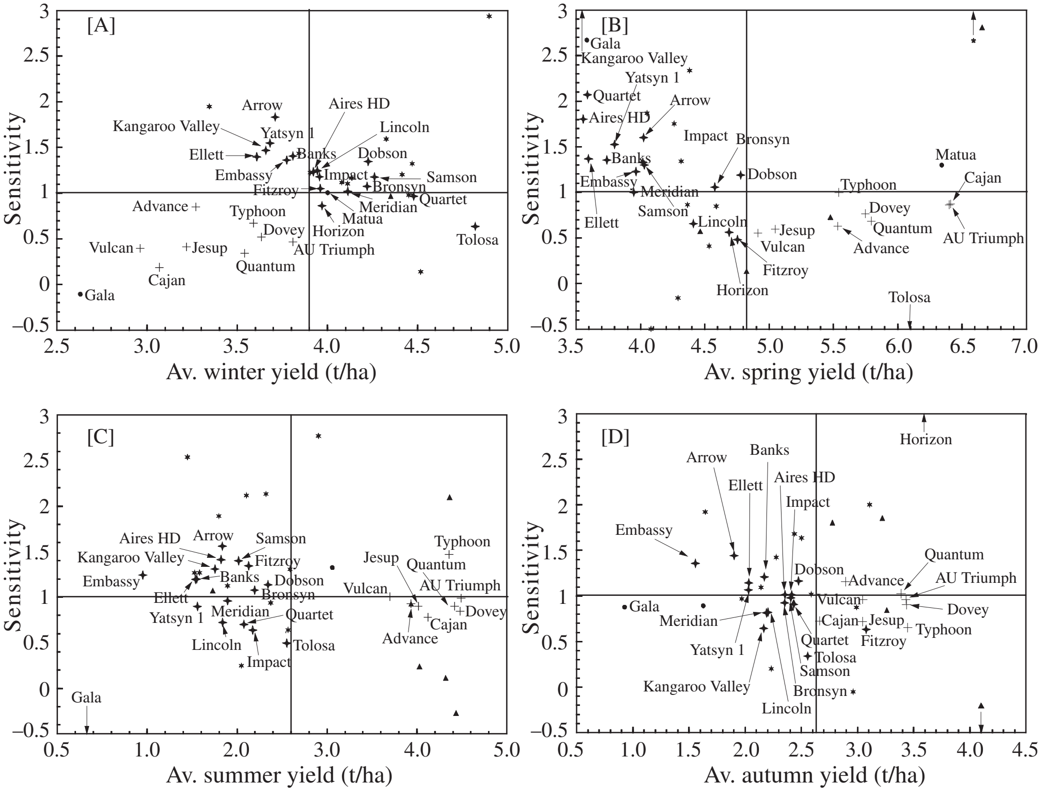

Figure 3. The relationship between cultivar adaptation (regression coefficient = sensitivity) and average seasonal DM yields for tall fescue (+), perennial or hybrid ryegrass (✦) and brome (•) cultivars and perennial ryegrass (✶) and tall fescue (▲) experimental lines. Average s.e. values for autumn, winter, spring and summer, respectively — perennial ryegrass (0.2, 0.2, 0.6, 0.3), tall fescue (0.2, 0.2, 0.2, 0.2) and experimental lines (1.0, 0.6, 1.0, 0.9).

ryegrasses (Figure 4), with no significant differences between the tall fescue cultivars. While Matua produced significantly less in summer than the tall fescues, it produced significantly more than all perennial ryegrass cultivars except Horizon and a number of the experimental lines. Horizon produced significantly (P<0.05) more in summer than all other perennial ryegrass cultivars except Fitzroy, Tolosa, Impact and Aires HD and a number of the experimental lines.

Individual experiment performance. Tall fescue produced 17–30% of its production in summer, depending on cultivar and year, compared with perennial ryegrass (9–22%), brome grasses (15–26%) and phalaris (around 20%) (Table 4). Generally, there were no significant (P>0.05) differences between the summer-active tall fescue cultivars but Resolute and Prosper and a number of the experimental lines (winter-active types) had significantly lower percentages (*e.g.* 1994, 1997 Exp. 2, 2000 Exp. 2). Tall fescue-perennial ryegrass mixtures generally had lower, and/or higher, (P<0.05) summer percentages than the equivalent pure tall fescue and ryegrass stands, respectively (*e.g.* 1997 Exp. 1, 2000 Exp. 1). On the other hand, there were larger differences between cultivars and experimental lines of perennial ryegrass and brome grasses. Dobson, Bronsyn, Impact, Cannon and Tolosa generally produced more of their growth in summer than other cultivars but this was not always the case (*i.e.,* Bronsyn — 2001 Exp. 1, Impact — 1999, 2002 Exp. 2, 2003). Gala brome produced significantly less in summer than Matua or the other brome cultivars in 1997 but not in 2001 Exp. 3.

Rust in spring

Overall performance. While rust infected the perennial grasses throughout the year, most severe infections occurred in spring. All tall fescue cultivars except AU Triumph showed similar (P>0.05) but low levels of foliar damage caused

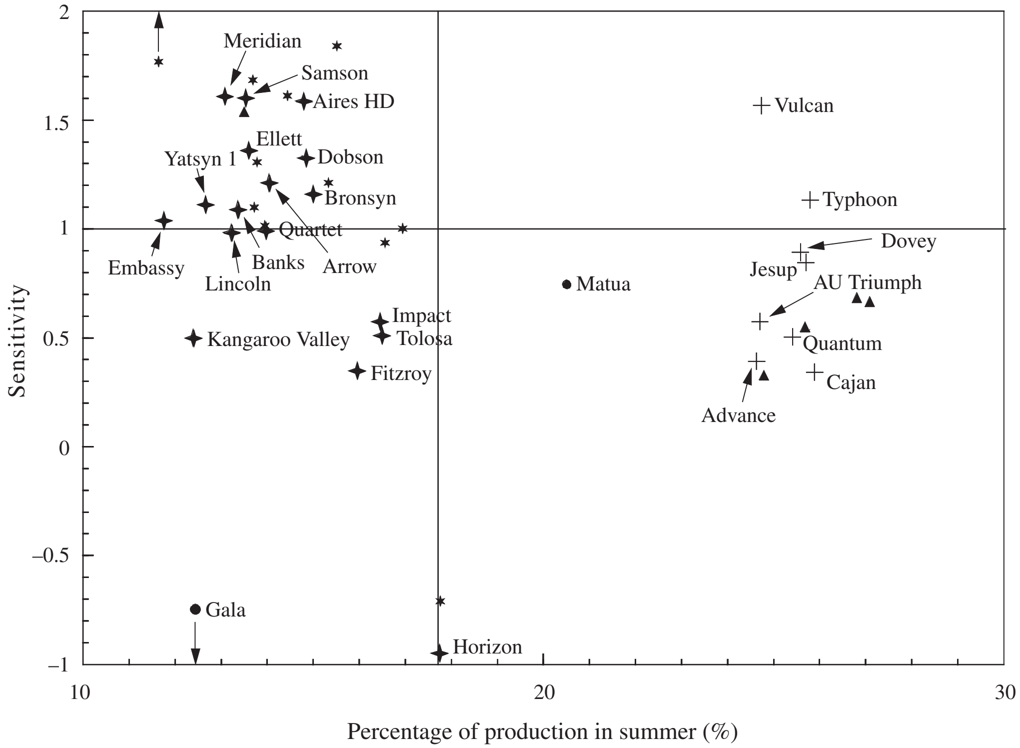

Figure 4. The relationship between cultivar adaptation (regression coefficient = sensitivity) and average summer DM yields as a percentage of total yield for tall fescue (+), perennial or hybrid ryegrass (✦) and brome cultivars (•) and perennial ryegrass (✶) and tall fescue (▲) experimental lines. Average s.e. values — perennial ryegrass (5.1), tall fescue (4.4) and experimental lines (8.7).

Table 4. The percentages of DM yields produced in summer by perennial ryegrass cultivars, cultivar mixtures and other temperate grasses over 3-year periods from sowings made annually from 1993 to 2003. Best and worst experimental lines provide the range of performance of breeding lines and differ from year to year.

Cultivar	Proportion of yield produced in summer (%)																	
	1993	1994	1995	1996[2]	1996[3]	1997[2]	1997[3,5]	1998	1999	2000[2]	2000[3]	2001[2]	2001[3]	2001[4]	2002[2]	2002[3]	2002[4,6]	2003
Ryegrass																		
Aires HD		18.8		11.9		11.0												
Alto												13.7			17.0			
Arrow						11.7			15.8						15.3			
Banks	19.0	17.0	10.4	10.1		12.2												
Barberia															17.8			
Boomer	18.5																	
Bronsyn		18.3	12.6	12.9				14.6	16.4			9.4		12.0	17.1		17.9	
Cannon										19.9								
Cobber												12.9						
Dobson	21.7	18.9		12.1	14.6	12.8	8.6	15.8	17.1	18.0					16.9			
Ellett	21.1	17.6	11.8	11.6		8.8												
Embassy	17.2	15.2	8.6															
Fitzroy								16.0	16.8	16.8								
Horizon															17.0			19.4
Impact	21.8	17.0	15.3			16.5		16.4	14.6	17.1	15.8	17.4			15.5		18.5	14.7
Kangaroo Valley				12.4		10.0		12.9										
Lincoln		15.7		11.1														
Maverick Gold		13.6																
Meridian				9.2				15.1	16.3	16.0		9.9			15.0		21.1	
Nevis			9.5															
Quartet				11.8					15.4									
Roper	19.4																	
Royce																		18.1
Samson								14.6	15.8	19.2		16.2			13.0		20.3	
Skippy			14.9															
Supreme Plus										17.0								
Tolosa						15.5			17.2									
Yatsyn 1	19.3	15.1	10.0	8.8		12.8												
Best exp. line	21.1	18.2	13.9	12.9		16.4		17.3	18.1	20.2		16.5			18.0			
Worst exp. line	15.3	16.8	9.2	9.4		12.0		13.7	15.4	17.0		10.4			15.0			
Mixtures																		
Bronsyn-Dovey												22.1						
Meridian-Dobson						14.4												
Impact-Dobson						14.1												
Impact-Dovey						20.3												
Supreme-Advance										20.9								
Samson-Jesup																25.3		

continued

Cultivar	Proportion of yield produced in summer (%)																	
	1993	1994	1995	1996[2]	1996[3]	1997[2]	1997[3,5]	1998	1999	2000[2]	2000[3]	2001[2]	2001[3]	2001[4]	2002[2]	2002[3]	2002[4,6]	2003
Tall fescue																		
Advance	28.6	23.6	24.3		23.6		25.5			26.7	23.1							
Advance MaxP													25.2			28.1		
AU Triumph	28.9	23.7			27.1		23.4											
AU Triumph[1]	28.0																	
Cajan	27.9						25.1											
Dovey		25.3	23.5		29.2		27.2			28.9	22.5		23.1			26.9		24.5
Jesup							23.8									26.9		
Jesup MaxP													24.8			26.7		
Malik		23.5																
Prosper					18.0													
Quantum	28.7				24.7		25.0			27.3	22.6		23.9			26.1		
Resolute											16.7							
Typhoon													22.4			27.4		23.9
Vulcan					26.4		21.1											
Best exp. line	29.9	25.2	21.9		29.6		15.2						25.1			27.8		
Worst exp. line	29.3	19.0	—		17.8		—						23.3			25.3		
Brome																		
Atom														20.5				
Bareno						19.6								21.8				
Gala						15.3								16.9				
Matua	23.3					19.4								17.7				
Matua[1]	26.4	22.3																
Best exp. line		21.9												23.9				
Phalaris																		
Atlas									20.6									
Holdfast									19.8									
General mean	23.0	19.4	13.3	11.1	24.5	14.3	21.3	15.4	16.8	19.8	21.4	13.8	24.0	18.8	16.2	26.7	18.6	20.1
LSD (P=0.05)	2.4	2.2	3.7	2.5	2.3	2.8	5.0	ns	2.9	2.7	1.6	5.8	ns	5.4	2.6	ns	ns	3.3

[1] Superstrike seed treatment.
[2,3,4] Different experiments conducted in the same year.
[5] Data reproduced from Callow *et al.* (2003).
[6] Data reproduced from Lowe *et al.* (2008a).

by rust (Figure 5). Damage to Horizon was similar (P>0.05) to that on Tolosa and all tall fescue cultivars, except AU Triumph. No experimental ryegrass was as tolerant of rust as Tolosa and Horizon, with most significantly less tolerant. Tolosa and Horizon were not significantly different from Samson, Kangaroo Valley, Arrow and Embassy but were more (P<0.05) rust-resistant than the remaining ryegrass cultivars and some of the experimental lines. All brome and Phalaris cultivars showed no leaf damage.

Individual experiment performance. In most years, rust levels in spring were similar in both perennial ryegrass and tall fescue (Table 5); the exceptions were in 1993–1996 where tall fescue cultivars showed less damage. AU Triumph carried more (P<0.05) rust than the other tall fescues in 1994 and 1996. There was no consistent effect on rust damage, of having the endophyte MaxP associated with Jesup.

No one ryegrass showed high levels of rust resistance in all experiments in which it was included. However, a number of cultivars, including Impact, Tolosa, Horizon and Samson, always showed moderate to high (5.2–8.5) levels of resistance. Banks, Barberia, Cannon, Ellett, Meridian, Fitzroy and Royce showed high resistance in 1 or more experiments but a number were badly affected by rust on other occasions (*e.g.* Fitzroy in 1999, Ellett in 1993 and Banks in 1994).

In most experiments, the best experimental ryegrass or tall fescue entry carried similar (P>0.05) levels of rust to the best commercial cultivar. Rust levels recorded for the mixtures of tall fescue and perennial ryegrass, or mixtures of perennial ryegrass cultivars, were generally intermediate between those of the component cultivars (if included).

Persistence

Overall performance. Persistence (as assessed by % occurrence) was higher (P<0.05) for Jesup

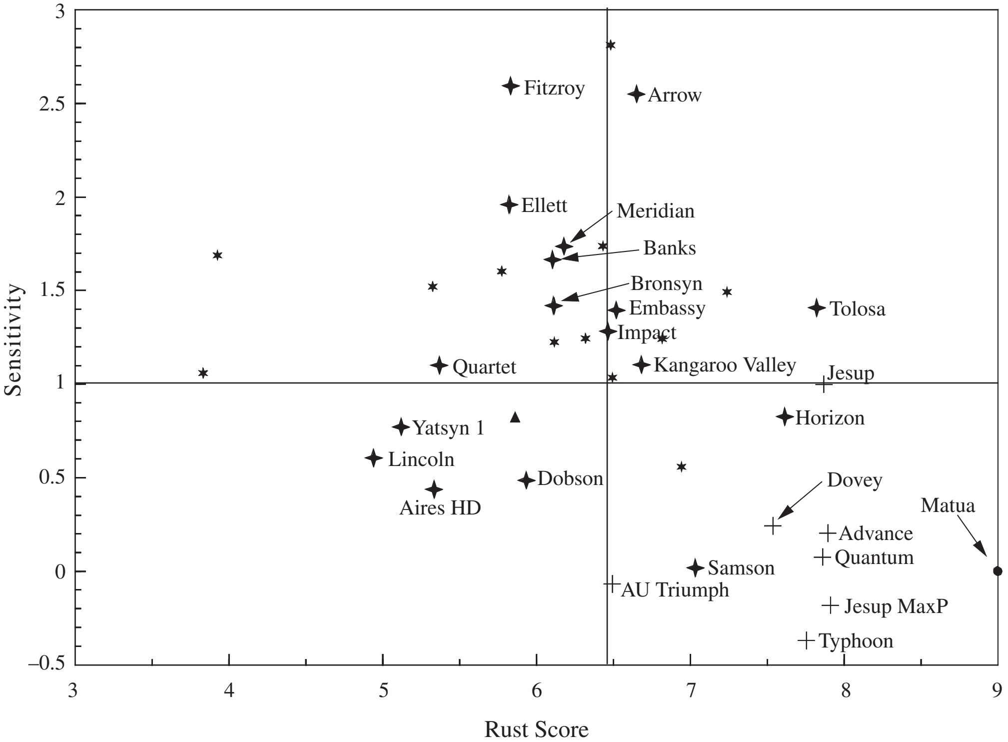

Figure 5. The relationship between cultivar adaptation (regression coefficient = sensitivity) and average spring cultivar rust score (where 9 = no rust and 1= >80% of the leaf blades severely damaged by rust pustules) for tall fescue (+), perennial or hybrid ryegrass (✦) and brome (•) cultivars and perennial ryegrass (✱) and tall fescue (▲) experimental lines. Average s.e. values — perennial ryegrass (0.4), tall fescue (0.3) and experimental lines (0.5).

Table 5. Level of rust damage, averaged for all spring harvests over the first year, of perennial ryegrass cultivars, cultivar mixtures and other temperate grasses evaluated at Gatton over 3-year periods from sowings made annually from 1993 to 2003. Best and worst experimental lines provide the range of performance of breeding lines and differ from year to year.

Cultivar	Rust damage[1]																	
	1993	1994	1995	1996[3]	1996[4]	1997	1998	1999	2000[3]	2000[4]	2001[3]	2001[4]	2002[3]	2002[4]	2002[5,6]	2003	2004	2005
Ryegrass																		
Aires HD		4.8		5.1		5.8												
Alto											6.8		5.3					
Arrow						6.7		4.3					5.7					
Banks	5.1	4.3	7.6	6.2		6.5												
Barberia													7.5					
Boomer	3.3																	
Bronsyn		5.0	7.5	7.4			5.6	3.5			6.7		5.3		5.6		7.0	6.8
Cannon									7.6								6.8	
Dobson	5.1	4.7		5.9	6.7	5.8	6.1	5.0	7.0				6.7					
Ellett	2.6	6.0	6.7	7.7		4.7												
Embassy	5.2	5.6	7.5															
Fitzroy							6.3	3.2	7.9									
Horizon													7.5			6.6	8.5	7.7
Impact	5.9	5.9	6.5			7.1	7.3	5.8	7.2	8.0	6.7		5.2		5.5	5.6	7.9	6.7
Kangaroo Valley				7.1		6.7	6.8											
Lincoln		4.6		5.2														
Maverick Gold		5.9																
Meridian				6.1			6.0	6.0	8.1		7.0		4.2		5.3			
Nevis			6.6															
Quartet				5.8				4.3										
Roper	2.0																	
Royce																7.4		
Samson							6.8	6.4	7.5		6.6		7.7		7.3		7.8	
Skippy			7.3															
Supreme Plus									7.3									
Tolosa						7.8		6.5										
Yatsyn 1	4.5	4.2	6.3	4.2		5.9												
Best exp. line	5.1	5.3	8.0	6.3		6.5	7.4	5.8	7.9		7.1		6.5				7.8	7.5
Worst exp. line	2.1	4.1	1.3	3.8		5.3	4.0	2.3	7.4		5.3		4.8				6.9	—
Mixtures																		
Bronsyn-Dovey											7.9							
Meridian-Dobson						6.7												
Impact-Dobson						5.9												
Impact-Dovey						8.2												
Supreme-Advance									7.0									
Samson-Jesup														7.8				

continued

Cultivar	Rust damage[1]																	
	1993	1994	1995	1996[3]	1996[4]	1997	1998	1999	2000[3]	2000[4]	2001[3]	2001[4]	2002[3]	2002[4]	2002[5,6]	2003	2004	2005
Tall fescue																		
Advance	8.4	7.3	8.7		8.3				8.0	8.0								
Advance MaxP												8.3		8.0				
AU Triumph	7.7	4.9			6.4													
AU Triumph[2]	7.9																	
Cajan	7.8																	
Dovey		6.9	8.6		8.2				7.8	7.3		7.3		7.3		7.6		
Jesup														6.5			8.8	
Jesup MaxP												7.1		8.2			7.8	
Malik		6.8																
Prosper					8.9													
Quantum	8.4				7.9				8.0	8.0		7.6		7.7				
Resolute										8.6								
Typhoon												7.8		8.3		8.1	7.5	
Vulcan					7.9													
Best exp. line	8.6	7.2	8.6		8.6							8.0		8.0			7.5	
Worst exp. line	7.7	5.2	—		7.5							7.0		7.7			—	
Festulolium																		
Duo																	5.6	
Matrix																	8.1	
Best exp. line																	7.6	
Brome																		
Atom																		
Bareno						9												
Gala						9												
Matua	9.0					9												
Matua[2]	9.0	9.0																
Best exp. line		9.0																
Phalaris								9.0										
Atlas																		
Holdfast								9.0										
General mean	5.8	5.6	6.9	5.7	7.9	6.8	6.0	5.1	7.6	8.1	6.8	7.5	6.0	7.7	5.8	7.1	7.4	7.8
LSD (P=0.05)	1.2	0.9	0.9	0.8	0.4	0.7	0.5	1.0	0.6	0.4	0.5	0.6	0.6	0.7	0.6	0.6	0.7	0.7

[1] Scoring scale: 1 = greater than 80% of the leaf area within the plot affected by rust pustules; 9 = no damage.
[2] Superstrike seed treatment.
[3,4,5] Different experiments conducted in the same year.
[6] Data reproduced from Lowe *et al.* (2008a).

than for Advance, Dovey and 2 experimental tall fescue lines (Figure 6). Advance was significantly (P<0.05) less persistent than all other tall fescues except an experimental line. Best of the perennial ryegrasses was Fitzroy (data not presented), which performed better (P<0.05) than all other ryegrass cultivars, but with a high negative sensitivity, showing greater resistance to environmental change. In the 3 experiments in which it was present, it performed worse when the environmental mean was highest and this inflated its estimated mean. The next most persistent ryegrass, Tolosa, also with a high negative sensitivity, performed better than Arrow, Banks, Dobson, Embassy, Lincoln, 1 experimental line, Meridian, Samson and Yatsyn 1. The persistence of Matua prairie was no better than that of the worst of the perennial ryegrasses.

Individual experiment performance. Persistence varied between experiments and species. Between-year variation was high and larger for ryegrass than tall fescue (Table 6). For example in perennial ryegrass, Dobson ranged from no survival at the end of the third year in 1996 to 48% in 1993, and Impact from 3% in 2002 Exp. 2 to 45% in 1993. In tall fescue, Dovey varied from 52% in 1996 to 85% in 2000 and Quantum from 53% in 1997 to 89% in 1993. Level of persistence is related to the conditions experienced during the experiments; conditions in 1995, 1996 and 2001 were extreme (Table 1) and this is reflected in lower plant survival. The 2001 experiment was terminated early. None of these ryegrass swards survived the final summer, with most of the damage occurring during the first summer (data not presented).

Advance was the only tall fescue not significantly (P>0.05) more persistent than the perennial ryegrasses in all years. It was also less persistent than all other tall fescues. Kangaroo Valley perennial ryegrass and its derivatives, Boomer, Roper and Skippy, and Fitzroy, bred in Australia from the old cultivar Victorian, were significantly (P<0.05) more persistent than the

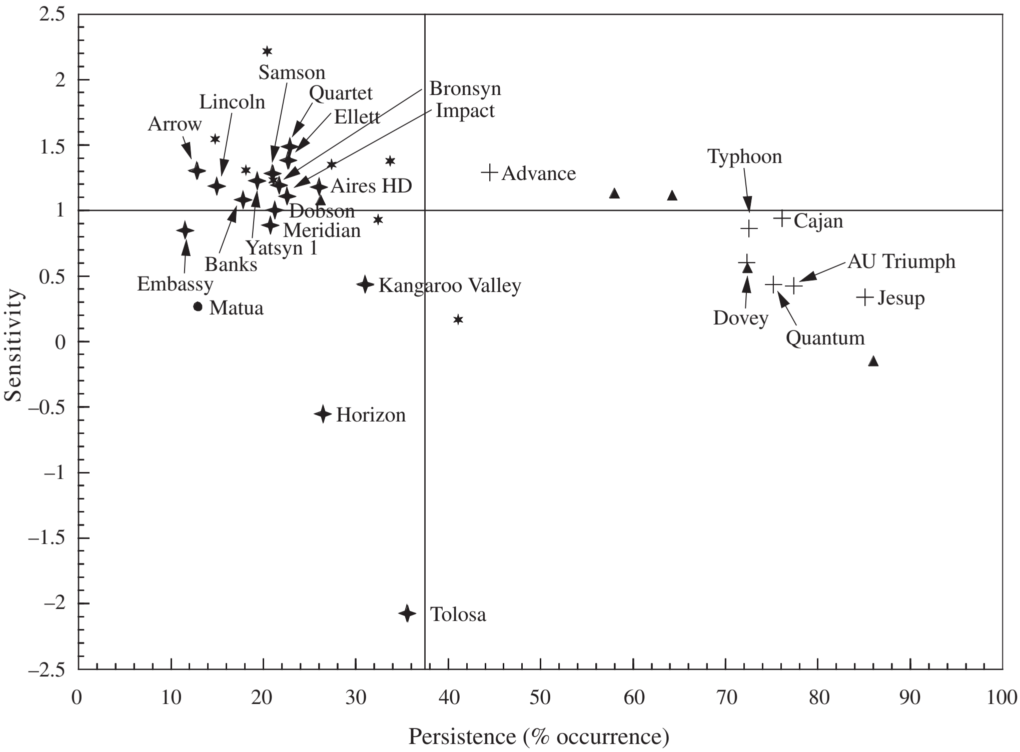

Figure 6. The relationship between cultivar adaptation (regression coefficient = sensitivity) and cultivar mean persistence at the end of the 3-year evaluation period for tall fescue (+), perennial or hybrid ryegrass (✦) and brome (•) cultivars and perennial ryegrass (✶) and tall fescue (▲) experimental lines. Average s.e. values — perennial ryegrass (1.0), tall fescue (1.0), experimental lines (1.8) and brome (4.1).

Table 6. Persistence (% occurrence at the end of 3 years) of perennial ryegrass cultivars, cultivar mixtures and other temperate grasses over 3-year periods from sowings made annually from 1993 to 2003. Best and worst experimental lines provide the range of performance of breeding lines and differ from year to year.

Cultivar	Persistence (% occurrence)															
	1993	1994	1995	1996[2]	1996[3]	1997[2]	1997[3,5]	1998	1999	2000[2]	2000[3,5]	2001	2002[2]	2002[5]	2002[4,6]	2003
Ryegrass																
Aires HD		45.7		10.3		21.0										
Alto													25.7			
Arrow						9.7			22.0				18.0			
Banks	35.7	39.3	0.0	1.0		1.3										
Barberia													19.3			
Boomer	63.3															
Bronsyn		38.7	4.3	7.0				30.0	38.3				28.7	5.3		
Cannon										44.0						
Cobber																
Dobson	47.7	39.3		7.3	0.0	14.3	0.0	29.7	34.7	25.6			24.0			
Ellett	58.0	31.7	6.7	0.0		20.7										
Embassy	25.7	26.7	0.0													
Fitzroy								46.7	64.7	43.0						
Horizon													25.7			22.7
Impact	44.9	39.0	5.3			38.7		31.0	36.3	34.7	43.8		25.0	3.0		36.0
Kangaroo Valley				25.0		29.7		35.7								
Lincoln		35.0		2.7												
Maverick Gold		21.7														
Meridian				3.7				39.3	16.7	26.0			22.3	18.7		
Nevis			5.7													
Quartet				2.0					33.3							
Roper	62.7															
Royce																17.7
Samson								30.0	25.0	47.7			16.3	6.7		
Skippy			42.0													
Supreme Plus										25.7						
Tolosa						40.7			21.0							
Yatsyn 1	37.7	45.7	1.0	5.7		12.0										
Best exp. line	42.0	49.7	7.0	31.0		57.0		45.3	42.0	53.3			29.3			
Worst exp. line	1.0	31.0	0.0	0.0		15.0		22.0	32.7	31.0			17.0			
Mixtures																
Bronsyn-Dovey																
Meridian-Dobson						41.0										
Impact-Dobson						43.7										
Impact-Dovey						87.3										
Supreme-Advance										48.0						
Samson-Jesup														81.0		

continued

Cultivar	Persistence (% occurrence)															
	1993	1994	1995	1996[2]	1996[3]	1997[2]	1997[3,5]	1998	1999	2000[2]	2000[3,5]	2001	2002[2]	2002[5]	2002[4,6]	2003
Tall fescue																
Advance	56.3	58.8	24.7		14.3		19.3			69.3	71.3					
Advance MaxP												30.3		73.3		
AU Triumph	86.7	89.3			76.2		62.3									
AU Triumph[1]	79.0															
Cajan	93.3						54.3									
Dovey		82.3	70.7		51.8		57.7			84.0	85.0	59.0		79.7		62.7
Jesup							77.3							89.7		
Jesup MaxP												63.0		92.7		
Malik		78.7														
Prosper					32.5											
Quantum	88.7				82.5		52.7			84.7	79.0	65.3		83.3		
Resolute											65.5					
Typhoon												50.3		83.7		79.7
Vulcan					87.2		75.7									
Best exp. line	90.0	93.7	98.3		92.0		0							84.0		
Worst exp. line	89.7	79.3	—		25.9									79.3		
Brome																
Atom																
Bareno						13.3										
Gala						4.7										
Matua	11.7					11.3										
Matua[1]	17.3	25.7														
Best exp. line		35.7														
Phalaris																
Atlas									43.0							
Holdfast									55.5							
General mean	51.4	51.8	14.3	8.2	59.6	29.0	40.3	34.4	35.6	46.0	70.4	57.7	22.9	82.7	12.4	43.7
Lsd (P=0.05)	15.6	16.5	11.5	12.9	18.6	16.2	15.8	10.1	13.5	11.6	11.8	ns	ns	ns	10.5	18.5

[1] Superstrike seed treatment.
[2,3,4] Different experiments conducted in the same year.
[5] Data reproduced from Callow *et al.* (2003).
[6] Data reproduced from Lowe *et al. (2008a).*

New Zealand-sourced cultivars (Table 2), with the exception of 1993, 1997, 1998 and 2000. There were differences within the New Zealand-sourced cultivars; Ellett was more persistent than Embassy, Banks and Yatsyn 1 in 1993, Tolosa more persistent than all except Impact in 1997 and Cannon more persistent than Dobson, Meridian and Supreme Plus in 2000. Mixtures of perennial ryegrass and tall fescue were more persistent than their ryegrass equivalent but less than that of their tall fescue component (where present), except in 1997, when the Impact-Dovey mixture was more persistent (P<0.05) than Dovey alone.

Discussion

General

This study has provided valuable information on growth, persistence and rust-resistance of a wide range of temperate perennial grasses over a range of seasons under irrigated conditions in the subtropics. The superior DM production (+30%) of summer-active tall fescue cultivars over perennial ryegrass cultivars over each 3-year period confirmed previous research (Lowe and Bowdler 1984; 1995) from single experiments with a restricted range of cultivars. Matua prairie grass and the other brome grasses were intermediate to these extremes, although Gala performed poorly in this environment. Differences in persistence were even greater, with tall fescues being 1.8 times more persistent than the ryegrasses over the 3-year periods. While Matua prairie grass was less persistent than the ryegrasses in our study, these results do not reflect the true picture as it persists better under grazing than perennial ryegrass (Lowe *et al.* 1999a; Fulkerson *et al.* 2000), although this is dependent on management factors (Fulkerson *et al.* 2000) for seeding and regeneration.

There were quite strong seasonal differences between the 3 grass types; winter was the only season where perennial ryegrasses outperformed the other grasses in the subtropics. Matua prairie grass showed more winter activity than tall fescue cultivars, while its spring production matched the best of the tall fescue cultivars and its DM production in summer and autumn was inferior. This poorer summer production somewhat contrasts with the results under grazing in the same environment (Lowe *et al.* 1999a; Fulkerson *et al.* 2000), where Matua's performance was superior to that of AU Triumph tall fescue.

There was considerable year-to-year variation in the performance of entries, mainly as a result of climatic differences, and this variation was generally greater than cultivar differences within experiments. This within-experiment variation was generally accounted for in the weighted, modified joint regression analyses (Digby 1979). While entries generally behaved similarly in the 'overall performance' and 'individual experiment' analyses, there were some inconsistencies. More confidence can be drawn from the results where entries have been included on more occasions. Thus, the data on performance of Dobson, Impact and Dovey (8, 10 and 8 experiments, respectively) would be more reliable than that for Tolosa, Quartet and Jesup (2 experiments).

Tall fescue performance

While the overall analyses suggested there was very little difference between the summer-active tall fescues (with the exception of the higher-quality cultivar Vulcan; Callow *et al.* 2003), there were significant differences between them in individual experiments. AU Triumph, Dovey and Quantum were the highest-yielding, while Advance generally produced lower yields and was less-persistent. These results agree with published results from similar (Fulkerson *et al.* 2000) and other environments (Clark *et al.* 1993; Hopkins and Alison 2006). Seasonal production of winter-active tall fescues, such as Prosper and Resolute, differs from that of summer-active tall fescues (Stewart and Charlton 2003), with less growth in summer; our data, which include a number of experimental lines, provide similar evidence under subtropical conditions. The production of both tall fescue and perennial ryegrass at Mutdapilly was substantially less than at Gatton, although persistence was similar. The yield difference has been reported previously with annual ryegrasses in the first paper of this series (Lowe *et al.* 2007), and relates mainly to differences in soil physical attributes, as climatic differences were small.

Persistence of tall fescue cultivars showed greater variation between experiments than did total yield and this appears to be related as much to environmental variation as to cultivar characteristics and morphological traits (Easton *et al.*1994). Jesup and Jesup MaxP showed best persistence although each was present in only 2 experiments, which had completed 3-years assessment. While endophyte presence conveyed greater persistence to tall fescue in USA (Burns *et al.* 2006), the results here with Jesup and Advance, infected with the novel endophyte MaxP, were less conclusive. This contrasted with results from other experiments in the same environment, where the novel endophyte provided significant improvement in seasonal yield and persistence of a number of tall fescue cultivars (K.F. Lowe and D.E. Hume, unpublished data). Vulcan performed well in the only experiment in which it was included, but other results (Fulkerson *et al.* 2000; Lowe *et al.* 2008b) suggested it was not persistent in the subtropics. The winter-active tall fescue cultivars and an experimental line were also less persistent and this result may parallel the behaviour of winter-active *Phalaris aquatica* cultivars, which are intolerant of regular summer defoliation in this environment (Kleinschmidt 1964; Lowe and Bowdler 1981).

Crown rust damage was generally relatively light on the tall fescue cultivars. Most averaged a visual score around 8, which suggested only 10–15% of the leaf surface had been affected by rust pustules, although levels fell as low as 5. As palatability is a major problem for tall fescue, the presence of any factor likely to reduce acceptability needs attention and Easton *et al.* (1994) suggest rust resistance is an area which needs to be targeted by plant breeders. However, of the experimental material we evaluated, none appeared to hold any promise of better rust tolerance than the current cultivars.

Perennial ryegrass performance

In New Zealand, Williams *et al.* (2007) suggest that incremental increases in herbage yields have been achieved through the successive releases of new ryegrass cultivars, particularly during the summer and autumn periods in the case of perennial ryegrass. Our data agree with this assertion, demonstrating that there was strong differentiation between the newer cultivars bred in the last 15 years and those developed earlier. Much larger differences were demonstrated between the perennial ryegrass cultivars under subtropical conditions than between the tall fescues described above. Likewise, R.G. Clarke (unpublished data, reported in Cunningham *et al.* 1994) suggested that a range of new cultivars and experimental material performed well in experiments in Victoria, with some showing better seasonal yields and more summer activity than existing cultivars and superior resistance to crown rust.

There was greater variation in persistence in perennial ryegrasses than in tall fescues and persistence was even more influenced by environmental conditions. It appears that severe conditions (very hot and dry) during the first summer predisposed perennial ryegrass to high population losses over the 3-year experimental periods studied. This was demonstrated in our experiments in 1996, where persistence was negligible for most cultivars after 3 years and in 2001, where the experiment had to be terminated at the end of the second year, as no ryegrass plants were present in most treatments. Kangaroo Valley and selections from it (Skippy, Roper and Boomer), Fitzroy and Tolosa were the most persistent cultivars, although persistence of perennial ryegrass was not always positively related to yield in this environment (Lowe and Bowdler 1984). Based on the limited data available, both Fitzroy and Tolosa appeared more adapted to high-stress environments, than other new cultivars.

Rust damage on perennial ryegrass in spring ranged from 2 (which suggests around 80% of the leaf area of the stand was affected by rust pustules) to 8, depending on cultivar and environmental conditions experienced. While there was not the same differentiation between old and new cultivars in rust resistance as in total yield, the new cultivars Tolosa, Horizon and Samson showed that improvements have been made in selecting for rust resistance. While Yatsyn 1, Ellett and Dobson were released with good resistance, substantial damage from rust occurred to these cultivars in our experiments as resistance broke down. Similar loss of resistance has been experienced in New Zealand (Stewart and Charlton 2003) and southern Australia (Cunningham *et al.* 1994).

Improved summer production from perennial ryegrass is a priority for all areas of Australia (Cunningham *et al.* 1994), but especially in the subtropics and northern Victoria, where it is required to justify the cost of irrigation. Our experiments demonstrated substantial variation between cultivars and experimental lines in the percentage of DM produced in summer. It ranged from 12% to 18%, which translates into an extra

1.8 t/ha DM in each summer from the superior cultivars. This additional feed is available for grazing at a time when quality feed is scarce.

Breeding objectives for perennial ryegrass in Australia and New Zealand (Cunningham *et al.* 1994) include increased environmental adaptation, improved seasonal growth, drought tolerance and increased resistance to diseases (all relevant to the subtropics), enhanced nutritive value and improved seedling vigour and seed yield (less relevant to the subtropics). If we postulate that the yields of Yatsyn 1, Banks and Ellett represent the older ryegrasses and those of Bronsyn, Dobson, Fitzroy and Horizon represent the newer cultivars (Figure 1), the improvement in performance from breeding and selection over the last 10–15 years is about 22% under subtropical conditions. Despite this, the long-term performance and persistence of perennial ryegrass are still less than satisfactory. While tall fescue cultivars achieve superior yields, animal production differences do not reflect these higher yields (Easton *et al.*1994; Lowe *et al.* 1999b).

Performance of other species

Yield and persistence of the 2 Phalaris cultivars were no better than those of the best perennial ryegrass cultivars in the experiment in which they were included. However, these yields were higher than those from earlier experiments at the same site and with similar management, where only 25 t/ha DM was produced by cv. Australian (Lowe and Bowdler 1981) and 40 t/ha from cv. Grasslands Maru (Lowe and Bowdler 1995), both over 2-year periods. The first-year performance of chicory in this environment is high and is confirmed by data obtained at Mutdapilly (K.F. Lowe and T.M. Bowdler, unpublished data), Gatton (Lowe *et al.* 2008b) and New Zealand (Hume *et al.* 1995).

Techniques for evaluating perennial grass under subtropical conditions

The data were used to assess how well first-year DM yield could predict the long-term performance of temperate grasses under subtropical conditions. First-year yields predicted 69% and 78% of the variation ($P<0.001$) in 3-year total yields for perennial ryegrass and tall fescue cultivars, respectively, but were uncorrelated with the 3-year total yields of the experimental lines. When all commercial grass cultivar data were combined, first-year yields explained 88% of the variation, while including the experimental line data reduced this figure to 67%. The lack of predictability for the experimental lines alone is disappointing but appears to reflect the greater variation in performance between experimental lines, which had not gone through the same intensive selection processes as cultivars.

Our data suggest that the long-term yields of potential new cultivars could reliably be assessed under subtropical conditions by intensively measuring only the first-year yields. We further analysed the data to see how well yields could predict persistence after 3 years. Three-year total yields predicted 53% of the variation ($P<0.001$) in persistence (as measured by % frequency) of the planted grass. If first-year yields were substituted for total yields, the predicted level fell by only 3 percentage units to 50% ($P<0.001$).

The levels of predictability for both total yield and persistence after 3 years are far higher than expected from temperate environments and possibly relate to the fact that in the subtropics few of the perennial cultivars reseed naturally (*i.e.*, less than 5% of tillers are reproductive). The only exception is the cultivar Kangaroo Valley and its derivatives. As seedling recruitment is unlikely, the initial population is not supplemented or replaced, and the population falls exponentially in a similar way to lucerne (Gramshaw 1978) in response to the impact of environmental conditions, diseases and insect pests.

We suggest that the DM yields of temperate perennial grasses could be assessed intensively for the first year as a technique for assessing their potential in this environment. Information on the reliability of persistence could be improved by maintaining stands for 3 years with regular defoliation, while monitoring persistence annually. Not recording yield measurements after the first year would save considerably on research costs.

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References

Burns, J.C., Fisher, D.S. and Rottinghaus, G.E. (2006) Grazing influences on mass, nutritive value, and persistence of stockpiled Jesup tall fescue without and with novel and wild-type fungal endophytes. *Crop Science,* **46**, 1898–1912.

Callow, M.N., Lowe, K.F., Bowdler, T.M., Lowe, S.A. and Gobius, N.R. (2003) Dry matter yield, forage quality and persistence of tall fescue (*Festuca arundinacea*) cultivars compared with perennial ryegrass *(Lolium perenne*) in a subtropical environment. *Australian Journal of Experimental Agriculture,* **43**, 1093–1099.

Cameron, D.G. (1967) A summary and review of fifteen years' investigations with irrigated pastures — Biloela Research Station, 1950–1964. *Agriculture Branch Technical Report* No. 2. *Queensland Department of Primary Industries, Brisbane.*

Cunningham, P.J., Blumenthal, M.J., Anderson, M.W., Prakash, K.S. and Leonforte, A. (1994) Perennial ryegrass improvement in Australia. *New Zealand Journal of Agricultural Research,* **37**, 295–310.

Digby, P.G.N. (1979) Modified joint regression analysis for incomplete variety × environment data. *Journal of Agricultural Science (Cambridge),* **93**, 81–86.

Easton, H.S., Lee, C.K. and Fitzgerald, R.D. (1994) Tall fescue in Australia and New Zealand. *New Zealand Journal of Agricultural Research,* **37**, 405–417.

Findlay, K.W. and Wilkinson, G.N. (1963) The analysis of adaptation in a plant-breeding programme. *Australian Journal of Agricultural Research,* **14**, 742–754.

Fulkerson, W.J., Fennell, J. and Slack, K. (2000) Production and forage quality of prairie grass (*Bromus willdenowii*) in comparison to perennial ryegrass (*Lolium perenne*) and tall fescue (*Festuca arundinacea*) in subtropical dairy pastures. *Australian Journal of Experimental Agriculture,* **40**, 1059–1067.

Gramshaw, D. (1978) A review of research on establishment, persistence and productivity of lucerne (*Medicago sativa* L.) at Biloela from 1950 to 1975. *Agriculture Branch Technical Report* No. 20, *Queensland Department of Primary Industries, Brisbane*.

Hopkins, A.A. and Alison, M.W. (2006) Stand persistence and animal performance for tall fescue endophyte combinations in the South Central USA. *Agronomy Journal,* **98**, 1221–1226.

Hume, D.E., Lyons, D.J. and Hay, R.J.M. (1995) Evaluation of 'Grasslands Puna' chicory (*Cichorium intybus* L.) in various grass mixtures under sheep grazing. *New Zealand Journal of Agricultural Research,* **38**, 317–328.

Kleinschmidt, F.H. (1964) The influence of grazing on the botanical composition of an irrigated pasture at Lawes, south-east Queensland. *Australian Journal of Experimental Agriculture and Animal Husbandry,* **4**, 231–235.

Lowe, K.F. and Bowdler, T.M. (1981) Performance of some Phalaris accessions under irrigation in south-eastern Queensland. *Australian Journal of Experimental Agriculture and Animal Husbandry,* **21**, 203–209.

Lowe, K.F. and Bowdler, T.M. (1984) Performance of temperate and tropical grasses and legumes under two irrigation frequencies in south-eastern Queensland. *Tropical Grasslands,* **18**, 46–55.

Lowe, K.F. and Hamilton, B.A. (1985) Dairy pastures in the Australian tropics and sub-tropics. In: Murtagh, M.G.J.and Jones, R.M. (eds) *Proceedings of the Third Australian Conference on Tropical Pastures, Rockhampton, Queensland. Tropical Grassland Society of Australia Occasional Publication* No. 3.

Lowe, K.F., Bowdler, T.M. and Mulder, J.C. (1986) Effect of early sowing on establishment, growth pattern and rust infection of annual sowings of ryegrass (*Lolium* spp.) in sub–coastal southeast Queensland. *Tropical Grasslands,* **20**, 112–120.

Lowe, K.F. and Bowdler, T.M. (1995) Growth, persistence, and rust sensitivity of irrigated, perennial temperate grasses in the Queensland subtropics. *Australian Journal of Experimental Agriculture,* **35**, 571–578.

Lowe, K.F., Bowdler, T.M., Casey, N.D. and Moss, R.J. (1999a) Performance of temperate perennial pastures in the Australian subtropics. 1. Yield, persistence and pasture quality. *Australian Journal of Experimental Agriculture,* **39**, 663–676.

Lowe, K.F., Bowdler, T.M., Casey, N.D. and Moss, R.J. (1999b) Performance of temperate perennial pastures in the Australian subtropics. 2. Milk production. *Australian Journal of Experimental Agriculture,* **39**, 677–683.

Lowe, K.F., Bowdler, T.M., Casey, N.D., Lowe, S.A., White, J.A. and Pepper, P.M. (2007) Evaluating temperate species in the subtropics. 1. Annual ryegrasses. *Tropical Grasslands,* **41**, 9–25.

Lowe, K.F., Bowdler, T.M., Hume, D.E., Casey, N.D. and Tapper, B.A. (2008a) The effect of endophyte on the performance of irrigated perennial ryegrass in subtropical Australia. *Australian Journal of Agricultural Research,* (submitted).

Lowe, K.F., Callow, M.N., Bowdler, T.M., Lowe, S.A., White, J.A. and Gobius, N. (2008b) The performance of irrigated mixtures of tall fescue, ryegrass and white clover in subtropical Australia. 1. The effect of sowing mixture combinations and nitrogen on establishment density and first year yields. *Australian Journal of Agricultural Research*, (submitted).

Mclaughlin, M.J., Williams, C.M.J., Mckay, A., Kirkham, R., Gunton, J., Jackson, K.J., Thompson, R., Dowling, B., Partington, D., Smart, M.K. and Tiller, K.G. (1994) Effect of cultivar on uptake of cadmium by potato tubers. *Australian Journal of Agricultural Research,* **45**, 1483–1495.

Mitchell, K.J. (1956) The influence of light and temperature on the growth of temperate species. *Proceedings of the VII International Grassland Congress, Palmerston North, New Zealand.* pp. 58–69.

Northcote, K.H. (1971) *A factual key for the recognition of Australian soils*. (Rellim Technical Publications: Glenside, South Australia).

Payne, R.W., Harding, S.A., Murray, D.A., Soutar, D.M., Baird, D.B., Welham, S.J., Kane, A.F., Gilmour, A.R., Thompson, R., Webster, R. and Tunnicliffe Wilson, G. (2007) *The Guide to GenStat Release 10, Part 2: Statistics*. (VSN International: Hemel Hempstead).

Prine, G.M. (1991) Evaluation of crown rust susceptibility and breeding of annual ryegrass at the University of Florida. *Proceedings — Soil and Crop Science Society of Florida,* **50**, 30–36.

Read, J., McGowan, A., Reed, K., Ward, G., Lowe, K. and Kaehne, I. (1990) Research in perennial pastures for the Australian dairy industry. In: Bartsch, B. and Mason, Warren (eds) *Feedbase 2000: a workshop to determine the priorities for research into soils, pastures and fodder crops*, *Albury-Wodonga.* pp. 35–43. (CSIRO and Dairy Research and Development Corporation: Melbourne, Australia).

Stace, H.C.T., Hubble, G.D., Brewer, R., Northcote, K.H., Sleeman, J.R., Mulcahy, M.J. and Hallsworth, E.G. (1972) *A handbook of Australian soils*. (Rellim Technical Publications: Glenside, South Australia).

Stewart, A. and Charlton, D. (2003) Pasture and forage plants for New Zealand. *New Zealand Grassland Association, Grassland Research and Practice Series* No. 8.

Williams, W.M., Easton, H.S. and Jones, C.S. (2007) Future options and targets for plant breeding in New Zealand. *New Zealand Journal of Agricultural Research,* **50**, 223–248.

Wilson, J.R. and Ford, C.W. (1971) Temperature influences on the growth, digestibility and carbohydrate composition of two tropical grasses *Panicum maximum* var. *trichoglume* and *Setaria sphacelata*, and two cultivars of the temperate grass *Lolium perenne*. *Australian Journal of Agricultural Research,* **22**, 563–571.

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