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Performance of temperate perennial pastures in the Australian subtropics
1. Yield, persistence and pasture quality

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Summary. Irrigated, pure stands of perennial ryegrass (*Lolium perenne* cv. Yatsyn), prairie grass (*Bromus willdenodii* cv. Matua) and tall fescue (*Festuca arundinacea* cv. AU Triumph) were compared with Italian ryegrass (*L. multiflorum* cv. Concord) under grazing in the subtropics of south-east Queensland.

Pastures were fertilised with 50 kg nitrogen/ha . month as urea and annual dressings of 20 kg phosphorus/ha and 50 kg potassium/ha (as superphosphate and muriate of potash, respectively). There were 4 pasture treatments grazed by multiparous Holstein-Friesian cows at 3 cows/ha in a 1-week-on, 3-weeks-off rotation with 2 replicates and 3 cows/treatment block. Feed on offer was measured weekly and pasture quality, at the mid point of each of the 4 seasons. Detailed measurements on plant and tiller dynamics were recorded on fixed quadrats within the grazing areas from November to May in the second and third years.

Yield of pasture on offer was greatest with prairie grass and the difference was most marked in spring and early summer. Yield of fescue was generally higher than that from the other 3 grasses in the autumn. In the second and third summers, the grass weed component in the 2 ryegrass, and to a lesser extent the prairie grass, pastures was greater than the sown grass component.

Fescue generally produced forage lower in quality than the other 3 grasses although the differences were small in summer. The forage quality of Italian ryegrass was higher than perennial ryegrass in most seasons and for most attributes measured. Generally prairie grass had similar quality forage to the ryegrasses but at times it was as low as fescue.

Fescue was the most persistent grass; it maintained a frequency of occurrence of 88, 56 and 71% in the first, second and third autumn periods, respectively, compared with 36, 37 and 21% for perennial ryegrass. To achieve these persistence figures, perennial ryegrass needed over-sowing in each autumn. Plant density and tiller numbers per plant fell in all grasses from November to May but the fall was significantly less in fescue than in other grasses.

It was concluded that all 3 temperate perennial grasses demonstrated traits which were useful for subtropical dairy pastures. Fescue was the most persistent and the only grass which could sustain grazing in autumn. The performance of Italian ryegrass was as good as that of perennial ryegrass in the first year but fell substantially in the second and third years as the level of summer grass invasion suppressed the existing population and made oversowing increasingly less effective. Prairie grass produced the highest dry matter on offer under grazing, its forage quality was generally similar to that of the ryegrasses and it regenerated from self-sown seed.

Introduction

Irrigated, Italian ryegrass (*Lolium multiflorum*) is the main forage for the cool season in the subtropics. These pastures are highly productive both in terms of herbage produced and milk production per cow and per hectare. However, they need to be resown annually, either into a fully prepared seedbed or by oversowing into an existing pasture base. This practice is time consuming, incurs an annual establishment cost and can result in grazing problems during excessively wet weather. There are also concerns about the long-term sustainability of the system.

Perennial temperate pastures based on perennial ryegrass (*Lolium perenne*) and white clover (*Trifolium repens*) have been used in the subtropical dairy industry

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since the 1950s (Luck 1970; Lowe 1978). While these were highly productive for the first 16–18 months following establishment, they lacked persistence, particularly the grass component. Perennial grass cultivars available at that time were poorly adapted to the subtropics. They produced insufficient growth in summer to justify the intensive irrigation schedules needed to maintain stands in the hot, humid subtropical conditions. Research also failed to establish management techniques to overcome the problems associated with these cultivars (Cameron 1969; Cameron *et al.* 1969).

Recent research (Lowe and Bowdler 1995) has demonstrated that newer cultivars of perennial ryegrass, prairie grass and fescue show improved yields and persistence compared with those available from the 1950s to the early 1980s. Fescue (*Festuca arundinacea*) and prairie grass (*Bromus willdenodii*) cultivars produced high yields in the subtropics (Lowe and Bowdler 1984) but there have been concerns about fescue quality for dairy pastures (Lowe and Bowdler 1984; Easton *et al.* 1994; Stone 1994) and prairie grass persistence (Cameron *et al*. 1969; Lowe 1974). Tall fescue is able to produce more total forage than perennial ryegrass (Lowe and Bowdler 1995) but its forage quality is lower, particularly as the foliage matures (Collins and Casler 1990).

Wilson and Ford (1973) showed that the *in vitro* digestibility of perennial ryegrass declined with increasing temperature in growth chamber studies. There is little data to indicate how this may influence quality attributes of temperate grasses in field situations.

One of the advantages of a perennial pasture is that it should not have to be resown each year. While establishment costs of the annual ryegrass system in the subtropics have been reduced by using oversowing, sod-sowing or mulch strike techniques instead of full seedbed preparation, the cost of purchasing seed and the extra cultural operations adds to total feed costs. During re-establishment, annual pastures are not able to be grazed so the autumn component of a perennial pasture will provide valuable feed at a period of known shortage (Lowe and Hamilton 1986).

This project compared the productivity of nitrogen-fertilised, pure stands of temperate perennial grasses under irrigation in the subtropics with the current practice of annually sowing Italian ryegrass. Milk production and quality, forage yield and quality, persistence, and costs and income were recorded for each pasture type.

In this paper, pasture production, plant and tiller dynamics and forage quality of the 3 temperate perennial grasses were compared with annually sown, short rotation ryegrass.

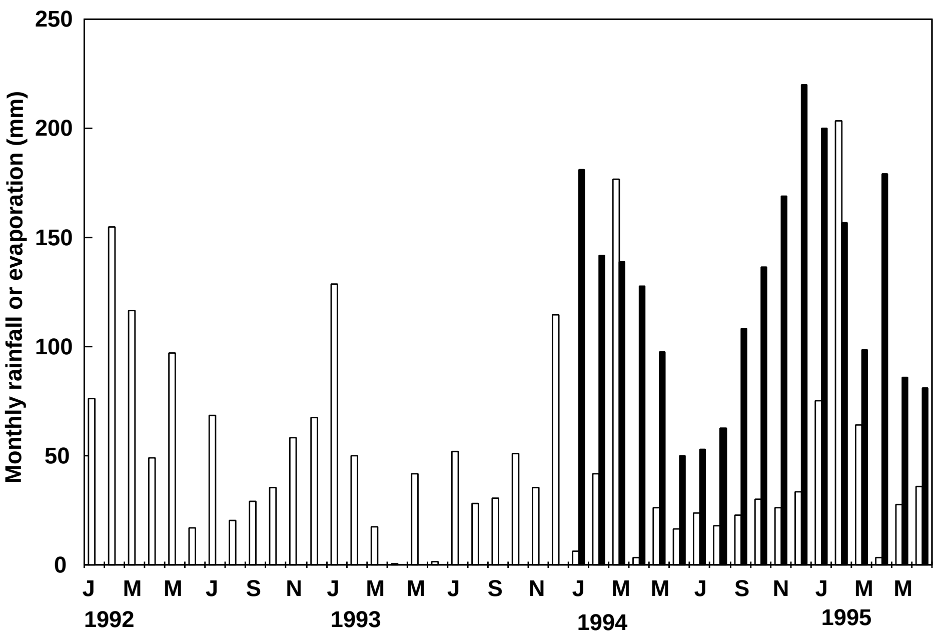

Figure 1. Monthly rainfall (open bars) received at Mutdapilly from January 1992 to June 1995 and evaporation (solid bars) from January 1994 to June 1995.

Materials and methods

Site

The experiment was located on Mutdapilly Research Station in south-east Queensland (26°46'S, 152°41'E, altitude 70 m) in a subtropical environment of predominantly summer rainfall. The soil was a heavy black clay alluvium (Ug5.16, Northcote 1971), poorly drained both internally and externally. Nutrient levels in the 0–10 cm layer were as follows: pH (H_2O) 6.2; phosphorus (P) (Colwell extraction) 43 mg/kg; potassium (K), 0.34 [mmol (+)/100 g]. The area was previously a paspalum (*Paspalum dilatatum*), green couch (*Cynodon dactylon*) pasture, with half the area sown in the previous 2 years to an oats–sorghum rotation and the other half to a 1 year oats–maize rotation.

Climatic conditions

Weather conditions during the 3-year experimental period were hotter and drier than normal, particularly in the last half of the experimental period. The extremely heavy soil causes waterlogging and pugging problems during excessively wet periods. However, over this 3-year period, intense rainfall events were rare, occurring only in May 1992 (during establishment), March 1994 and February 1995 (Fig. 1). Low humidity and high temperatures (Fig. 2) in summer resulted in high evapotranspiration levels and these conditions suited temperate grass survival (low rust incidence and less aggressive summer grass invasion).

Design and treatments

The experiment was a randomised block design with 4 treatments (grass species) and 2 replicates. The pastures were grazed on a 4-week rotation through 4 blocks, with a block providing 1 week's grazing for all treatment animals. A block consisted of 2 sets of 4 paddocks. Sets were randomly allocated to replicates and pasture treatments were allocated at random within each set. Individual paddocks were 0.25 ha, with a total experimental area of 8 ha. Pasture types were pure stands of Yatsyn perennial ryegrass, Matua prairie grass, AU Triumph tall fescue and Concord Italian ryegrass.

Animal management

Thirty-two multiparous Holstein-Friesian cows were allocated to the 8 treatment groups (4 treatments by 2 replicates) by stratified grouping on their previous lactation production. All animals calved in spring between September and December. The initial stocking rate of 4 cows/ha was reduced to 3 cows/ha in January 1993, leaving a 3-animal experimental unit in each cell for the remainder of the experimental period.

Pasture management

Pastures were sown by broadcasting into a fully prepared seedbed in early April 1992. The site was rolled after sowing and irrigated for establishment. Weekly irrigations of 10–15 mm were applied for the first 4 weeks and then followed by fortnightly irrigations of 25 mm for the remainder of the experimental period unless rain made this unnecessary. A basal fertiliser application of 24 kg P/ha (as superphosphate), 60 kg K/ha (as muriate of potash) and 50 kg nitrogen (N)/ha (as urea) were applied before sowing.

Experimental grazing commenced in October 1993 after the

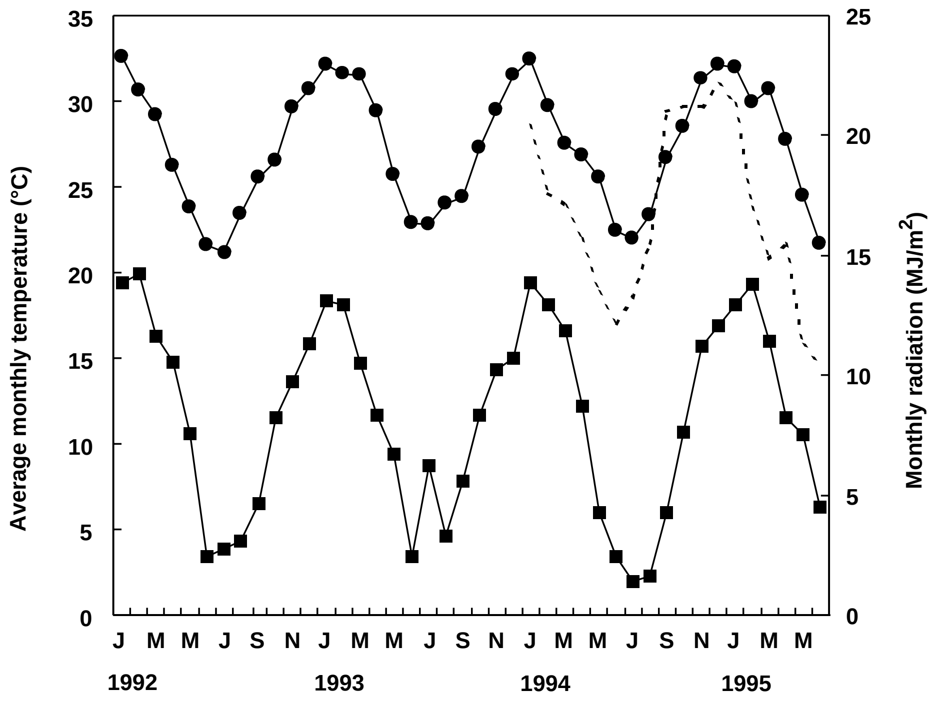

Figure 2. Mean monthly maximum (●) and minimum temperatures (■) at Mutdapilly from January 1992 to June 1995 and average monthly radiation (- - -) from January 1994 to June 1995.

majority of the cows had calved. Following grazing, the area was fertilised with 50 kg N/ha (as urea) and irrigated using a travelling irrigator. It was found that, after the first summer, there was a substantial amount of unused forage in the fescue areas. Subsequently, mulching of the fescue areas every second month removed rank, uneaten material and improved utilisation.

In April 1993 and 1994, Italian ryegrass needed to be oversown with 20 kg seed/ha as it behaves as an annual in the subtropics; only a small percentage of the original population survives over summer (Lowe and Bowdler 1995). While perennial ryegrass persisted better than Italian ryegrass, it was also oversown at 20 kg/ha when it was obvious that an adequate stand would not survive the first summer. The areas were not oversown in 1995. Drought severely limited the research station's irrigation capability from June 1995.

Cows grazed each block for 1 week. During that week, individual pasture units were grazed for 24 h during winter and spring but only between afternoon and morning milkings in summer. Autumn grazing was affected by the need to re-establish both ryegrasses and prairie grass each year. Ryegrass and prairie grass pastures were ungrazed for an 8-week period each autumn. When not on the pastures, cows were held in pens and fed supplements [hay or silage, see Lowe *et al*. (1999*a*) for details]. For the remaining 4 weeks of autumn, cows had access to pastures between afternoon and morning milkings. Prairie grass re-established from self-sown seed; however, the pastures were spelled to allow seedlings to establish. Fescue was grazed through autumn without spelling; however, when the other pasture types were spelled, it was grazed only during the night.

Sampling

Plant material. Before each grazing, paddocks were sampled for yield by cutting, at random, ten 0.5 by 0.5 m quadrats to about 5 cm above the soil surface. This material was bulked and weighed, and a subsample sorted into leaf, stem and dead material of sown grasses, and weeds and clover and the samples dried in a forced-draught oven at 80°C for 24 h. For 4 weeks in the middle of each of the 4 seasons [defined as spring (from 1 September to 30 November), summer (from 1 December to 28–29 February), autumn (from 1 March to 31 May), and winter (from 1 June to 31 August)], samples of the bulk (unsorted) material and the sorted components were ground through a 1 mm sieve and submitted for analysis of *in vitro* dry matter digestibility (IVDMD) and N, acid detergent fibre (ADF) and neutral detergent fibre (NDF) content.

Plant and tiller density. Two fixed quadrats were randomly located in each paddock of blocks 1 and 4 of the grazing experiment. One 0.25 by 1.0 m quadrat was located near a fence line and was enclosed by an electric fence to eliminate grazing. Another was located within the grazed area. Plant density measurements were made on these fixed quadrats using a 100 square grid after defoliating the quadrat area to 5 cm. No differentiation was made between established plants and seedlings in the determinations.

Tiller numbers were determined in 20 of the 100 sectors of the quadrat. The same sectors were used on each occasion to determine tiller number and encompassed an area of 0.048 m^2. Only live tillers were counted. Live tillers were defined as those which showed a green shoot or live basal tissue. Live plants were defined as those which had one or more live tillers present.

Within these fixed quadrats, 5 sown plants were selected at random and marked with 25 mm, zinc-plated plaster board screws with a 7-mm-diameter head, located 1–2 cm to a fixed side of the selected plant. Each marker was permanently coded with the plant number it identified. Tiller numbers and tiller weights were measured on these 5 plants by cutting the plants to 5 cm, collecting, counting, drying and weighing the tillers.

Chemical analyses

Pasture samples were analysed for IVDMD using the modified technique of Goto and Minson (1977). Nitrogen content was determined by the microkjeldahl method using an autoanalyser. Organic matter levels were determined by ashing samples at 600°C for 4 h. Analysis for NDF used the method of Van Soest and Wine (1967). Analysis for ADF was carried out by the method of Goering and Van Soest (1970). Both NDF and ADF were extracted using a Filtrex apparatus as described in Faichney and White (1983). Metabolisable energy (ME) was calculated from IVDMD using the formula (Anon. 1975):

$$\text{ME (MJ/kg DM)} = 0.15 \times \text{IVDMD (\%)}.$$

Statistical analyses

Pasture yield, plant density, tiller number, tillers per plant, and N, ADF, NDF content, IVDMD and ME were analysed using analysis of variance by including grass treatments as the main plots and weekly sampling dates within each 4-week grazing cycle as subplots. Pasture yield was also analysed using monthly grazing cycles as the main plots and grasses as the subplots to compare pasture on offer throughout the 3-year period.

Results

Feed on offer

Monthly feed on offer to cows grazing the 4 pasture types over the experimental period is presented in Figure 3. Prairie grass and fescue had higher (P<0.05) dry matter (DM) on offer than the ryegrasses, although the differences were small in autumn and winter. Prairie grass had higher DM on offer in spring compared with the other 3 grasses. Feed on offer from all grasses decreased in January–February in each year. Total DM on offer for the 2 ryegrass pastures were similar over the 3-year period.

Generally, the mean monthly total feed on offer increased over the 3 years but much of the increase came from invading species (Table 1; Fig. 4). Fescue and prairie grass had significantly (P<0.05) higher feed on offer than the 2 ryegrasses in the first year although there was no significant difference between them. In the second and third years prairie grass maintained significantly (P<0.05) higher DM on offer than fescue. There was no difference in the total DM on offer of fescue or perennial or Italian ryegrasses in the third year. However, the large increase in the weed component in the second, and particularly in the third, years inflated total yield in all but the fescue pastures (Table 1). The main weeds were paspalum (*Paspalum dilatatum*) and barnyard grass (*Echinochloa* sp.). There were significantly (P<0.05) greater amounts of weed in prairie

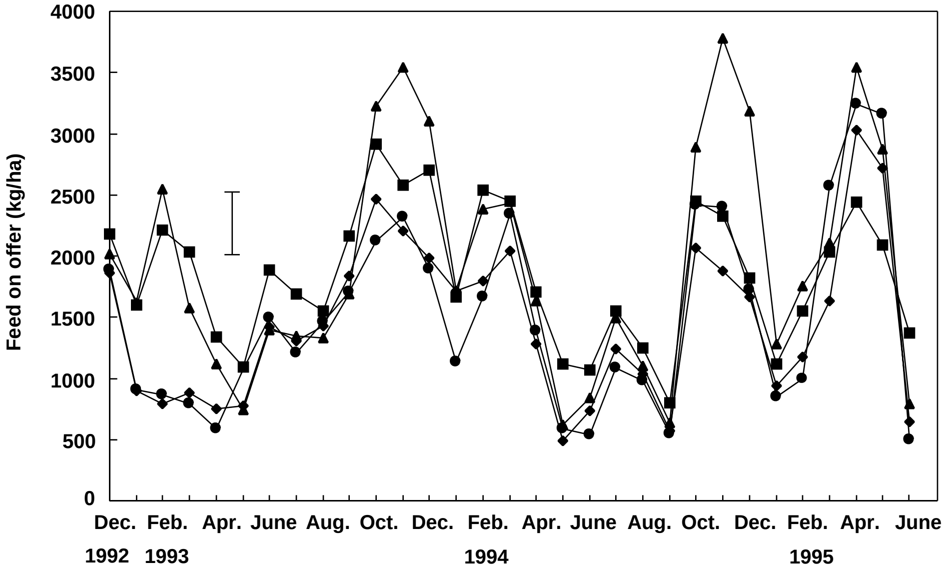

Figure 3. Monthly feed on offer (kg/ha) from 4 temperate grasses (● Yatsyn, ◆ Concord , ■ AU Triumph, ▲ Matua) grown under irrigation at Mutdapilly, south-east Queensland. Vertical bar indicates l.s.d. (P = 0.05).

grass and perennial ryegrass in the first year than in Italian ryegrass and fescue pastures but, in the second and third years, Italian ryegrass had a significantly (P<0.05) greater weed component than the other 3 grasses. The weed component of fescue was low throughout, averaging just 98 kg DM/ha.

Despite the high rate of N fertiliser applied, both white clover and red clover invaded all pastures although there were significantly (P<0.05) lower amounts of clover in fescue pastures. Clover was more (P<0.05) invasive in perennial ryegrass pastures than the other 3 grasses, averaging 24% over the 3-year period, and peaking at 32% in the second year.

Figure 3 shows the seasonal changes in the botanical composition of these pastures. Only fescue maintained a high leaf yield in each autumn period and in the last summer. Clover made a significant contribution in the 2 ryegrass swards in spring and autumn but this is much less evident in prairie grass and fescue pastures. Stem comprised about half the yield of Italian ryegrass and prairie grass in late spring. Stem yields were lower for perennial ryegrass and fescue, indicating the lower emphasis of these 2 grasses on seed set.

Pasture quality

Nitrogen content. Significant (P<0.05) differences in the N content of the whole plant occurred in winter and spring but not in autumn 1993 or in either summer (Table 2). Italian ryegrass had a significantly (P<0.05) higher N content than perennial ryegrass, prairie grass or fescue in winter 1993, fescue in winter 1994 and fescue and prairie grass in spring 1993. In winter 1993, perennial ryegrass and prairie grass had significantly (P<0.05) higher N content than fescue.

Italian ryegrass generally had the highest, and fescue, the lowest, leaf N content. Significant (P<0.05) differences in leaf N content between grasses occurred in autumn and spring 1993 and winter 1994. Stem N content was lower than leaf N content in all seasons. Prairie grass and fescue had a lower stem N content than the ryegrasses in most seasons. Stem N content of the 2 ryegrasses was similar (P>0.05) in all seasons.

In vitro *digestibility*. There was no significant (P>0.05) difference in the IVDMD of the 4 grasses in summer 1992–93 and 1993–94 and in autumn 1993 (Table 3). In other seasons fescue had lower (P<0.05) IVDMD than the other 3 grasses.

The IVDMD of fescue leaf was significantly (P<0.05) lower than that of the other grasses in all seasons. There were no differences between the leaf IVDMD of the other grasses except in winter 1994 when prairie grass was higher (P<0.05) than perennial ryegrass. Seasonal differences within species for stem IVDMD were greater than species differences. Species differences were only measured in spring 1993, with the stems of the 2 ryegrasses significantly (P<0.05) more digestible.

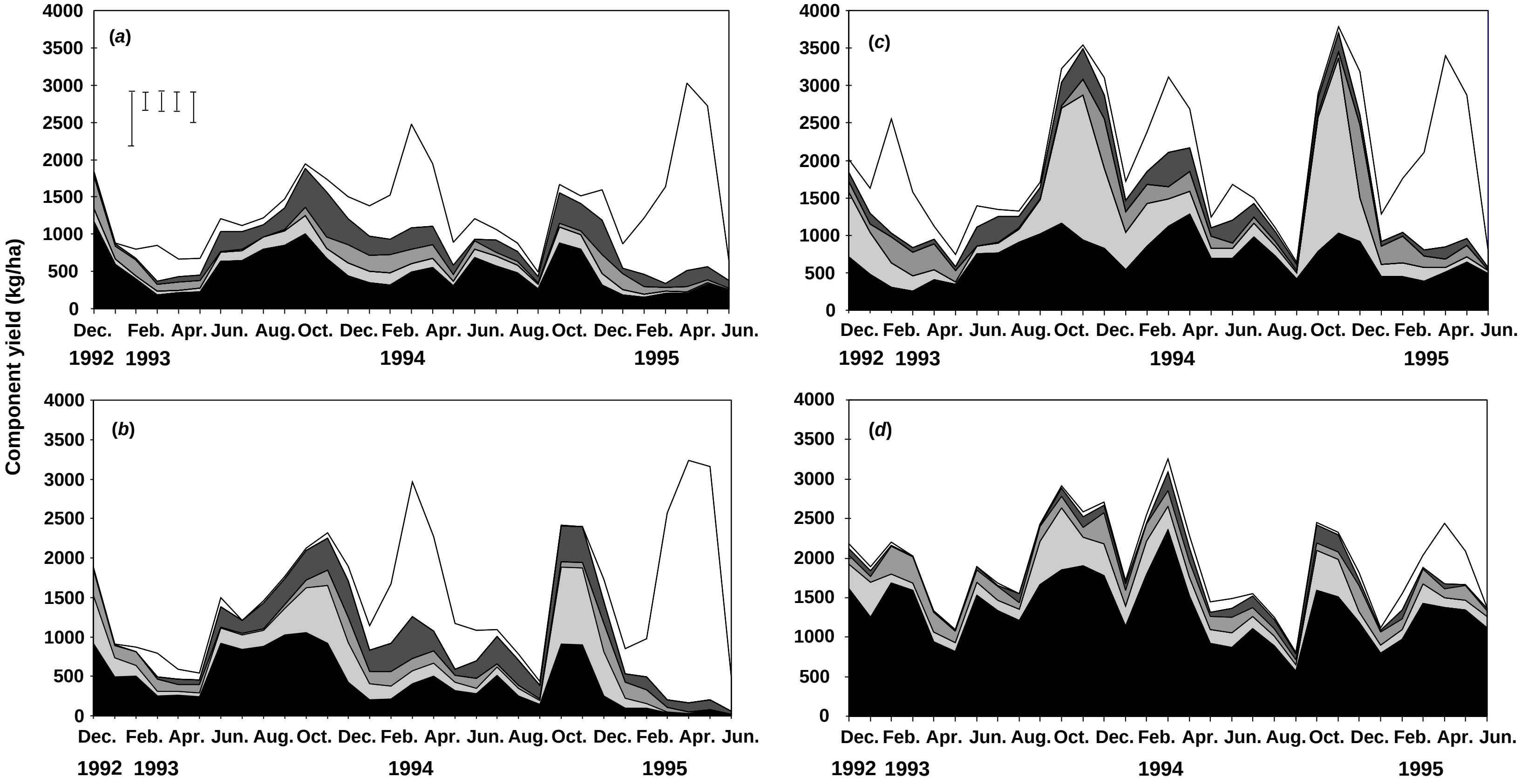

Figure 4. Botanical composition of forage on offer in 4 temperate grasses from November 1992 to June 1995. (*a*) Concord, (*b*) Yatsyn, (*c*) Matua and (*d*) AU Triumph. Closed area, sown grass leaf; lightly shaded area, sown grass stem; mediumly shaded area, dead grass; heavily shaded area, white clover; open area, weeds. Bars from left to right indicate l.s.d. (P = 0.05) for sown grass leaf, sown grass stem, dead, white clover and weed yield, respectively.

Table 1. Average total and component feed on offer (kg DM/ha) available weekly from the four grasses over the three-year experimental period

Cultivar	Year 1	Year 2	Year 3	Average
		Total feed on offer		
Concord	1289	1772	2043	1641
Yatsyn	1343	1665	1808	1567
Matua	1861	2352	2523	2191
AU Triumph	1915	2121	1923	1980
l.s.d. (*P* = 0.05)	139	169	291	111
		Green leaf		
Concord	661	563	129	488
Yatsyn	595	541	282	494
Matua	639	912	601	713
AU Triumph	1430	1510	1240	1403
l.s.d. (*P* = 0.05)	87	89	81	51
		Green stem		
Concord	277	313	240	278
Yatsyn	110	139	62	106
Matua	544	698	385	548
AU Triumph	253	261	188	238
l.s.d. (*P* = 0.05)	71	105	87	51
		Dead material		
Concord	121	93	125	114
Yatsyn	130	95	100	112
Matua	154	152	350	206
AU Triumph	176	138	193	169
l.s.d. (*P* = 0.05)	32	35	73	28
		Invading weeds		
Concord	75	426	1395	539
Yatsyn	152	377	1101	477
Matua	345	338	1060	535
AU Triumph	28	66	242	98
l.s.d. (*P* = 0.05)	69	86	265	82
		Invading clover		
Concord	155	363	139	215
Yatsyn	356	527	246	379
Matua	178	241	99	176
AU Triumph	54	146	54	83
l.s.d. (*P* = 0.05)	43	59	52	30

Table 2. Nitrogen content (%) of feed on offer in four temperate grasses at the middle of each season from summer 1992–93 to winter 1994

Season	Concord	Yatsyn	Matua	AU Triumph	l.s.d. (*P* = 0.05)
		Whole plant			
Summer 1992–93	3.60	3.10	2.30	3.10	n.s.
Autumn 1993	3.70	3.43	3.70	3.70	n.s.
Winter 1993	4.28	3.88	3.84	3.49	0.33
Spring 1993	4.08	3.86	3.31	3.44	0.29
Summer 1993–94	3.08	2.97	3.24	2.91	n.s.
Winter 1994	4.18	3.83	3.98	3.46	0.39
l.s.d. (*P* = 0.05)[A]		0.43			
		Leaf			
Summer 1992–93	4.30	3.90	3.35	2.85	0.61
Autumn 1993	5.17	4.53	5.07	4.10	0.43
Winter 1993	4.13	4.11	4.22	3.56	0.22
Spring 1993	4.73	4.08	4.19	3.74	0.37
Summer 1993–94	3.80	3.85	3.68	3.17	0.31
Winter 1994	4.64	4.21	4.53	3.87	0.17
l.s.d. (*P* = 0.05)[A]		0.31			
		Stem			
Summer 1992–93	2.15	2.00	1.80	1.90	n.s.
Autumn 1993	3.37	3.27	3.14	3.19	0.15
Winter 1993	2.60	2.64	2.60	2.65	n.s.
Spring 1993	2.57	2.45	2.05	2.45	0.35
Summer 1993–94	2.46	2.41	2.15	2.17	0.25
Winter 1994	3.26	2.41	2.19	2.26	0.45
l.s.d. (*P* = 0.05)[A]		0.37			

[A] For testing within and between columns and rows.

Neutral detergent fibre content. There were no significant (*P*>0.05) differences in the NDF content of the 4 grasses in either summer period or in autumn 1993 (Table 4). In both winter periods, fescue was significantly (*P*<0.05) higher than the other 3 grasses while in spring 1993, the 2 ryegrasses had a significantly (*P*<0.05) lower NDF content than fescue and prairie grass. NDF content of the 2 ryegrasses was similar throughout.

There was no significant difference (*P*>0.05) in the NDF content of the leaf component of the 4 grasses in autumn 1993. However, in the 2 summer periods, the leaf NDF content of the ryegrasses was higher (*P*<0.05) than that of fescue and prairie grass while in the 2 winters, fescue was higher (*P*<0.05) than the other 3 grasses. The only differences between the NDF content of grass stem material occurred in spring 1993 and summer 1993–94 at which times prairie grass was significantly (*P*<0.05) higher than the 2 ryegrasses. The stem NDF content of fescue was significantly (*P*<0.05) lower than that of prairie grass in summer 1993–94.

Acid detergent fibre content. There were no significant differences (*P*>0.05) in the ADF content of the 4 grasses in either summer period or in autumn 1993 (Table 5). Over the 2 winter periods and in spring 1993, ADF values for perennial ryegrass, fescue and prairie grass were significantly (*P*<0.05) higher than Italian ryegrass.

The ADF content in leaf of prairie grass was higher than fescue in summer and spring. Italian ryegrass had lower (*P*<0.05) ADF values than perennial ryegrass in autumn, spring and winter 1994; there were no significant differences (*P*>0.05) between the

Table 3. *In vitro* digestibility (%) of feed on offer in four temperate grasses at the middle of each season from summer 1992–93 to winter 1994

Season	Concord	Yatsyn	Matua	AU Triumph	l.s.d. (*P* = 0.05)
		Whole plant			
Summer 1992–93	55.3	56.4	56.7	60.7	n.s.
Autumn 1993	61.3	59.8	59.1	58.5	n.s.
Winter 1993	80.5	78.7	78.7	67.1	5.1
Spring 1993	73.7	73.2	62.1	69.5	3.9
Summer 1993–94	61.1	63.0	59.7	58.6	n.s.
Winter 1994	77.5	75.5	75.2	70.0	5.0
l.s.d. (*P* = 0.05)[A]		5.9			
		Leaf			
Summer 1992–93	65.3	65.2	66.1	56.1	7.7
Autumn 1993	71.6	68.9	73.0	63.7	4.3
Winter 1993	80.7	81.5	81.6	69.4	3.3
Spring 1993	74.2	73.8	72.5	63.1	2.7
Summer 1993–94	64.9	69.2	69.6	60.9	3.9
Winter 1994	80.7	79.3	81.6	75.4	1.5
l.s.d. (*P* = 0.05)[A]		3.2			
		Stem			
Summer 1992–93	58.0	53.9	57.4	57.4	n.s.
Autumn 1993	64.3	66.1	64.6	64.9	n.s.
Winter 1993	84.4	83.4	84.6	84.7	n.s.
Spring 1993	74.5	72.9	63.9	65.6	8.2
Summer 1993–94	65.9	68.9	61.8	68.9	n.s.
Winter 1994	86.0	84.2	85.5	81.1	1.9
l.s.d. (*P* = 0.05)[A]		5.2			

[A] For testing within and between columns and rows.

Table 4. Neutral detergent fibre content (%) of four temperate grasses at the middle of each season from summer 1992–93 to winter 1994

Season	Concord	Yatsyn	Matua	AU Triumph	l.s.d. (*P* = 0.05)
		Whole plant			
Summer 1992–93	51.1	56.0	65.5	53.0	n.s.
Autumn 1993	50.5	55.2	51.6	52.1	n.s.
Winter 1993	39.1	41.4	42.6	49.5	4.0
Spring 1993	46.2	44.7	54.3	55.0	4.0
Summer 1993–94	55.1	51.4	58.7	56.3	n.s.
Winter 1994	37.6	39.5	42.1	48.1	4.8
l.s.d. (*P* = 0.05)[A]		4.9			
		Leaf			
Summer 1992–93	46.9	50.0	57.0	59.4	6.2
Autumn 1993	55.2	55.6	56.7	56.1	n.s.
Winter 1993	39.2	42.2	41.0	47.5	2.0
Spring 1993	42.9	45.5	48.6	52.3	2.8
Summer 1993–94	51.1	51.0	54.6	55.6	1.6
Winter 1994	37.4	40.9	39.7	44.8	2.2
l.s.d. (*P* = 0.05)[A]		4.0			
		Stem			
Summer 1992–93	73.3	74.7	71.2	73.0	n.s.
Autumn 1993	57.3	62.6	61.4	59.5	n.s.
Winter 1993	48.5	49.1	47.6	47.8	n.s.
Spring 1993	58.8	61.4	66.2	64.7	5.0
Summer 1993–94	59.8	56.0	65.7	59.4	6.0
Winter 1994	n.a.	n.a.	n.a.	52.1	—
l.s.d. (*P* = 0.05)[A]		9.2			

[A] For testing within and between columns and rows.

2 ryegrasses in other seasons. Only in summer 1993–94 was there a significant difference between ADF content of grass stem, with perennial ryegrass and fescue significantly ($P<0.05$) lower than the other 2 grasses.

Metabolisable energy. There were no differences in the ME values of the grasses in summer and autumn (Table 6). AU Triumph generally had the lowest ME values and this difference was significant in winter and spring in 1993. ME values of all the grasses were significantly ($P<0.05$) higher in winter than in the other seasons.

Persistence

Frequency of occurrence (paddock data). There was little difference between the overall persistence (as measured by frequency of occurrence of sown species) in years 1 and 2 but persistence at the end of year 3 was significantly ($P<0.05$) reduced (Table 7). Fescue demonstrated the highest ($P<0.05$) frequency of occurrence and Italian ryegrass the lowest. There was also a grass x year interaction, with the 2 ryegrasses persisting better in years 1 and 2 than in year 3. The frequency of occurrence of prairie grass was low at the end of the first year but showed a marked improvement in the second year, and this was maintained in the third year. The frequency of occurrence of fescue was significantly ($P<0.05$) lower in the second year than the first and third years.

Plant persistence within fixed quadrats. The plant density of all species in 1993–94 decreased from spring to autumn except for prairie which rose in summer and then fell (Fig. 5). The plant density of fescue was least affected, and that of Italian ryegrass, most affected by season. Only 11 Italian ryegrass plants/m^2 were alive in early April, a decrease of 92% compared with the October reading.

Under grazing, plant density in the fixed quadrats in 1994–95 fell ($P<0.05$) in all grasses from November to February (Fig. 5). From February, there was a continued fall in plant numbers in all grasses although the fall was only significant in perennial ryegrass. Only 3 Italian

Table 5. Acid detergent fibre content (%) of four temperate grasses at the middle of each season from summer 1992–93 to winter 1994

Season	Concord	Yatsyn	Matua	AU Triumph	l.s.d. (P = 0.05)
		Whole plant			
Summer 1992–93	29.2	32.1	41.6	32.3	n.s.
Autumn 1993	30.6	33.0	33.1	29.2	n.s.
Winter 1993	23.2	24.9	26.8	27.8	2.6
Spring 1993	27.6	28.9	33.6	31.7	2.0
Summer 1993–94	35.9	34.2	34.3	33.2	n.s.
Winter 1994	22.1	25.3	26.8	28.1	2.7
l.s.d. (P = 0.05)[A]		3.9			
		Leaf			
Summer 1992–93	26.1	27.6	35.6	32.8	5.8
Autumn 1993	24.5	26.3	26.6	27.4	1.3
Winter 1993	22.0	22.4	24.7	26.5	1.8
Spring 1993	25.3	27.3	31.1	29.5	1.2
Summer 1993–94	28.6	29.3	33.8	30.7	1.3
Winter 1994	22.1	23.9	23.8	25.3	1.4
l.s.d. (P = 0.05)[A]		2.2			
		Stem			
Summer 1992–93	41.8	42.2	41.1	39.5	n.s.
Autumn 1993	n.a.	n.a.	31.1	n.a.	—
Winter 1993	26.8	26.8	26.8	26.8	n.s.
Spring 1993	33.2	34.9	38.4	37.1	n.s.
Summer 1993–94	33.8	30.9	38.1	31.6	3.9
Winter 1994	n.a.	27.1	26.6	27.3	—
l.s.d. (P = 0.05)[A]		4.4			

[A] For testing within and between columns and rows.

ryegrass plants/m^2 remained alive in February and they all died before April. The fall in density in prairie grass and fescue from February to April was 47 and 6% of the February population respectively.

Tiller density within fixed quadrats (1993–94 only). In spring the ryegrasses had the highest tiller density (Fig. 6). However, densities fell rapidly in summer, particularly with Italian ryegrass. The tiller density of fescue and prairie grass was similar in October and December but fescue maintained a higher (P<0.05) tiller density in February and April. Tiller density of perennial ryegrass was higher (P<0.05) than fescue in spring but similar at other times. Fescue lost fewer tillers during the measurement period. Though not significant in the final sampling, the absolute differences between grasses were still substantial (75–900 tillers/m^2 for Italian ryegrass and fescue respectively).

Tiller densities of all grasses were significantly (P<0.05) higher in the grazed areas compared with those in areas excluded from grazing (Table 7). The effect of grazing was less pronounced with fescue than for the other 3 grasses.

Tiller numbers per plant from marked plants (1993–94). Both ryegrasses had higher (P<0.05) tiller numbers (38–40 tillers/plant) than fescue and prairie grass in October (Table 7). Perennial ryegrass maintained the highest tiller number per plant in December–January. Only 26% of the initial tillers of Italian ryegrass survived from October until December. Tiller numbers fell to about 5 tillers/plant by February and there were no differences (P>0.05) between grasses. By this stage only 5% of the original tillers of Italian ryegrass survived; by April only 3% remained. Only

Table 6. Metabolisable energy (MJ/kg) of four temperate grasses at the middle of each season from summer 1992–93 to winter 1994

Season	Concord	Yatsyn	Matua	AU Triumph	l.s.d. (P = 0.05)
		Whole plant			
Summer 1992–93	7.15	7.35	7.5	7.75	n.s.
Autumn 1993	8.13	7.90	7.97	7.63	n.s.
Winter 1993	10.53	10.35	10.28	8.73	0.63
Spring 1993	9.45	9.58	9.13	8.02	0.57
Summer 1993–94	8.13	8.38	7.98	7.68	n.s.
Winter 1994	9.93	9.83	9.75	9.10	n.s.
l.s.d. (P = 0.05)[A]		0.79			

[A] For testing within and between columns and rows.

Table 7. Changes in persistence over time as affected by grass species, differences between tiller densities (tillers/m^2) of grasses in grazed swards and grazing exclosures measured in February 1994 and tiller survival (tillers/plant) on marked plants within fixed quadrats from October to May in both 1993–94 and 1994–95

Means within columns followed by the same letter are not significantly different at P = 0.05

Season	Concord	Yatsyn	Matua	AU Triumph
		Frequency of occurrence (%)		
1992–93	25.3a	35.8a	13.8b	88.7a
1993–94	34.5a	37.2a	43.6a	56.2c
1994–95	2.2b	21.4b	39.2a	70.8b
		Tiller density (tillers/m^2)		
Grazed	170.8a	1624.3a	615.8a	1603.8a
Ungrazed	108.5a	450.0b	124.0b	1210.8b
		Tiller survival on marked plants (tillers/plant) 1993–94		
October	38.0a	45.5a	13.3a	17.0a
February	1.5b	6.3b	2.5b	7.0b
May	0.8b	0.8b	0.5b	4.5b
		Tiller survival on marked plants (tillers/plant) 1994–95		
October	17.2a	28.4a	12.1a	17.0a
February	0b	13.0b	4.3b	15.4a
May	0b	12.8b	4.0b	14.2a

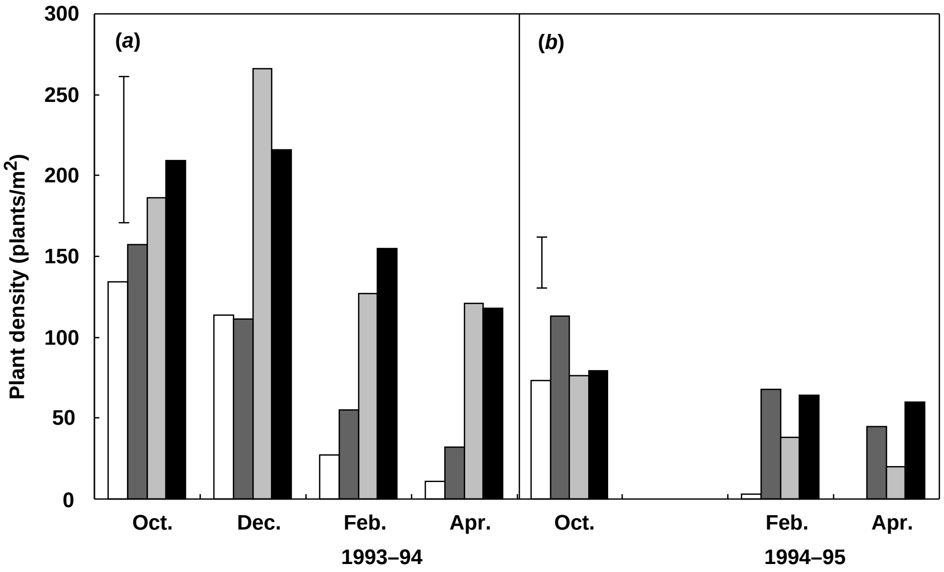

Figure 5. Average plant density (plants/m^2) of 4 temperate grasses (open bars, Concord; heavily shaded bars, Yatsyn; lightly shaded bars, Matua; solid bars, AU Triumph) from fixed quadrats located in grazed areas at Mutdapilly, over the periods October–April (*a*) 1993–94 and (*b*) 1994–95.

fescue maintained a tiller density of about 5 tillers/plant in April which was 27% of the initial number.

Tiller number per plant from marked plants (1994–95). There was a significant decline in tiller number of marked plants from November to February in all grasses but this was only significant for the 2 ryegrasses (Table 7). All tillers of Italian ryegrass were dead by February 1994.

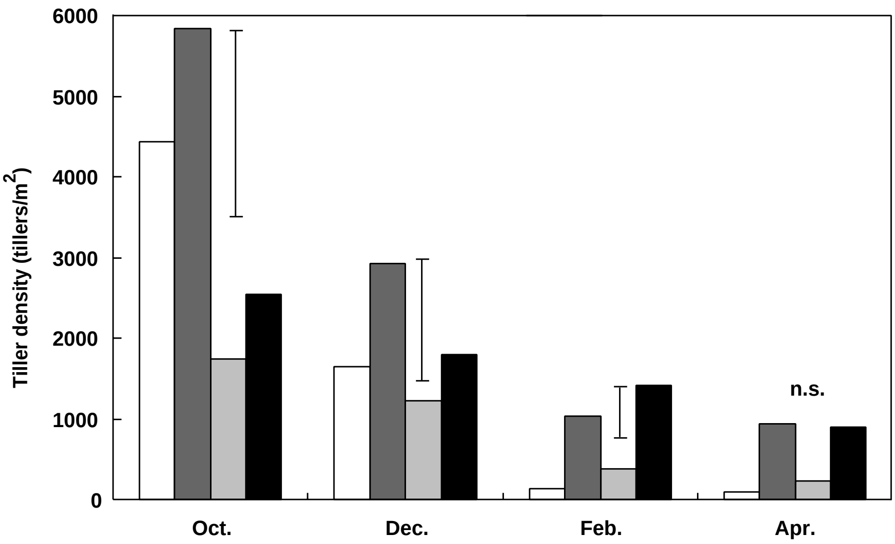

Figure 6. Tiller number of marked plants within fixed quadrats located in swards of 4 temperate grasses (open bars, Concord; heavily shaded bars, Yatsyn; lightly shaded bars, Matua; solid bars, AU Triumph) under grazing at Mutdapilly.

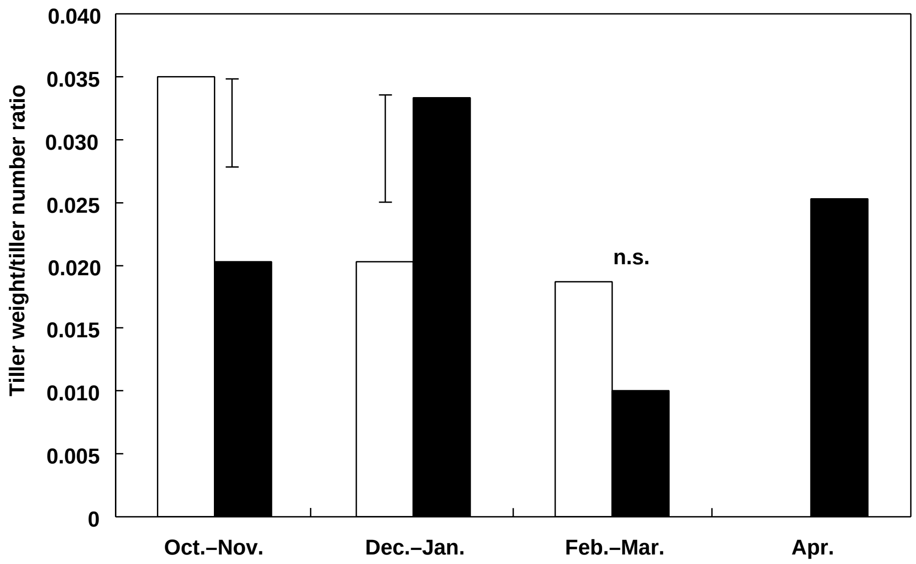

Figure 7. Tiller weight to tiller number ratio from October 1993 to April 1994 in fixed quadrats located within the grazing areas (open bars) and in grazing exclosures (solid bars) of Yatsyn ryegrass swards.

Ratio of tiller weight to tiller number (1993–94 only). Initially the grazed areas of perennial ryegrass had heavier tillers than the non-grazed areas (Fig. 7) but by January the ratio was higher in the non-grazed areas. The weight : tiller ratio in March was lower than in previous months in both grazed and non-grazed swards and this appeared to be due to a greater reduction in tiller weight than tiller number. This had increased in the non-grazed plots by April. Unfortunately, none of the marked plants survived in the grazed plots so our data cannot confirm that a similar trend occurred under grazing. These trends were similar for the other grasses.

Discussion

Pasture on offer

Fescue and prairie grass produced more forage than the ryegrasses except in the first year and this is consistent with results of cutting experiments in the subtropics (Lowe and Bowdler 1995) and elsewhere (Cunningham *et al.* 1994; Easton *et al.* 1994). Our current results suggest that prairie grass performed better under grazing than under cutting although in cutting experiments fescue produced higher yields (Lowe and Bowdler 1995; K. F. Lowe and T. M. Bowdler unpublished data). The reason for this result appears 2-fold. First, stands of prairie grass thin dramatically under cutting unless plants are allowed to set and drop seed which would be the case under grazing. Second, feed-on-offer measurements underestimated the growth of fescue because no estimate was made of the losses incurred as a result of the mulching imposed every 2 months.

Dry matter production from the 4 grasses in the grazing experiment was lower than predicted from previous cutting experiments (Lowe and Bowdler 1995) and this necessitated a reduction of the stocking rate from 4 to 3 cows per hectare mid-way through the first 12-month period. This appears to be related to soil type as we have previously measured maximum yields from Italian ryegrass under cutting of 29 t/ha at Gatton (Lowe and Bowdler 1993) but only 14 t/ha at Mutdapilly (Lowe *et al.* 1998*a*).

Botanical composition

All 4 pastures remained relatively weed-free until the second spring. The first major invader was clover (both red and white clover). Clovers contributed up to 30% of the feed on offer in the ryegrass pastures, 15% in the prairie grass pasture but below 10% in fescue. By the second summer, the major contaminant was summer-growing grasses which contributed over half the total feed on offer; this component increased further in the third summer. In winter and spring, the content of sown grasses increased but the weed component was still substantial in both ryegrass pastures. This is consistent with previous research in the subtropics (Kleinschmidt 1964; Cameron *et al.* 1969; Lowe and Bowdler 1984).

There was little invasion of summer grass and clover into the fescue pasture throughout the experiment. This ability to resist summer-growing grass invasion is important as loss of temperate grass components from perennial pastures in the subtropics has been attributed to the invasion of summer-growing grasses (Cameron *et al.* 1969; Fulkerson *et al.* 1993). Prairie grass was less effective in restricting this invasion; summer grasses tended to suppress the re-establishment of prairie grass in the final autumn.

The ability of clover to invade perennial pastures under high levels of N fertilisation has not been described elsewhere in the subtropics as previous grazing experiments in this environment (Schroder 1961; Kleinschmidt 1964) had white clover as a sown component. Invasion into cutting experiments by clovers has not been significant (Lowe and Bowdler 1995; K. F. Lowe and T. M. Bowdler unpublished data) so it must be assumed that this invasion was promoted by grazing. This level of clover invasion may be related to the vigour of the sown grass and to the management practices employed, clovers invaded all grass treatments except fescue. Clover seed was not sown at establishment and must have remained viable in the soil from previous sowings.

Pasture quality

Pasture quality was consistently high for all 4 temperate grasses, considerably higher than levels measured for tropical species (Minson 1980). The forage quality of Italian ryegrass was generally the highest, and fescue the lowest. Differences between the grasses were least in summer and autumn and greatest in winter and spring. At times, prairie grass produced forage which was as good or better than the ryegrasses but fescue was rarely equivalent to the ryegrasses. Despite these differences the quality of fescue was well above levels required for high milk production (ARC 1980) and above the values for tropical grasses (Lowe *et al.* 1998*b*).

One of the reasons for the differences in crude protein, *in vitro* digestibility, NDF and ADF between fescue and the other grasses was the maturity of the forage on offer. Maturity of forage affects the quality of all pasture species but it is particularly true for fescue (Easton *et al.* 1994). Fescue grew faster than the other grasses, particularly in summer and autumn. The inflexible management system employed in this experiment contributed to this quality difference. Better utilisation and higher forage quality would have resulted from either increasing the stocking rate or the grazing frequency to utilise the extra forage before it matured, as is used by dairy farmers in New Zealand (G. Milne pers. comm.). This aspect needs further study before fescues can become widely adopted in subtropical dairying areas. While there was little seeding in Yatsyn perennial ryegrass in the subtropics because of the lack of vernalisation (F. Wilson pers. comm.), the other 3 grasses seeded profusely in late spring and early summer. Our quality data were only collected in the middle of each season and do not indicate how seeding may have affected quality. Mid summer values are consistently low for all 4 grasses and reflect the influence of above optimum temperatures on pasture quality (Wilson and Ford 1973).

Pasture persistence and dynamics

Fescue was the most persistent grass and this agrees with the results of cutting experiments (Lowe and Bowdler 1984, 1995). Italian ryegrass was the least persistent and behaved similarly to Grasslands Manawa (H1) hybrid ryegrass (Kleinschmidt 1964; Lowe 1974; Lowe and Bowdler 1984). Yatsyn has been shown to be more persistent than older perennial ryegrass cultivars such as Victorian and Grasslands Nui but less than Kangaroo Valley or cultivars derived from it (Lowe and Bowdler 1995; Lowe *et al.* 1999*b*). However, under grazing, only about 40% of the plants survived from one year to the next, necessitating oversowing to increase the plant population. On the other hand, prairie grass persisted better in the grazing experiment than in cutting experiments.

It was observed in the first year that a large proportion of the perennial ryegrass plants appeared to die over summer. However, in autumn many of these ‘dead’ plants produced 1 or 2 new tillers in the centre of an otherwise dead crown and the plant then recovered. This suggests that, for the long-term productivity of perennial temperate pastures in the subtropics, plant density is more important than tiller density. Plant breeders need to be mindful of this survival factor when selecting for adaptation to this environment.

Detailed studies were conducted on both grazed and ungrazed areas in the second and third years to document tiller dynamics. All grasses showed this cyclic build up in tiller numbers in spring followed by a decline in summer, with fescue and prairie grass least affected. The data show that both plant number and tiller number per plant decline rapidly in late summer. The reduction in weight/tiller ratio in late summer also confirms that plants were producing smaller tillers. This cyclic pattern is also demonstrated in perennial ryegrass in New Zealand (Hunt 1989) although without the extremes demonstrated here.

The tiller densities we measured in spring are similar to those recorded under rotational grazing in New Zealand of around 5000 tillers/m^2; However the tiller densities recorded in autumn (1000 tillers/m^2) were still very much lower than in New Zealand (4000 tillers/m^2, Hunt 1989). While our data from grazed areas do not show tiller numbers increasing in late autumn as we expected, it confirms that losses in both plant number and tiller number per plant cease in autumn. In the 2 years we studied tiller dynamics, recovery may have been delayed until early winter. In the ungrazed, fixed quadrat areas, tiller number and weight did increase in autumn.

Fescue maintained plant numbers of about 60–100 plants/m^2 throughout the experimental period and produced a more stable pasture than perennial ryegrass. Fescue has failed to thicken up after poor establishment in the Northern Tablelands of New South Wales (Hill 1985) but this does not appear to occur under irrigation in the coastal subtropics. Fescue plants carried fewer tillers than perennial ryegrass but the tillers were larger and did not appear as ephemeral under grazing as those of perennial ryegrass.

In cut and removal experiments, plant populations of prairie grass are reduced substantially (Lowe and Bowdler 1995; Lowe *et al.* 1999*b*). In this experiment plant survival of mature plants from one year to the next was extremely low although these were replaced in autumn by an extremely high population of seedlings. Farmer experience (K. Lowe unpublished data) suggests that grazing when these seedlings are establishing can cause high mortality. Therefore prairie grass appears to be a less stable pasture system than fescue and as such requires more complex management to maintain both plant numbers and tiller density. Tiller numbers were lower in our system than in New Zealand pastures because of the short grazing rotation we imposed and the high mortality rate of plants under subtropical conditions. Bell and Ritchie (1989) found that a 40- to 50-day rotation produces the highest tiller density which is longer than the 21- to 24-day rotation used in our experiment.

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References

Anon. (1975). Energy allowances and feeding systems for ruminants. Ministry of Agriculture, Fisheries and Food Technical Bulletin 33, London.

ARC (1980). The nutrient requirements of ruminant livestock. Technical Review by an Agricultural Research Council Working Party (CAB: London.)

Bell, C. C., and Ritchie, I. M. (1989). The effect of frequency and height of defoliation on the production and persistence of 'Grasslands Matua' prairie grass. *Grass and Forage Science* **44**, 245–8.

Cameron, D. G. (1969). Effect of paspalum on the production pattern of Ladino white clover under irrigation on heavy clay soils in Central Queensland. *Queensland Journal of Agricultural and Animal Sciences* **26**, 373–8.

Cameron, D. G., Courtice, J., and Mullaly, J. D. (1969). Effect of nitrogen fertilisation and slashing on the Priebe prairie grass (*Bromus unioloides*) component of an irrigated pasture. *Queensland Journal of Agricultural and Animal Sciences* **26**, 209–16.

Collins, M., and Casler, M. D. (1990). Forage quality of five cool-season grasses. II. Species effects. *Animal Feed Science and Technology* **27**, 209–18.

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

Easton, H. S., Lee, C. R., and Fitzgerald, R. D. (1994). Tall fescue in Australia and New Zealand. *New Zealand Journal of Agricultural Science* **37**, 405–17.

Faichney, G. J., And White, G. A. (1983). 'Methods for the Analysis of Feeds Eaten by Ruminants.' (CSIRO Division of Animal Production: Melbourne.)

Fulkerson, W. J., Slack, K., Moore, K., and Rolfe, C. (1993). Management of *Lolium perenne*/*Trifolium repens* pasture in the subtropics. 1. Effect of defoliation interval, seeding rate and application of N and lime. *Australian Journal of Agricultural Research* **44**, 1947–58.

Goering, H. K., and Van Soest, P. J. (1970). 'Forage Fibre Analyses.' USDA Agricultural Handbook No. 379, Jacket No. 387–598. (Agricultural Research Service, USDA.) pp. 5–12.

Goto, I., and Minson, D. J. (1977). Prediction of the dry matter digestibility of tropical grasses using a pepsin–cellulase assay. *Animal Feed Science and Technology* **2**, 247–53.

Hill, M. J. (1985). Direct drilling of tall fescue (*Festuca arundinacea* Schreb.), prairie grass (*Bromus catharticus* Vahl.) and Italian ryegrass (*Lolium multiflorum* Lam.) into kikuyu and paspalum pastures. *Australian Journal of Experimental Agriculture* **25**, 840–9.

Hunt, W. F. (1989). Grazing management effects on perennial ryegrass and white clover tiller populations. XVI International Grasslands Congress, 4–11 October 1989, Nice, France. (Association Francais pour la Production Fourragerie: Versailles, Cedax, France.)

Kleinschmidt, F. H. (1964). The influence of grazing on the botanical composition of an irrigated pasture at Lawes, south-eastern Queensland. *Australian Journal of Experimental Agriculture and Animal Husbandry* **4**, 231–45.

Lowe, K. F. (1974). The growth, nutritive value and water use of irrigated pasture mixtures at Gatton, southeast Queensland. MAgrSc. Thesis, University of Queensland, St Lucia.

Lowe, K. F. (1978). Irrigated pasture Research in South-east Queensland. *In* 'Management of South-east Queensland

Coastal Pastures'. Queensland Department of Primary Industries Mimeograph. pp. 52–73.
Lowe, K. F., and Bowdler, T. M. (1984). The performance of temperate and tropical grasses under two irrigation frequencies. *Tropical Grasslands* **18**, 46–55.
Lowe, K. F., and Bowdler, T. M. (1993). Performance of annually sown ryegrasses in subcoastal south east Queensland from 1984 to 1992. Queensland Department of Primary Industries Project Report QO93019, Brisbane.
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**, 571–8.
Lowe, K. F., Bowdler, T. M., Casey, N. D., Fulkerson, W. J., and Walker, R. G. (1998*a*). Nitrogen responses from irrigated annual ryegrass pasture. *Animal Production in Australia* **22**, 362.
Lowe, K. F., Bowdler, T. M., Casey, N. D., and Moss, R. J. (1999*a*). Performance of temperate pastures in the Australian subtropics. 2. Milk production. *Australian Journal of Experimental Agriculture* **39**, 667–83.
Lowe, K. F., Bowdler, T. M., Lowe, S. A., Gobius, N., and Fulkerson, W. J. (1999*b*). Evaluation of temperate species in the subtropics—1998. Queensland Department of Primary Industries, Brisbane.
Lowe, K. F., and Hamilton, B. A. (1986). Dairy pastures in the Australian tropics and subtropics. *In* 'Proceedings of the 3rd Australian Conference on Tropical Pastures'. Rockhampton, Queensland (8–12 July 1985). Tropical Grassland Society of Australia, Occasional Publication No. 3. (Eds G. J. Murtagh and R. M. Jones.) pp. 68–79. (Tropical Grasslands Society of Australia: Brisbane.)
Lowe, K. F., Moss, R. J., Bowdler, T. M., and Martin, F. D. (1998*b*). Digestibility and degradability of dry matter and crude protein of four temperate and one tropical grass in a subtropical environment. *Animal Production in Australia* **22**, 149–52.
Luck, P. E. (1970). The role of improved pastures in the Near North Coast Region of south-east Queensland. *In* 'Proceedings of the 11th International Grasslands Congress'. Surfers Paradise. (Ed. M. J. T. Norman.) pp. 161–5.
Minson, D. J. (1980). Nutritional differences between tropical and temperate pastures. *In* 'Grazing Animals'. (Ed. F. W. Morley.) pp. 143–57. (Elsevier Scientific: Amsterdam, The Netherlands.)
Northcote, K. H. (1971). 'A Factual Key for the Recognition of Australian Soils.' 3rd Edn. (Rellim Technical Publications: Glenside, South Australia.)
Schroder, C. A. (1961). Effect of grazing management on an irrigated pasture in south-eastern Queensland. *Queensland Journal of Agricultural Science* **18**, 209–16.
Stone, B. A. (1994). Prospects for improving the nutritive value of temperate, perennial pasture grasses. *New Zealand Journal of Agricultural Science* **37**, 349–63.
Wilson, J. R., and Ford, C. W. (1973). Temperature influences on the *in vitro* digestibility and soluble carbohydrate accumulation of tropical and temperate grasses. *Australian Journal of Agricultural Research* **24**, 187–98.
Van Soest, P. J., and Wine, P. J. (1967). Use of detergents in the analysis of fibrous feeds. IV. Determination of plant cell-wall constituents. *Journal of the Association of Official Analytical Chemists* **50**, 50–5.

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