Evaluating temperate species in the subtropics. 3. Irrigated lucerne

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Abstract

Performance of lucerne cultivars and breeding lines, when grown under irrigation in the Queensland subtropics in individual experiments and when averaged over the 25 years from 1981 to 2006, is presented. In the overall analyses, only cultivars which were entered in at least 2 experiments were included. Entries were evaluated in small plot cutting experiments over 3-year periods. Seasonal, annual and total dry matter yields were recorded, along with field disease assessments and persistence.

Highest seasonal, annual and total (60–64 t/ha) yields were produced by highly winter-active cultivars (activity levels 8 and 9) with little differences between Sequel, Sequel HR, Hallmark, Sceptre, Aquarius and Pioneer L90, although yields of a number of Queensland-bred cultivars with lower activity levels (<8) were not significantly lower. Individual experiments were more discriminating, with the Queensland-bred cultivars Sequel and Trifecta producing the highest ($P<0.05$) or equal to the highest yields in 8 of 10 and 9 of 14 experiments in which they were included, respectively. Other high-yielding cultivars included Aquarius, Aurora, Genesis, Hallmark, Pioneer L55, Sceptre and UQL-1. Average winter yields ranged from 1.7 t/ha for Hunter River to 3.2 t/ha for Hallmark, while the range in individual experiments was larger (1.1–5.7 t/ha), taking into account the range from dormant to highly active material.

Disease played a significant role in defining production levels until the drought years of 2001–2006, when the effects of colletotrichum crown rot (CCR), phytophthora root rot (PRR) and the leaf disease complex of *Stemphylium vesicarum* and *Leptosphaerulina trifolii* were reduced. Trifecta was consistently in the group of cultivars showing most resistance to these diseases, while Hunter River showed equal or better resistance to colletotrichum crown rot and the leaf disease complex.

On average, only 12 – 20% of the original populations survived until the end of the third year, with Hallmark, Trifecta and Sequel consistently the most persistent cultivars. There was a wide range in persistence between experiments (general mean of 29% in 1984 compared with 5% in 1995), with environmental conditions appearing to play as important a role as disease resistance.

The best performing cultivars under subtropical conditions were winter-active (7 and 8) or highly winter-active (9 and 9+) ones, that had either been specifically bred for the region or undergone screening for disease resistance, particularly for CCR and PRR, which are recognised as a problem in the region. Cultivars with lower winter activity levels were generally lower-yielding, even though in some instances they showed good persistence.

Introduction

Lucerne (*Medicago sativa*) remains one of the most important forages for the Australian grazing industries. Over 200 000 ha are gown annually in Australia to provide hay for the dairy, beef and horse racing industries (Irwin *et al.* 2001), with around 1.1 Mt of hay produced (Peace 2007). In 1997 in eastern Australia, aphids devastated lucerne stands, which were based on the single

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cultivar, Hunter River. Cultivars imported from USA to fill the gap displayed a wide range in performance under irrigated (Lowe *et al.* 1985; 1987a) and raingrown conditions (Lloyd *et al.* 1985). While insect resistance was important, resistance to local diseases was equally critical (Irwin 1977), particularly in the subtropical areas of Australia. Breeding programs were begun in Australia to develop cultivars with better adaptation to the region (Irwin *et al.* 2001). Most of these early Australian-bred lines were based on CUF 101 to provide aphid resistance (Lowe *et al.* 1987a; Irwin *et al.* 2001) and the most winter-active (activity levels 8 and 9) cultivars have proved the highest-yielding types in the subtropical environment under both irrigated and raingrown conditions (Irwin *et al.* 2001). The advantage gained from better persistence from less dormant cultivars in cooler environments (Humphries *et al.* 2008) does not appear to hold in the subtropics, where a range of acute diseases actively reduce plant populations (Lowe *et al.* 1985; Lloyd *et al.* 1985; D.L. Lloyd, personal communication).

This paper, the third in the series to evaluate temperate species in the Queensland subtropics, reports the performance, under irrigation, of the cultivars produced by the Australian lucerne breeding industry since 1977, along with imported cultivars from USA. Total and seasonal yield, persistence and disease resistance of around 220 breeders' lines and released cultivars are reported for the period 1981–2006.

Materials and methods

Site

Seventeen field evaluations were conducted at Gatton Research Station (27° 34' S, 152° 20' E; elevation 95 m) in south-east Queensland from 1981 to 2006. The soils are deep, alluvial black clays (black earth, Stace *et al.* 1972; Ug 5.15 and 5.16, Northcote 1971) with pH of 7.8–8.3 (H_2O) and containing 128–134 mg/kg P (Colwell extraction), 0.87–1.0 mmole/100 g potassium (K) and 67–70% clay.

Treatments and design

Experiments were conducted when sufficient new cultivars or breeders' lines were available. All were laid out as randomised blocks with 3 or 4 replicates. The number of treatments per experiment varied from 4 to 35, with the lower treatment numbers associated with 4 replicates. Treatments included elite breeders' lines of lucerne, selected by public and commercial plant breeders from their programs, together with newly released and standard (benchmark) commercial cultivars. Experiments also contained cultivars and experimental lines from USA. Generally, the standards included Hunter River, Trifecta or Sequel, but other standards were included when requested by seed companies.

Techniques

In July or August, seed was sown at 15 kg/ha by hand into weed-free seedbeds, which were then rolled and irrigated. Plot size was 5 m x 2 m. Experimental seed was hand-scarified but it was assumed that mechanical harvesting provided sufficient scarification for commercially produced seed.

For the first 4 weeks, 12.5 mm of irrigation was applied weekly but subsequently plots received 50 mm 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. Superphosphate, to provide 18 kg/ha P and 22 kg/ha sulphur (S), was applied during the second and third spring periods to satisfy a known sulphur deficiency at the sites. Swards were sprayed when necessary (usually once or twice a year) with Fluazifop-p at a rate of 2 L/ha to control the invasion of grasses.

Harvesting of each experiment commenced around 10 weeks after sowing. Regrowth was assessed over a 3-year period every 4 weeks except in winter, when the interval was extended to 6 weeks. 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 (1997–2006) m^2 using a reciprocating mower. When weeds were present, the botanical composition of the harvested herbage was determined by sorting a sub-sample into legume 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.

Seasonal yields were calculated by summing individual yields from the samplings that fell within the following periods: Autumn – 1 March to 31 May, Winter – 1 June to 31 August, Spring – 1 September to 30 November and Summer – 1 December to 28/29 February. A sampling was deemed to fall into a season if more than half the growth period occurred in that season.

Incidences of the diseases phytophthora root rot (PRR) (*Phytophthora medicaginis*), anthracnose (*Colletotrichum trifolii*) and the leaf spot complex (*Stemphylium vesicarium* and *Leptosphaerulina trifolii*) were scored visually using a scale of 0-5, described in Anon. (2007) but with modifications described by Gramshaw *et al.* (1985) and Lowe *et al.* (1987a; 1987b). Anthracnose was scored on lesions evident on stems. Colletotrichum crown rot (CCR), which invades the crown (Irwin 1974), was not assessed in these experiments. All assessments were carried out only when epiphytotics occurred. No disease assessments were conducted between 2001 and 2006 because symptoms of disease were minimal, owing to prevailing dry conditions.

Counts were recorded in a 2 m x 0.25 m permanent quadrat, positioned approximately in the centre of each plot, 6 weeks after sowing and again in May and October of each year. Plant survival at each count was assessed as a percentage of the initial population. Persistence was defined as the number of plants remaining at the end of the experiment, expressed as a percentage of the initial density.

Climate

Seasonal and total rainfall and seasonal maximum and minimum temperatures, relative humidity and radiation received for years 1984–2005 have previously been published in Lowe *et al.* (2007; 2008). Seasonal rainfall and temperatures varied considerably between years, with winter temperatures the most variable. Over the first 13-year period (1981–1993), autumn and total rainfalls were well above the long-term average, subsequently referred to as the 'normal' period (Table 1). On the other hand, autumn, winter, summer and annual rainfalls in the second period (1994–2006) were below average, subsequently referred to as the 'dry' period. Maximum temperatures in the 'normal' period were around the long-term average and autumn and winter minimum temperatures were above average. Maximum and minimum temperatures for all seasons in the dry period were similar to the long-term average. Relative humidity and radiation differences between the 2 periods were small. Minimum relative humidity showed greater variation between seasons than the maximum.

Rainfall was very low in 1993 (345 mm), 1994 (486 mm), 2000 (459 mm) and 2002 (387 mm), as was relative humidity in summer. On the other hand, rainfall exceeded 1000 mm in 4 of the 13 years (1981–1993) but only once between 1994 and 2006 (1037 mm, 1996). Summer temperatures were well above average in 1984–1986 (32.3ºC), 1990 (32.0ºC), 1997 (32.6ºC), 2001 (32.8ºC) and 2003 (32.4ºC), peaking in 2005 (33.3ºC). Winters were coldest in 1982 (5.1ºC), 1994 (5.1ºC), 2000 (5.8ºC) and 2002 (5.8ºC), and were mild in 1983 (8.1ºC), 1988 (8.4ºC), 1993 (8.4ºC), 1998 (9.0ºC) and 1999 (8.0ºC).

Statistical analyses

Data for DM yields, persistence and disease effects 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 3-year total yields, yield in Year 1, seasonal yields, % of yield in winter, % of yield in Year 3, final persistence and disease scores. The technique has been described in Lowe *et al.* (2007); however, in this instance, 'environment' was defined as different 3-year periods. Results for any cultivar or breeders' line, which appeared in only one environment, were not used in the analysis. For some cultivars/breeders' lines, the iterative process did not converge and it was necessary to drop those which appeared only a few times to attain convergence. The sensitivities of each cultivar to environmental effects are plotted against the final estimates of the cultivar means. Cultivars with a large mean (or a small mean in the case of disease scores) and a sensitivity of around 1.0 should indicate a reliable cultivar under variable conditions, as proposed by Finlay and Wilkinson (1963). Cultivars with a high sen-

Table 1. Seasonal and total rainfall averages (mm), seasonal average maximum and minimum temperatures (ºC) and relative humidity (%) and seasonal daily radiation received (MJ/m²) at Gatton Research Station from 1981 to 2006. Long-term average is over 66 years for temperature and 98 years for rainfall. Averages for relative humidity and radiation are not available.

	Mean 1981–1993 (± s.e.)	Mean 1994–2006 (± s.e.)	Long-term average
Rainfall			
Autumn	236±39	138±33	178
Winter	117±22	64±9	111
Spring	171±17	179±21	176
Summer	292±33	274±26	313
Annual[1]	826±63	662±52	778
Maximum temperature			
Autumn	26.5±0.3	27.0±0.2	26.9
Winter	21.0±0.7	21.7±0.6	21.2
Spring	27.6±0.3	28.1±0.3	28.0
Summer	31.2±0.3	31.4±0.3	31.2
Minimum temperature			
Autumn	14.5±0.3	14.0±0.2	13.8
Winter	7.1±0.3	6.9±0.3	6.6
Spring	12.6±0.2	13.1±0.2	12.7
Summer	18.9±0.2	19.0±0.2	18.8
Maximum relative humidity			
Autumn	97.1±0.3	96.8±0.3	-
Winter	96.0±0.3	96.5±0.5	-
Spring	93.4±0.4	94.0±0.7	-
Summer	95.1±0.6	94.2±0.7	
Minimum relative humidity			
Autumn	52.4±1.4	48.9±0.7	-
Winter	46.1±0.9	45.0±1.1	-
Spring	41.9±0.9	42.5±1.2	-
Summer	48.7±0.7	48.1±0.7	
Radiation			
Autumn	16.2±0.3	16.9±0.1	-
Winter	14.3±0.2	14.4±0.2	-
Spring	22.0±0.3	22.0±0.3	-
Summer	22.8±0.2	23.0±0.1	

[1] Annual rainfall - based on a calendar year.

sitivity have below average stability and are specifically adapted to favourable environments, while those with sensitivities below 1.0 are specifically adapted to unfavourable environments (Finlay and Wilkinson 1963).

To assess the potential for reducing the assessment period for lucerne in this environment, simple and multiple correlations were calculated. The data for these analyses were split into 2 periods, 1981–1996 and 1997–2003 as the 'normal' and 'dry' periods, respectively. For the period 1981–1996, field disease rankings were also included as explanatory variables.

Results

Total yields

Overall performance. The performance of the top-yielding cultivars was not significantly different, averaged over the 25 years of experimentation (Figure 1). As a result of the differing number of times cultivars were included in experiments (resulting in large standard errors for cultivars with few occurrences), the analysis failed to distinguish between Hallmark (average 64.0 t/ha)

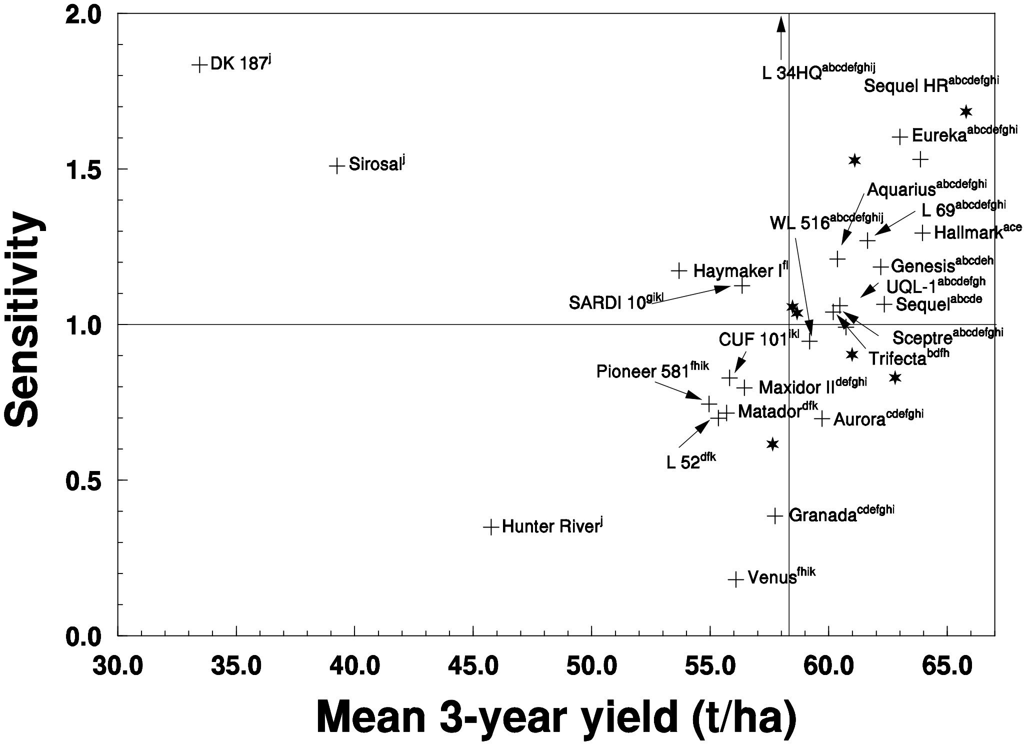

Figure 1. The relationship between cultivar adaptation (regression coefficient = sensitivity) and cultivar mean total DM yield over 3-year evaluation periods for cultivars (+) and experimental lines (*) of lucerne. A new experiment was sown annually for 25 years over the period 1981–2005 at Gatton in south-east Queensland, although the 2006 experiment was not included in this data as it had not been completed at the time. Cultivars with the same superscript are not significantly different at P=0.05.

and Aurora (59.7 t/ha) or Maxidor II (56.4 t/ha). Hunter River yielded significantly less than all other cultivars except L34HQ, WL 516, Sirosal and DK 187. Cultivars such as Sequel, UQL-1, Sceptre and Trifecta are likely to perform well under most environmental conditions (*i.e.*, they produced good yields with a sensitivity around 1). On the other hand, Eureka, Sequel HR and Hallmark should perform best in more favourable environments, while Aurora, Granada and Venus are likely to perform relatively better than other cultivars under unfavourable conditions. A number of experimental lines performed as well as the top cultivars.

Individual experiment performance. Sequel produced the highest cultivar yield ($P<0.05$) or was not significantly different from the highest cultivar yield in 8 of the 10 experiments in which it was included (Table 2). In one of the other experiments (1982), Sequel outyielded all except one other cultivar ($P<0.05$). Trifecta was the top-yielding cultivar or was not significantly different from the top-yielding cultivar in 9 of 14 experiments. The best experimental line produced the highest yield ($P<0.05$) or was not significantly different from the highest-yielding entry in 12 experiments. Other top-performing cultivars were Aquarius (1995 and 1997), Aurora (1996, 1999 and 2003), Genesis (1989 and 2003), Hallmark (1995, 1997, 2003 and 2005), Sceptre (1986, 1989 and 2000) and UQL-1 (1997, 1998 and 2000). Cultivars, which reached the top-yielding group on one occasion, included CUF 101, Granada, Pioneer 5929, Pioneer L52, Pioneer L55, Pioneer L69, Pioneer L90, Queensland 11, Rippa, SARDI 5, Sequel HR and WL 516. Hunter River produced the lowest yields in all but 2 of the 8 experiments in which it was included.

Table 2. Total DM yields of lucerne cultivars over 3-year periods from sowings made annually from 1981 to 2005. Best and worst experimental lines provide the range of performance of breeding lines and differ from year to year.

Cultivar	Country of origin[1]	Activity level[2]	DM yields (t/ha)															
			1981[3]	1982[3]	1984	1986	1989	1993	1995[4]	1995[5]	1996	1997	1998	1999	2000	2001	2003	2005
Aquarius	NSW	8						64.0		54.2		50.9			51.0	55.8		
Aurora	NSW	6			63.0		58.9				70.5			51.9			58.8	
Baron	USA	9		61.7														
Cimarron	USA	4	48.3										40.0					
Condura 73	USA	6	48.6															
CUF 101	USA	9	52.4	53.9							67.7		52.2	48.1	50.6			
Diamond	USA	8			64.6													
DK 167	USA	6	48.0															
DK 185	USA	9	45.8															
DK 187	USA	9			52.2	76.7												
Eureka	SAust	6						65.4		53.4								
Falkiner	NSW	6	48.9															
Generation	SAust	9+																59.9
Genesis	NSW	7					66.7	60.6				50.7				59.8	58.1	
Granada	USA	9	56.4	58.3														
Hallmark	Qld	8								56.5		51.6					59.5	65.7
Haymaker	USA	9	49.8	55.5														
Haymaker II	USA	9		52.4														
Hunter River	Aust	5	33.8	32.5	54.2	59.9		46.5		42.2		41.6			50.1			
Hunterfield	SAust	6		35.1														
Matador	USA	9	53.3	56.8														
Maxidor I	USA	8	49.6															
Maxidor II	USA	9	53.8	57.7														
Megluce I	USA	9	53.3															
Megluce II	USA	9	52.6															
Nova	NSW	6	44.8															
Pioneer 532	USA	4	39.4															
Pioneer 555	USA	5	45.9															
Pioneer 577	USA	8	48.7			81.7												
Pioneer 581	USA	6	52.4	56.1	62.5													
Pioneer 5929	USA	9							53.2									
Pioneer L34HQ	USA	3							42.7						43.5			
Pioneer L52	USA	5					56.9		50.3									
Pioneer 54Q53	USA	4													43.6			
Pioneer L55	USA	5													50.7		59.8	
Pioneer L56	USA	5																
Pioneer L69	USA	8						63.5	52.5									
Pioneer L90	USA	9													46.8		58.8	

Cultivar	Country of origin[1]	Activity level[2]	DM yields (t/ha)															
			1981[3]	1982[3]	1984	1986	1989	1993	1995[4]	1995[5]	1996	1997	1998	1999	2000	2001	2003	2005
Quadrella	Qld	7					51.3	59.3										
Queensland 11	USA	9														62.1		
Rippa	USA	9										51.6						
Sapphire	USA	7			67.3													
SARDI 5	SAust	5																64.3
SARDI 7	SAust	7															57.0	
SARDI 10	SAust	10															52.6	58.0
Sceptre	SAust	9				84.1	63.5	65.0		53.3				49.3	53.4			
Sequel	Qld	9		64.7	73.0	86.7	61.4	68.5		57.2		53.0			54.1		58.2	64.2
Sequel HR	Qld	9+						66.5		52.7					54.1			
Sheffield	SAust	6	42.3															
Siriver	ACT	9	46.2															
Siro Peruvian	ACT	9		49.6														
Sirosal	ACT	9				74.8	42.6											
Siro Tasman	ACT	5	50.5															
Springfield	SAust	6	47.5															
Stargrazer	USA	7	45.9															
Trifecta	Qld	7	60.9	68.1	72.0	84.8	63.5	59.5		55.3	69.9	47.3	56.2	50.2	51.9		56.5	61.4
UC Cibola	USA	9	38.2															
UQL-1	Qld	7										51.9	58.4		53.5			62.1
Validor	USA	4	45.2															
Venus	NSW	5														55.6		56.3
Wakefield	SAust	6	42.9															
WL 320	USA	3				72.1												
WL 515	USA	5	46.9															
WL 516	USA	6				81.5					70.7							
WL 525HQ	USA	8																
WL 605	USA	9				75.0												
WL Southern Special	USA	3				75.2												
Best exp.[6]			35.8	59.6	69.1	85.1	66.5	72.8	-	56.3	72.2	54.9	56.2	52.6	55.3	65.0	57.6	62.5
Worst exp.			34.8	48.1	60.2	73.8	53.4	58.6	-	51.5	70.4	43.4	40.4	42.3	51.8	56.4	55.3	47.7
General mean			47.6	54.3	64.3	79.0	60.4	63.2	49.7	53.6	70.3	50.5	51.1	49.3	50.9	58.7	57.3	60.5
LSD (P=0.05)			6.4	2.9	3.4	4.8	4.2	4.7	2.9	3.6	ns	3.6	5.0	2.4	2.2	3.5	2.1	1.7

[1] USA – United States of America, NSW – New South Wales, SAust – South Australia, Qld – Queensland, ACT – Australian Capital Territory, Aust – natural selection, Australia.

[2] Based on Anon. (2007) where 1 = completely winter-dormant and 9 = highly winter-active. Note: New material from Saudi Arabia now suggests that there is a further category – 10, which is more active than the original 9 category (Irwin *et al.* 2008).

[3] Data reproduced from Lowe *et al.* (1987a).

[4, 5] Different experiments conducted in the same year.

[6] Best experimental line.

First-year yields

Overall performance. Sequel HR was the highest-yielding cultivar in the first year (23.3 t/ha) in absolute terms but it was not different (P>0.05) from 15 other winter-active or highly winter-active cultivars (Figure 2). Pioneer 581 yielded significantly less than Sequel HR, Pioneer L69, Hallmark, Sequel, UQL-1, Sceptre, SARDI 10 and Trifecta. Hunter River yielded less (P<0.05) than all except Cimarron, Pioneer L34HQ, Pioneer L52, SARDI 7 and WL 516. Sequel HR, Pioneer L69 and Pioneer L90 were superior under favourable conditions and SARDI 10, Maxidor II and Granada were superior under less favourable conditions. A number of experimental lines performed as well as the best cultivars in the first year.

Individual experiment performance. In contrast to the 3-year totals, the best experimental line was usually the top-yielding (P<0.05) or equal top-yielding entry in the first year; this trend was most evident after 1995 (Table 3). Sequel was equal to the top-yielding entry in all but 2 of the experiments in which it was included. Trifecta was the top-yielding or equal top-yielding cultivar from 1981 to 1997 (except for the 1993, 1995 and 1996 experiments) but after 1998 it was never in the top-yielding group. Other cultivars to fall into the top-yielding group included Sceptre (1986, 1989 and 1995), Sequel HR (1993, 1995 and 2000), UQL-1 (1997 and 1998), Hallmark (1995, 1997 and 2005), Genesis (1989 and 1997) and Aquarius (1995 and 1997), while Baron, CUF 101, Granada, Generation, Maxidor II, Pioneer L69, Queensland 11 and WL 516 were equivalent to the best entry on one occasion. Many of these high-performing entries were equal to the second highest-yielding entry on further occasions. Hunter River produced low yields in every experiment, always being lower than the general experimental mean.

The best entries yielded 17–29 t/ha DM, depending on the seasonal conditions experi-

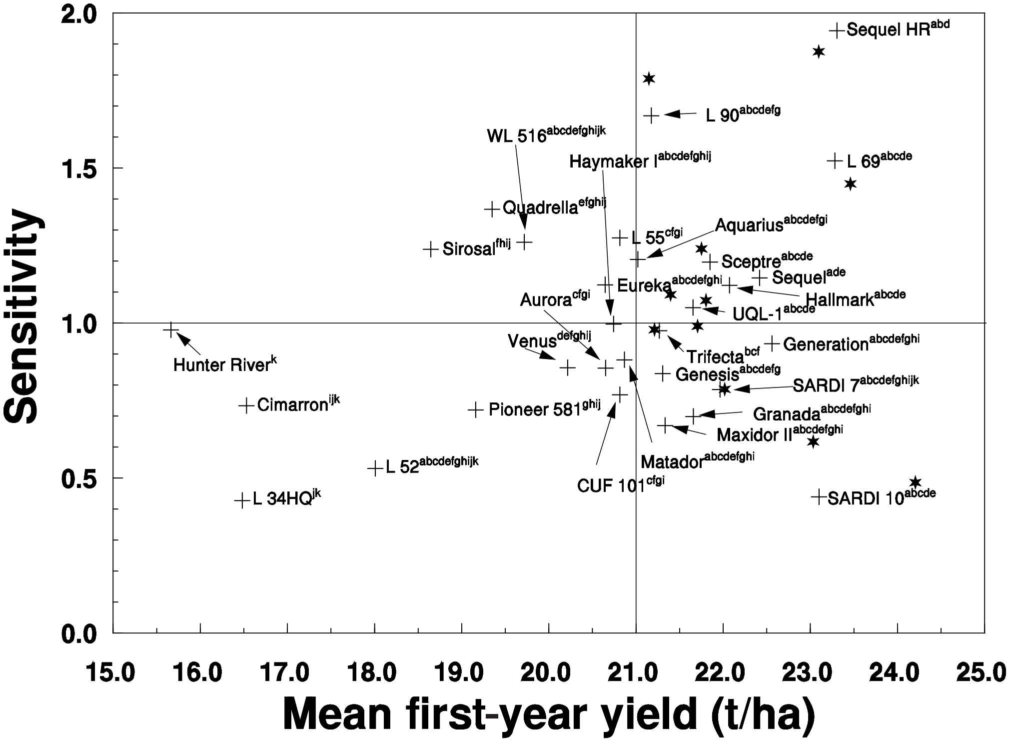

Figure 2. The relationship between cultivar adaptation (regression coefficient = sensitivity) and mean first-year DM yield for cultivars (+) and experimental lines (*) of lucerne. The 2006 experiment was included in this analysis. Cultivars with the same superscript are not significantly different at P=0.05.

enced. Most were highly winter-active and were bred in Queensland or, if bred elsewhere, have had strong selection pressure for CCR and PRR.

Seasonal yields

Overall performance. Winter production of semi-dormant and dormant cultivars (activity levels below 7) such as Pioneer L34HQ, Cimarron, Pioneer 581 and Hunter River was significantly (P<0.05) lower than that of winter-active and highly winter-active cultivars (except for the poorly performing DK 187 and Sirosal). Within the winter-active and highly winter-active cultivars, there were no significant differences (Table 4). Spring yields of the majority of cultivars were similar, although Hunter River, DK 187 and Sirosal produced less (P<0.05) than most other cultivars.

Apart from significant differences between Pioneer L55 and Hallmark and a group including SARDI 10, CUF 101, Quadrella, Aurora, Cimarron, Hunter River, DK 187 and Sirosal, there were no significant differences (P>0.05) in summer yield between the majority of the cultivars. Hallmark yielded more (P<0.05) in autumn than Aquarius, CUF 101, Sceptre, UQL-1, Pioneer L69, Pioneer L52, Pioneer L34HQ, Hunter River and DK 187. Again there was little difference between most of the remaining winter-active and highly winter-active cultivars.

Percentage of yields produced in winter

Overall performance. Despite some cultivars being included in only a small number of years, the data in Figure 3 for percentage of total yield produced in winter agreed well with the activity levels presented in Table 2. Highly winter-active cultivars such as Pioneer L90, Granada, Maxidor II, SARDI 10, CUF 101, Sequel and Sequel HR were not significantly different. The analysis generally did not distinguish between these and winter-active lines such as Hallmark, Pioneer L69, UQL-1, Aurora, Aquarius, WL 516 and Quadrella. However, the semi-dormant and dormant cultivars such as Pioneer L34HQ, Cimarron and Pioneer 581 were distinguished as inferior (P<0.05). Venus, Pioneer L55 and Pioneer L52 were intermediate in performance between the foregoing groups but were not different (P>0.05) from the highly active lines.

Disease

Overall performance. Disease played a significant role in the performance of cultivars before very dry conditions commenced in 2001. Subsequent to this, little disease was evident and no assessments were conducted (Table 5). Therefore, the overall analyses have been conducted only for the period 1981–1998 for PRR and the leaf disease complex and 1981–2000 for anthracnose. Trifecta showed the best (P<0.05) or equal best resistance to all 3 diseases among the cultivars (Table 4). It was significantly better than Pioneer 581, DK 187, WL 516, Sirosal and Haymaker I for resistance to anthracnose. A ranking of 2 or less indicated that these cultivars would be expected to show symptoms no worse than small dark lesions on the stems and little damage in the plant crown under moderate disease attack. Trifecta was also more (P<0.05) resistant to PRR than Granada, Haymaker I, Hunter River, Quadrella and Sirosal. Under moderate PRR infection, most plants would show only small lesions on the roots with this level of resistance. Damage was greater from the leaf disease complex, with none of the cultivars showing 'resistance' and all cultivars recording levels of 3 or more. In 1989, Quadrella, which had been selected from Trifecta for *Stemphylium* resistance, showed significantly more resistance (2.04) than Trifecta (2.64) (Table 5). Generally, Quadrella, Trifecta, Cimarron and Hunter River showed the least damage from the leaf spot complex among cultivars, although differences were generally not significant (P>0.05).
Individual experiment performance. Trifecta and Hunter River were generally the most (P<0.05) resistant cultivars to anthracnose infection (or equal most resistant) (except in 2000) (Table 5). The best experimental line showed similar resistance to the best cultivar in individual experiments except in 2000. Other cultivars showing good resistance were Pioneer 532, Pioneer 577 and Wakefield (1981), Sequel, Haymaker and Hunterfield (1982), Sequel (1984), WL 320 (1986), Eureka and Sequel HR (1995) and Pioneer L34HQ, Pioneer 54Q53 and UQL-1 (2000). In 2000 Trifecta showed as much damage as the worst affected cultivar, which may have been due

Table 3. First-year DM yields of lucerne cultivars from sowings made annually from 1981 to 2006. Best and worst experimental lines provide the range of performance of breeding lines and differ from year to year.

Cultivar	DM yields (t/ha)																
	1981	1982	1984	1986	1989	1993	1995[1]	1995[2]	1996	1997	1998	1999	2000	2001	2003	2005	2006
Aquarius						23.2		21.3		17.1			18.4	22.4			
Aurora			23.6		15.8				27.3			18.4			22.1		23.4
Baron		21.5															
Cimarron	11.0										17.0						
Condura 73	10.8																
CUF 101	16.2	19.1							27.2		20.3	18.6	19.8				
Diamond			25.1														
DK 167	10.7																
DK 185	11.6																
DK 187			17.3	23.2													
Eureka						22.8		19.5									
Falkiner	10.6																
Generation																25.6	23.4
Genesis					19.7	22.8				17.4				22.2	22.6		
Granada	16.4	21.4															
Hallmark						24.5		21.4		17.5					23.2	25.9	24.3
Haymaker	13.3	20.3															
Haymaker II		19.2															
Hunter River	4.9	11.8	20.6	16.2		17.7		13.8		13.6			16.7				
Hunterfield		13.8															
Matador	14.3	20.5															
Maxidor I	14.1																
Maxidor II	16.3	21.0															
Megluce I	15.0																
Megluce II	14.9																
Nova	11.2																
Pioneer 532	8.9																
Pioneer 555	10.5																
Pioneer 577	10.5			24.1													
Pioneer 581	12.8	20.2	22.2														
Pioneer 5929							17.1										
Pioneer L34HQ							14.6						15.9				
Pioneer L52					16.4		15.7										
Pioneer 54Q53													15.6				20.4
Pioneer L55													19.1		22.8		22.3
Pioneer L56																	23.4
Pioneer L69						26.2	16.5										
Pioneer L90													19.1		24.3		21.2

Cultivar	DM yields (t/ha)																
	1981	1982	1984	1986	1989	1993	1995[1]	1995[2]	1996	1997	1998	1999	2000	2001	2003	2005	2006
Quadrella					15.3	22.0											
Queensland 11														25.6			24.6
Rippa										16.7							
Sapphire			25.9														
SARDI 5																24.4	22.4
SARDI 7															23.2		22.7
SARDI 10															23.6	24.6	24.0
Sceptre				25.7	19.4	24.4		20.7				17.6	20.1				
Sequel		23.1	27.4	26.7	18.4	25.5		21.3		17.1			21.1		24.7	26.0	22.1
Sequel HR						27.2		21.1					21.0				
Sheffield	8.0																
Siriver	10.9																
Siro Peruvian		17.4															
Sirosal				22.5	15.0												
Siro Tasman	13.3																
Springfield	13.4																
Stargrazer	11.5																
Trifecta	17.2	23.0	29.0	26.1	19.1	22.7		19.6	27.0	16.8	21.3	17.8	18.9		22.8	24.2	22.4
UC Cibola	10.5																
UQL-1										18.5	23.6		19.9			25.1	22.5
Validor	12.1																
Venus														20.5		23.0	21.5
Wakefield	9.0																
WL 320				21.6													
WL 515	13.1																
WL 516				23.7					28.7								
WL 525																	
WL 605				21.3													
WL Southern Special				21.9													
Best exp.[3]	12.7	21.5	26.7	26.1	20.1	26.3	-	21.5	29.6	18.4	22.7	20.5	20.3	26.6	25.3	26.1	26.4
Worst exp.	10.7	17.0	22.9	22.3	15.3	23.0	-	19.2	27.4	14.4	19.4	16.3	19.1	22.1	21.5	23.4	19.3
General mean	12.1	19.5	24.7	23.5	17.8	23.9	16.0	20.0	28.1	17.0	20.9	18.3	19.1	23.4	23.2	25.0	23.4
LSD (P=0.05)	2.1	1.6	1.5	2.2	1.8	2.3	ns	1.2	1.8	1.8	2.5	1.4	0.9	1.7	0.9	1.0	1.6

[1,2] Different experiments conducted in the same year.

[3] Best experimental line.

Table 4. The relationship between cultivar adaptation (regression coefficient=sensitivity) and mean seasonal yield and disease ranking for lucerne cultivars at Gatton. Best and worst experimental lines provide the range of performance of breeding lines and differ from year to year. Cultivars with the same superscript are not significantly different at P=0.05.

Cultivar	Winter		Spring		Summer		Autumn		Disease ranking					
	Yield	Sens[1]	Yield	Sens	Yield	Sens	Yield	Sens	CCR	Sens	PRR	Sens	Stemp.[2,3]	Sens
Aquarius	2805^{def}	1.03	6493^{abcde}	1.22	7034^{abcde}	1.11	3485^{efghi}	1.09	$2.61^{bcdefgh}$	1.24	1.68^{hi}	0.43	3.34	3.06
Aurora	2670^{efg}	0.72	6456^{abcd}	0.82	6786^{ce}	0.75	$3787^{abcdegh}$	0.58	2.21^{fgh}	0.97	1.65^{h}	0.37	3.28	1.03
Cimarron	1052^{j}	0.26			5439^{ghi}	-2.79	$3868^{abcdefghij}$	2.4			2.65^{bcde}	0.53	2.91	0.38
CUF 101	2826^{de}	0.84	6064^{ce}	1.11	6206^{fg}	0.74	3462^{fgi}	0.81	2.35^{cdefgh}	0.56	$2.17^{cdefghi}$	1.21	3.44	0.9
DK 187	$1989^{abcdefghij}$	1.07	3681^{h}	1.79	4542^{ij}	1.5	2453^{fik}	1.73	3.14^{b}	0.48				
Eureka	2795^{bcdefg}	1.41	6370^{abcdef}	0.89	$7090^{abcdefg}$	1.18	$3784^{abcdegh}$	1.4			2.44^{bcde}	2.03		
Genesis	2856^{bcde}	0.91	6551^{abcd}	0.92	7310^{abcd}	1.47	3875^{abcde}	0.82			2.28^{bcdefg}	1.46	3.79	2.87
Granada					$6712^{abcdefg}$	0.59	$3856^{abcdefghij}$	0.97	$1.68^{bcdefgh}$	-0.85	3.56^{abc}	-4.16		
Hallmark	3200^{bd}	1.2	6590^{abcd}	1.11	7318^{ad}	1.23	4030^{ac}	1.26			2.09^{defghi}	0.48		
Haymaker I					6185^{defghi}	0.8	$3284^{abcdefghij}$	0.63	5.00^{a}	5.96	3.68^{ab}	-2.87		
Hunter River	1654^{ij}	0.56	5401^{fg}	0.47	5400^{hi}	0.39	2728^{jkl}	1	2.14^{gh}	1.14	3.39^{a}	0.99	2.92	0.38
Matador					6139^{defghi}	0.79	$3542^{abcdefghij}$	0.84	$2.74^{abcdefgh}$	1.29	1.28^{defghi}	4.75		
Maxidor II					$6619^{abcdefgh}$	0.66	$3005^{abcdefghij}$	-0.1	$2.22^{bcdefgh}$	0.15	$2.30^{abcdefghi}$	0.56		
Pioneer 581	2095^{h}	0.44	6021^{bdef}	0.45	$6857^{abcdefg}$	0.76	3465^{cfghi}	0.72	2.41^{cdefg}	0.89	2.05^{eghi}	0.8		
Pioneer L34HQ	1165^{j}	1.6	5994^{def}	0.87	$7452^{abcdefghi}$	1.61	2742^{jkl}	0.38						
Pioneer L52	$2677^{abcdefghij}$	3.58	6376^{abcde}	1.3	6750^{abcdef}	0.96	3253^{fhij}	0.99						
Pioneer L55	2647^{cefg}	0.47	7002^{a}	1.53	8149^{ab}	2.04								
Pioneer L69	$3177^{abcdefg}$	1.3	6562^{abcd}	1.19	$6342^{abcdefghi}$	0.71	3266^{efghij}	1.58						
Pioneer L90	2714^{cefg}	0.64	6969^{ab}	2	7841^{abcde}	2.14								
Quadrella	2317^{fgh}	1.1	$5240^{abcdefgh}$	-0.27	6039^{fghi}	-0.14					2.79^{bc}	3.04	3.44	3.12
SARDI 10	$3052^{abcdefg}$	1.27	6011^{def}	0.74	6517^{ef}	1.53	$3139^{abcdefghij}$	-1.51						
Sceptre	3051^{bcd}	1.13	6377^{abcd}	0.89	6807^{abcde}	1.06	3613^{bdefgh}	1.18	2.29^{defgh}	0.85	2.14^{defghi}	1.17	3.13	0.52
Sequel	3167^{b}	1.13	6565^{abd}	1.08	7053^{abcd}	1.12	3863^{abcd}	0.83	2.29^{efgh}	0.83	1.86^{ghi}	0.84	3.55	1.12
Sequel HR	3005^{bcde}	1.57	6120^{abcdef}	0.8	$6956^{abcdefgh}$	1.03	$3678^{abcdegh}$	1.39	1.93^{gh}	0.73	2.27^{cdefgi}	2.42	4.6	7.61
Sirosal	2138^{ghi}	1.05	5311^{eg}	1.2	3730^{j}	1.63			2.60^{bcde}	2.02	2.60^{bcd}	1.81	3.55	1.43
Trifecta	2837^{ce}	0.97	6467^{abcd}	0.99	6866^{bce}	1.13	3754^{abcdeh}	0.69	2.11^{h}	0.86	2.02^{eghi}	1.04	3.03	1.02
UQL-1	2841^{bcdef}	1.02	6705^{ab}	1	$69^{41abc}de$	1.12	3535^{defghi}	0.45						
Venus	$2471^{bcdefgh}$	1.05	6545^{abcd}	0.76	7510^{abcdef}	-1.22								
WL 516	$3059^{abcdefgh}$	0.66	6313^{abcdef}	0.85	6928^{abcdef}	1.01	$3286^{abcdefghij}$	1.5	2.52^{bcdef}	2.83			3.36	0.65
Best exp.[4]	3850^{a}	1.29	6571^{abcde}	0.93	7717^{abcde}	1.50	4314^{ab}	1.29	2.54^{bcdef}	0.66	1.84^{fhi}	0.91	2.86	0.51
Worst exp.	2776^{bcdefg}	1.43	6261^{abcdef}	0.71	$3175^{abcdefghij}$	-5.67	$2474^{abcdefghij}$	2.09	2.75^{bc}	1.59	2.40^{bcdef}	1.06	3.72	1.10

[1] Sens –sensitivity. [2] *Stemphylium*/*Leptosphaerulina* leaf spot complex. [3] No significant differences. [4] Best experimental line.

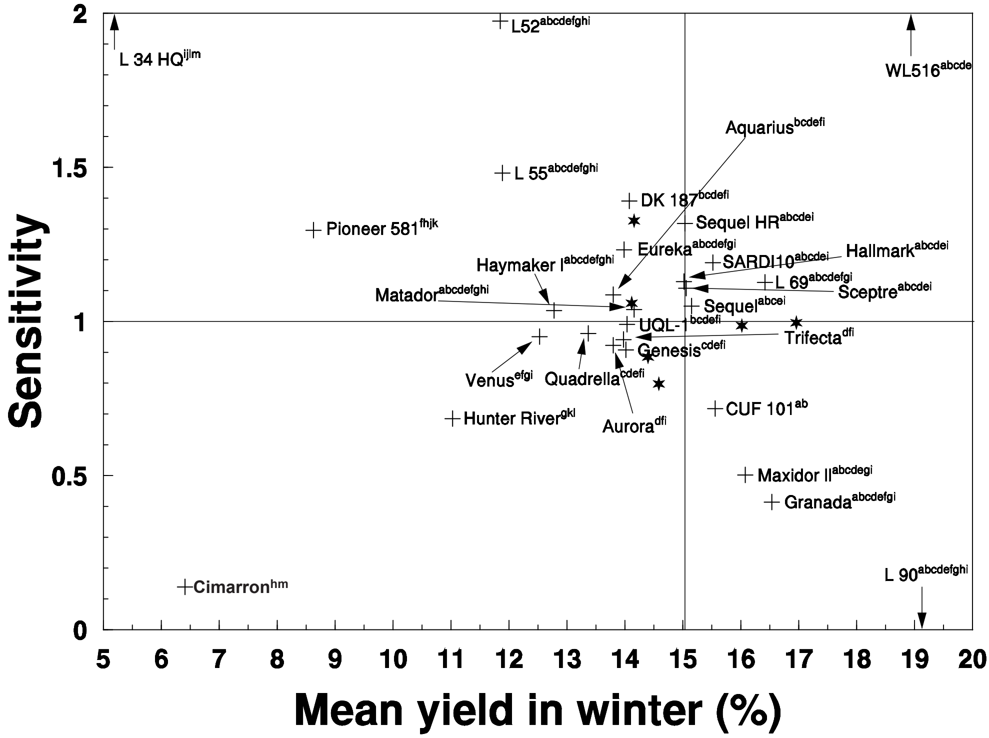

Figure 3. The relationship between cultivar adaptation (regression coefficient = sensitivity) and the percentage of total yield produced in winter for cultivars (+) and experimental lines (*) of lucerne. Cultivars with the same superscript are not significantly different at P=0.05.

to the presence of Race 4 of *C. trifolii* (Mackie *et al*. 2003).

Sequel consistently showed good resistance to PRR; it was either the most resistant ($P<0.05$) or equal to the most resistant on all occasions it was assessed. Trifecta showed good resistance in 4 of 8 experiments. Other cultivars showing good resistance were: Pioneer 581 (1981, 1982 and 1984), Sceptre (1986, 1989 and 1993), Hallmark (1995) and Aquarius (1993 and 1995). The best experimental line was at least equal to the best cultivar in all experiments except in 1981. On the other hand, Hunter River always showed little resistance to PRR.

Few cultivars showed resistance to the leaf disease complex of *Stemphylium* and *Leptosphaerulina.* Aquarius, Quadrella, Trifecta and Hunter River were the most resistant. Condura 73, Eureka, Pioneer 555, Stargrazer, UQL-1 and Validor were equal to the best cultivar on the occasions they were assessed.

Persistence

Overall performance. Hallmark, Pioneer L34HQ and Trifecta were significantly ($P<0.05$) more persistent than CUF 101 and Hunter River, and all other cultivars (Figure 4) were not different ($P>0.05$) from either of these groups. Hallmark, Aquarius, Aurora, Sceptre, Venus and Genesis performed well under all environmental conditions. WL 516, Pioneer L34HQ, UQL-1, Pioneer 581 and Sirosal could be expected to persist well only under favourable conditions while Pioneer L55, Hunter River, Pioneer L90, Pioneer L69 and SARDI 10 handle unfavourable conditions better. *Individual experiment performance.* Persistence varied substantially over the years, with the experimental general mean ranging from 29% in 1984 to <5% for the 2 experiments in 1995 (Table 6). Best persisting cultivars (*i.e.,* cultivars which have been either the most persistent or equal to the most persistent entry) include Aquarius (twice from 5 experiments), Hallmark

Table 5. Level of damage caused by CCR (exhibited as anthracnose aerial lesions), phytophthora root rot and leaf disease complex, experienced during epiphytotics, at Gatton during 3-year experimental periods from sowings made between 1981 and 2000. Best and worst experimental lines provide the range of performance of breeding lines and differ from year to year.

Cultivar	Colletotrichum ratings								Phytophthora ratings								Leaf disease complex ratings						
	1981[1]	1982[1]	1984	1986	1989	1995	1996	2000	1981[1]	1982[1]	1984	1986	1989	1993	1995	1998	1981[1]	1986	1989	1993	1995	1996	1998
Aquarius						1.70		3.48						1.58	1.86					3.00	2.78		
Aurora			3.35		2.03		2.07				1.31		1.76						2.81			2.65	
Baron		1.87								1.96													
Cimarron	2.06								2.78								3.39						2.66
Condura 73	2.19								3.33							2.97	3.50						
CUF 101	2.34	1.93					2.18	2.95	2.45	2.68						2.86	4.59					2.69	3.10
Diamond			3.52								1.78												
DK 167	2.10								2.47								4.06						
DK 185	2.00								3.16								4.40						
DK 187			3.70	3.29							1.00	1.23						4.12					
Eureka						1.38								2.00	3.29						2.64		
Falkiner	2.13								2.58								4.07						
Genesis					2.01								2.72	1.97					2.50	3.47			
Granada	2.08	2.23							2.54	2.00							4.53						
Hallmark						1.58								1.98	2.29						3.18		
Haymaker	2.64	1.55							2.98	2.61							4.39						
Haymaker II		2.10								3.40													
Hunter River	1.54	1.57	3.42	2.74		1.18		2.42	3.83	3.68	2.39	2.84		2.80	3.62		3.29	3.87			2.81		
Hunterfield		1.67								3.96													
Matador	2.14	1.90							2.44	3.06							4.23						
Maxidor I	2.24								2.47								4.29						
Maxidor II	2.15	2.12							2.44	2.51							4.22						
Megluce I	2.36								2.42								4.40						
Megluce II	1.99								2.73								4.36						
Nova	2.26								2.26								3.93						
Pioneer 532	1.63								3.16								4.18						
Pioneer 555	2.09								3.15								3.76						
Pioneer 577	1.80								3.65								4.31						
Pioneer 581	1.90	1.92	3.46						2.31	2.23	1.30						4.04						
Pioneer L34HQ								2.05															
Pioneer L52					2.47								2.39						2.78				
Pioneer 54Q53								1.53															
Pioneer L55								2.50															
Pioneer L69														1.70									
Pioneer L90								2.51															

Cultivar	Colletotrichum ratings								Phytophthora ratings								Leaf disease complex ratings						
	1981[1]	1982[1]	1984	1986	1989	1995	1996	2000	1981[1]	1982[1]	1984	1986	1989	1993	1995	1998	1981[1]	1986	1989	1993	1995	1996	1998
Quadrella					2.04								3.70	2.13					2.04	3.09			
Sapphire			3.61								1.14												
Sceptre				2.52	2.06	1.70		3.08				1.29	2.37	1.75	2.76			3.65	3.01		2.93		
Sequel		1.45	3.29	2.47	2.08	1.88		3.08		2.00	1.07	1.07	2.27	2.07	2.14			4.26	2.93	3.42	3.50		
Sequel HR						1.40		2.44						1.75	3.29					3.75	3.20		
Sheffield	2.28								3.38								3.82						
Siriver	2.53								3.40								4.24						
Siro Peruvian		2.37								3.22													
Sirosal				3.23	2.17							1.19	3.14					4.62	2.91				
Siro Tasman	2.41								3.25								3.90						
Springfield	2.29								2.83								4.31						
Stargrazer	2.43								2.63								3.22						
Trifecta	1.74	1.58	3.15	2.15	1.99	1.43	2.06	2.87	2.06	2.65	1.14	1.08	2.39	1.87	2.55	2.66	4.35	3.61	2.64	2.92	2.74	2.58	2.15
UC Cibola									2.71								4.46						
UQL-1								1.55								1.76							2.39
Validor	1.99								2.56								3.75						
Venus																							
Wakefield	1.88								3.43								3.80						
WL 320				2.41								1.25						3.32					
WL 515	2.13								2.25								4.11						
WL 516				3.32			2.16					1.30						3.84				2.96	
WL 605				3.85								1.21						3.99					
WL Southern Special				3.82								1.80						2.75					
Best exp.[2]	1.75	1.42	3.27	2.06	1.88		1.91	2.31	2.52	1.82	1.08	1.05	1.81	1.53	2.24	1.69	3.13	3.18	2.44	n/a	2.84	2.62	2.00
Worst exp.	2.10	2.18	3.90	3.60	2.75		2.21	3.31	2.73	3.46	1.91	1.46	2.88	2.20	3.24	3.03	4.46	4.54	3.31	n/a	3.38	3.08	2.90
General mean	2.10	1.83	3.53	2.97	2.26	1.53	2.10	2.58	2.81	2.69	1.45	1.27	2.42	1.91	2.75	2.50	4.05	3.80	2.81	3.25	3.07	2.76	2.63
LSD (P=0.05)	0.35	0.32	0.32	0.31	0.32	0.27	ns	0.68	0.41	0.60	0.50	0.61	0.67	ns	0.58	0.59	0.63	ns	0.57	0.25	ns	ns	0.44

[1] Data reproduced from Lowe *et al.* (1987a).

[2] Best experimental line.

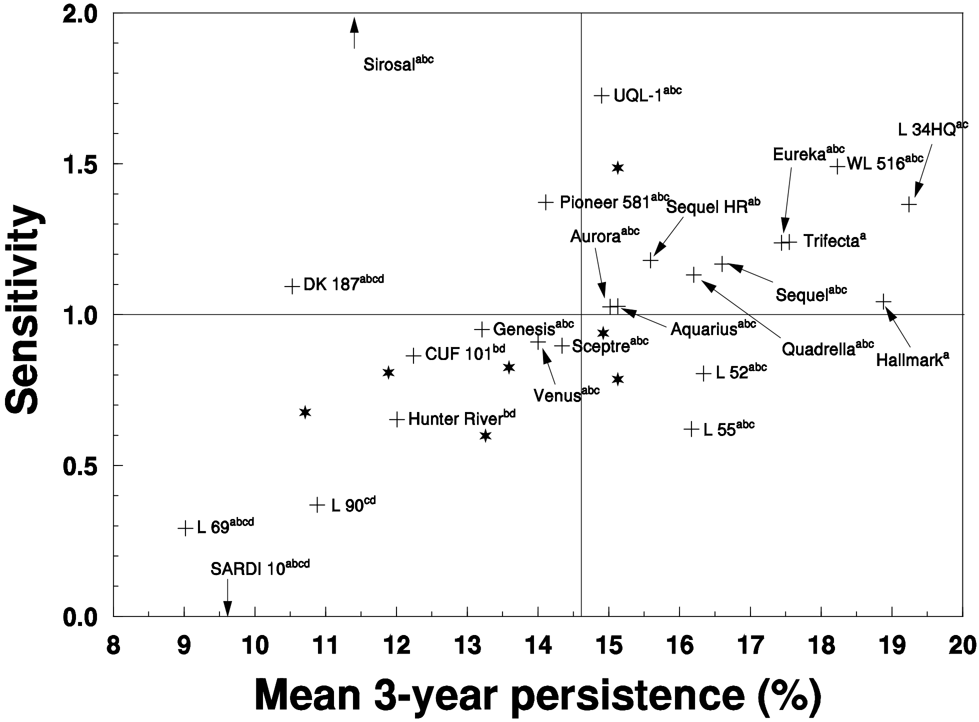

Figure 4. The relationship between cultivar adaptation (regression coefficient = sensitivity) and cultivar mean persistence at the end of the 3-year evaluation periods for cultivars (+) and experimental lines (*) of lucerne. Cultivars with the same superscript are not significantly different at P=0.05.

(4 from 5), Hunter River (2 from 8), Pioneer 581 (2 from 3), Pioneer L52 (2 from 2), Sceptre (2 from 6), Sequel (7 from 10), Trifecta (6 from 14) and UQL-1 (2 from 4). The best experimental line persisted as well as the best cultivar in 11 out of 15 experiments. Baron, Pioneer 54Q53, Queensland 11, Sapphire and SARDI 7 were equal to the best cultivar in the only experiment in which they appeared.

Percentage of total yield in the third year

Overall performance. Third-year performance is an indicator of how a cultivar performs at the end of the expected 3-year life of the stand. Percentage of total yield in the third year was highest in Venus, Pioneer 581, Genesis, Pioneer L55, Hallmark and Aurora (semi-winter-dormant or winter-active cultivars) and these cultivars showed good long-term performance (Figure 5). Hunter River showed yield improvement, relative to many better performing cultivars, at the latter end of 3 years. Two older highly winter-active cultivars (Granada and Maxidor II) also performed well in the third year, and were superior to the better performing highly winter-active cultivars such as Sequel HR, Sequel, Sceptre, Pioneer L90, CUF 101 and SARDI 10, in some cases significantly so.

Factors affecting 3-year yield and persistence

During the 'normal' period, environment accounted for 79% of the variation in 3-year yield. For the subset of data when PRR was scored, the PRR rating explained 70% of variation in yield over the 3 years. For the subset of data when CCR was scored, CCR accounted for 28% variation. Yield in Year 1 explained 36% of the variation in Year 2 and yield in Year 2 only 23% of that in Year 3.

During the dry years, environment accounted for 43% of the variation in 3-year yield. Yield in Year 1 explained only 16% of the variation in

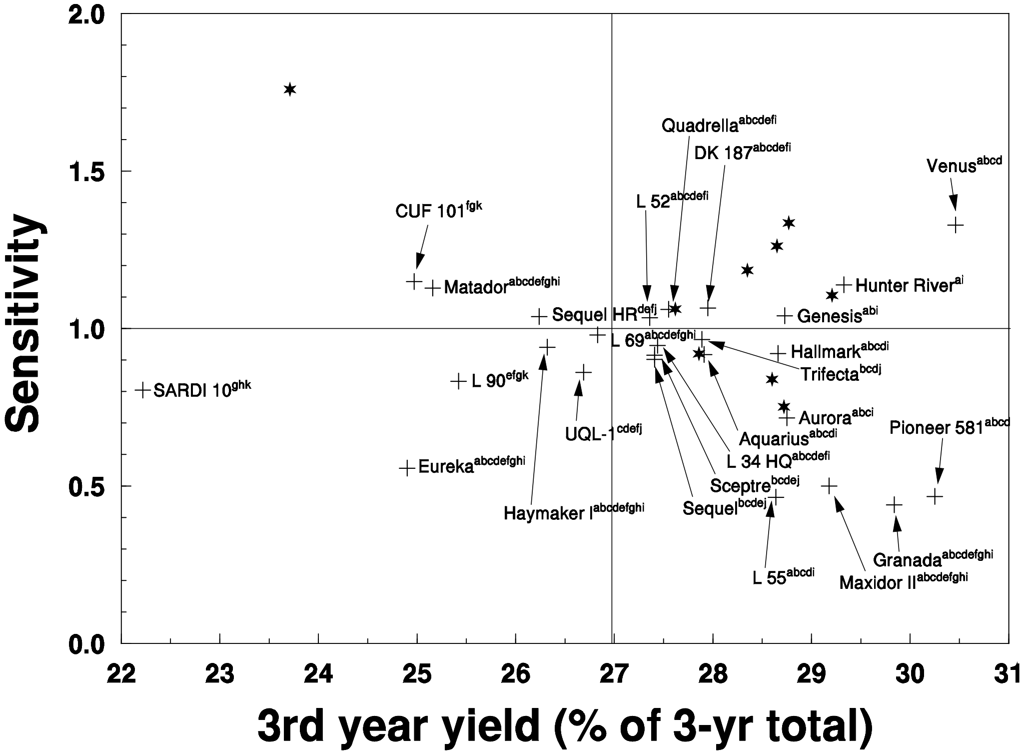

Figure 5. The relationship between cultivar adaptation (regression coefficient = sensitivity) and the percentage of total yield produced in the third year for cultivars (+) and experimental lines (*) of lucerne. Cultivars with the same superscript are not significantly different at P=0.05.

Year 2 and yield in Year 2 was not significantly correlated with that in Year 3.

Persistence at the end of the third year in the 'normal' period explained 23% of the variation in the percentage of total yield produced in the third year, 17% of the variation in third-year yields and 17% of the variation in summer yields. In the years when assessments were made, leaf disease rating explained 38.5% of the variation in persistence, CCR (19%) and PRR (15%). Multiple correlation including the factors Year 3 yields, spring yield and the leaf disease complex accounted for 62% of the variation. In the dry years, persistence was influenced by yield in Year 1 (45% of the variation), % of yield in winter (36%), winter yields (32%) and % of the yield in the third year (25%). The multiple regression including summer and autumn yields and % of yield in winter accounted for 68% of the variation.

Discussion

General

Australian-bred cultivars, particularly those selected specifically for the subtropical environment of south-eastern Queensland, performed best. These are predominantly those bred in Queensland [Trifecta, Sequel (Oram 1990), Sequel HR (Bray and Irwin 1998), Hallmark (Bray and Irwin 1999) and UQL-1 (Irwin 2000)]; all were selected for disease resistance to CCR and PRR within the breeding programs. Aquarius (Waterhouse *et al.* 1993), Sceptre (Kobelt 1997), SARDI 5 (Kobelt and Humphries 2007), SARDI 7 (Kobelt 2002), SARDI 10 (Kobelt 2006) and Venus (Williams 2003) came from other Australian programs but did have similar disease pressures exerted during selection. A number of cultivars imported from USA also performed well. While many had been selected for disease resistance, none was specifically tested against

Table 6. Persistence (% occurrence), at the end of 3-year periods, of lucerne cultivars from sowings made annually from 1981 to 2005. Best and worst experimental lines provide the range of performance of breeding lines and differ from year to year.

Cultivar	Persistence															
	1981[1]	1982[1]	1984	1986	1989	1993	1995[2]	1995[3]	1996	1997	1998	1999	2000	2001	2003	2005
Aquarius						14.3	3.3			25.9			14.8	7.1		
Aurora			24.9		11.1				7.9			22.8			9.8	
Baron		22.0														
Cimarron	29.1										14.6					
Condura 73	25.2															
CUF 101	21.1	18.1							6.4		14.6	16.8	12.7			
Diamond			25.8													
DK 167	18.2															
DK 185	21.0															
DK 187			25.3													
Eureka						11.2	4.6									
Falkiner	23.1															
Generation																7.7
Genesis					12.6	7.3				24.6				5.2	9.0	
Granada	21.4	22.6														
Hallmark						12.5	8.5			31.3					8.8	21.1
Haymaker	18.4	21.1														
Haymaker II		19.1														
Hunter River	11.7	6.7	18.2	6.9		8.7	4.5			27.9			23.5			
Hunterfield		8.9														
Matador	20.4	25.6														
Maxidor I	16.6															
Maxidor II	20.6	25.9														
Megluce I	19.4															
Megluce II	17.1															
Nova	22.1															
Pioneer 532	16.7															
Pioneer 555	16.0															
Pioneer 577	20.7															
Pioneer 581	23.4	22.0	32.6													
Pioneer 5929								4.1								
Pioneer L34HQ								3.2					20.3			
Pioneer L52					14.0			6.9								
Pioneer 54Q53													22.6			
Pioneer L55													16.6		11.6	
Pioneer L56																
Pioneer L69						7.6		5.6								
Pioneer L90													11.2		8.2	

Cultivar	Persistence															
	1981[1]	1982[1]	1984	1986	1989	1993	1995[2]	1995[3]	1996	1997	1998	1999	2000	2001	2003	2005
Quadrella					12.9	10.5										
Queensland 11														6.2		
Rippa										13.3						
Sapphire			28.1													
SARDI 5																31.2
SARDI 7															8.7	
SARDI 10															11.7	9.6
Sceptre				15.7	11.5	12.7	4.5					19.3	14.1			
Sequel		26.5	34.6	26.3	15.5	12.6	4.9			28.6			12.6		5.6	11.3
Sequel HR						9.5	3.4						16.6			
Sheffield	14.7															
Siriver	22.8															
Siro Peruvian		17.6														
Sirosal				14.7	5.2											
Siro Tasman	15.2															
Springfield	21.9															
Stargrazer	20.9															
Trifecta	25.7	26.0	36.9	15.4	10.1	12.9	5.5		9.3	31.8	26.5	24.2	18.7		8.7	20.5
UC Cibola	34.9															
UQL-1										34.8	27.8		16.3			13.6
Validor	25.5															
Venus														6.6		13.7
Wakefield	16.3															
WL 320				14.1												
WL 515	18.1															
WL 516				20.5					8.2							
WL 525																
WL 605				17.4												
WL Southern Special				10.8												
Best exp.[4]	39.0	26.5	34.6	28.9	15.0	15.0	7.0	-	10.8	26.1	19.3	30.8	18.3	8.8	14.0	21.6
Worst exp.	7.6	18.3	21.8	12.8	7.3	6.4	3.3	-	5.8	16.9	6.2	8.9	11.2	4.0	8.6	2.2
General mean	20.8	20.7	28.9	18.6	10.7	10.0	4.7	4.9	8.0	23.6	17.3	20.4	16.2	6.4	9.7	14.5
LSD (P=0.05)	8.0	4.6	9.1	9.8	4.4	4.4	1.2	1.2	1.4	7.0	8.1	4.7	4.5	ns	ns	7.3

[1] Data reproduced from Lowe *et al.* (1987a).

[2,3] Different experiments conducted in the same year.

[4] Best experimental line.

Australian races of the diseases before release. Generally, the highly winter-active or winter-active cultivars produced the highest yields in this subtropical environment in agreement with other data collected in Australia (Humphries *et al.* 2008; Irwin *et al*. 2008), although they did not always persist as well as less winter-active material (Humphries *et al.* 2008; Boschma and Williams 2008).

Total yield

The average production of the best cultivars (60–64 t/ha over a 3-year period) was similar to that reported in central Queensland by Cameron and Mullaly (1972) and central and southern Queensland (Lowe *et al.* 1985; 1987a) and greater than that reported in southern states (Gault *et al.* 1995). The decline in yield from 21 t/ha in the first and second years to 16 t/ha in the third year contrasted with the increase in yields over time recorded in more temperate areas (Gault *et al.* 1995; Kelly *et al.* 2006). This suggests fewer diseases, lower disease pressures and therefore fewer plant losses in temperate areas relative to subtropical conditions (Irwin 1977).

The proportion of total yield achieved in the third year is important, especially in a subtropical environment, where most stands do not persist longer than 3 years. Generally in this study, it was strongly related to persistence, few lines achieving more than 30%, with most highly winter-active cultivars below 28%. Such a measurement may be less important in temperate regions, where plants survive longer than 3 years (Irwin *et al.* 2001).

Seasonal performance

Disease resistance is closely linked to the performance of a cultivar and it is often difficult to distinguish between its effect and that of winter activity level. For example, CUF 101 is as winter-active as Sequel but its performance is reduced by susceptibility to anthracnose. Hallmark has an activity level of only 8 but performs as well as Sequel HR and SARDI 10, which are rated 9+. In the subtropics, highly winter-active cultivars (8, 9 and 9+) perform well in all seasons. This has been demonstrated here and in a study of single crosses of disease-susceptible lucerne clones, which were sprayed to control diseases (Irwin *et al.* 2008). There was little evidence in our data of any compensatory improvement in summer yields from less winter-active cultivars. Humphries *et al.* (2008) recommended that lucerne growers continue to use highly winter-active cultivars in short-term (2–4 year) situations and our data agreed with this recommendation for lucerne grown under irrigation in the subtropics.

Disease

While field assessment of lucerne disease is less reliable than laboratory measurements, because it relies on severe epiphytotics which are rarely evenly distributed across a lucerne stand, our data generally agree with the assessments of Irwin (1974), Stovold and Francis (1988), Mackie and Irwin (1998) and Mackie *et al.* (2003). The differences between cultivars in field resistance were greater for PRR than for anthracnose and the leaf disease complex, which agrees with the above research. The lack of field data on many of the newer cultivars is a limitation of this data set because epiphytotics did not occur from 2000 to 2006, owing to very dry conditions. Under such conditions, yield differences between susceptible and resistant cultivars are much smaller, as demonstrated by the performance of the PRR-susceptible line, Hunter River. Under minimal (2000) and moderate to high (1981–1993) disease pressure, it yielded 96.5 and 65.7%, respectively, of that of Trifecta. Generally, the data show that cultivars subjected to disease pressures during their breeding and selection carry more resistance; for example, Trifecta has resistance to PRR and CCR, Sequel and Sceptre to PRR and Quadrella to the leaf disease complex. However, some appear to have acquired resistance through natural selection pressures, *i.e.,* the resistance of Hunter River to anthracnose (Gramshaw *et al.* 1985) and the leaf disease complex (demonstrated from our data), although it is susceptible to CCR (Irwin *et al.* 1980; Mackie and Irwin 1998). Differences in susceptibility to the leaf disease complex may be related to differential infection levels of the 2 diseases at the time of assessment; Quadrella was selected for resistance to stemphylium leaf spot and not to pepper spot (*Leptosphaerulina trifolii*) (Bray and Irwin 1992).

Other factors can indiscriminately affect the performance of lucerne in the subtropics. While lucerne aphids (*Therioaphis trifolii, Acyrthosiphon kondai* and *A. pisum*), leaf roller (*Merroophyas divulsana*) and jassids did not cause major damage or were controlled by spraying, the poorer performances in 1995 and 2005 were the result of white fringe weevil (*Graphognathus leucoloma*) attack, which affected all entries and for which there was no effective control measure. Loss of most taproots resulted in little top growth following the attacks, although persistence was less affected as adventitious roots replaced taproots.

Persistence

Persistence is dependent on disease incidence and environmental conditions (abiotic stress) as well as activity level (Irwin 1977; Lowe *et al.* 1985; Humphries *et al.* 2008). The environmental effect is explained in our study by the variation between years, in both the general mean and the performance of standard cultivars like Trifecta (Table 6). In the worst year (1995), only 4.7% of the initial population survived for 3 years, which equated to around 16 plants/m^2, and, in the best year (1984), 28.9% survived, equivalent to 55 plants/m^2. Although soils at the experimental site were classified as black earths, there was some variation in clay content from site to site and this was reflected in the incidence of phytophthora root rot. The best performance in 1984 was on the lightest soil, in which there was little root disease.

The level of persistence after 3 years was similar to experiences in other parts of Queensland (Cameron and Mullaly 1972; Gramshaw 1978) and southern Australia (Humphries *et al.* 2008). In most cases, the final population was about 20–40 plants/m^2, suggested by Palmer and Wynn-Williams (1976) and Gramshaw (1978) as the minimum required before yield loss could be expected. Cultivars with good resistance to CCR and PRR were most persistent in this subtropical environment. While cultivars with low activity levels have normally been the most persistent in other environments (Gramshaw 1978; Boschma and Williams 2008; Humphries *et al.* 2008), this was not evident under irrigated subtropical conditions. Queensland-bred and tested cultivars were generally the most persistent in this environment, although, in single experiments, cultivars with lower activity levels tended to show better persistence as in other regions. Cultivars such as Trifecta, Sequel, Hallmark, Sequel HR and UQL-1 (activity levels 7, 9, 8, 9+ and 7, respectively), demonstrated good resistance to CCR and PRR, and appeared to also have added resistance to unidentified factors in this environment. Irwin (1977) and Irwin *et al.* (2004) suggested that other root or crown diseases were present in eastern Australia and these cultivars may inadvertently have been subjected to selection pressures for these factors during field evaluation in their development. One such disease is aphanomyces root rot (*Aphanomyces euthices*), known to be present here (Othieno Abbo and Irwin 1990) and a major issue in the USA (Delwiche *et al.*1987).

Techniques for evaluating lucerne under subtropical conditions

The long-term performance of lucerne under subtropical conditions could not be reliably predicted from our interrogation of factors affecting 3-year yield and persistence. However, the influence of lucerne diseases (Irwin 1977) was strong; for the years between 1981and 1995 when we have PRR rankings, PRR explained 69.7% of the variation in the 3-year yield. CCR and the leaf disease complex ratings influenced persistence more strongly than yield (38.5 and 19.1%, respectively). This agreed with research on American cultivars in Australia, which suggested that disease had the greatest effect on persistence (Lowe *et al*. 1985). Aphids played no significant role in the health of these aphid-resistant lucerne cultivars.

Future development of lucerne cultivars

The performance of material from the gene pool used to develop the current Queensland cultivars appears to have reached a plateau with the performance of Sequel, and only very modest gains have been made with the more recently released cultivars. While UQL-1 has a very different genetic background from Trifecta and Sequel, containing significant levels of *M. sativa* ssp. *falcata* in its genetic background (Irwin 2000), it has not produced dramatic yield increases over Trifecta and Sequel, as occurred when those cultivars replaced Hunter River. However, to date, we have utilised in Australian breeding programs only a relatively small component of the world genetic variation that exists in lucerne (Irwin *et al*. 2001).

Molecular genetics must play a role in the future improvement of lucerne, with DNA markers linked to disease resistance and yield already identified in Queensland-adapted material (Musial *et al.* 2005; 2006). We have worked with the introgression of genes of *M. sativa* ssp. *falcata* into *M. sativa* ssp. *sativa* (Mackie *et al.* 2005) and single cross hybrids of *M. sativa* ssp. *falcata* and *M. sativa* ssp. *sativa* (Irwin *et al.* 2008) with moderate levels of heterosis being obtained. While *M. sativa* ssp. *falcata* genes may have the potential to increase lucerne productivity in this region, substantial breeding and selection will be needed to achieve this. Such material is more likely to have a role in dryland grazing situations than under irrigation, where biomass production is the major goal. Work is now in progress with crosses between Queensland-bred material and highly winter-active lucerne material from Middle-eastern countries and *M. arborea* (Irwin *et al*. 2008; Armour *et al*. 2008)**.** These crosses are showing considerable improvement (25% greater than Sequel) in yield, although they have large stems, poor leaf:stem ratios and few branches per crown. With further breeding, it should be possible to improve this material to create gains equivalent to those achieved by Sequel over Hunter River.

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References

ANON (2007) *Standard tests to characterise alfalfa cultivars*. 3rd Edn. (Amended 2004). http://www.naaic.org/stdtests/index.html. Accessed 28/9/2007. (North American Alfalfa Improvement Conference: Oklahoma, USA)

ARMOUR, D.J., MACKIE, J.M., MUSIAL, J.M. and IRWIN, J.A.G. (2008) Transfer of anthracnose resistance and pod coiling traits from *Medicago arborea* to *M. sativa* by sexual reproduction. *Theoretical Applied Genetics*, **117,** 149–156.

BOSCHMA, S.P. and WILLIAMS, R.W. (2008) Using morphological traits to identify persistent lucernes for dryland agriculture in NSW, Australia. *Australian Journal of Agricultural Research,* **59**, 69–79.

BRAY, R.A. and IRWIN, J.A.G. (1992) Register of Australian herbage plant cultivars. b. Legumes 8. Lucerne (a) *Medicago sativa* L. (lucerne) cv. Quadrella. *Australian Journal of Experimental Agriculture,* **32**, 263.

BRAY, R.A. and IRWIN, J.A.G. (1998) Register of Australian herbage plant cultivars. b. Legumes 8. Lucerne (a) *Medicago sativa* L. (lucerne) cv. Sequel HR. *Australian Journal of Experimental Agriculture,* **38**, 209.

BRAY, R.A. and IRWIN, J.A.G. (1999) Register of Australian herbage plant cultivars. b. Legumes 8. Lucerne (a) *Medicago sativa* L. (lucerne) cv. Hallmark. *Australian Journal of Experimental Agriculture,* **39**, 643–644.

CAMERON, D.G. and MULLALY, J.D. (1972) The performance of lucerne (*Medicago sativa*) lines in pure stands under irrigated and raingrown conditions in sub-coastal central Queensland. *Australian Journal of Experimental Agriculture,* **12**, 646–652.

DELWICHE, P.A., GRAU, C.R., HOLUB, E.B. and PERRY, J.B. (1987) Characterization of *Aphanomyces eutiches* isolates recovered from alfalfa in Wisconsin. *Plant Disease*, **71**, 155–161.

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

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

GAULT, R.R., PEOPLES, M.B., TURNER, G.L., LILLEY, D.M., BROCKWELL, J. and BERGERSEN, F.J. (1995) Nitrogen fixation by irrigated lucerne during the first three years after establishment. *Australian Journal of Agricultural Research,* **46**, 1401–1425.

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.*

GRAMSHAW, D., LANGDON, P.W., LOWE, K.F. and LLOYD, D.L. (1985) Performance of North American and Australian lucernes in the Queensland subtropics. 1. Field reaction to important root and crown diseases. *Australian Journal of Experimental Agriculture,* **25**, 76–81.

HUMPHRIES, A.W., ZHANG, X.G., MCDONALD, K.S., LATTA, R.A. and AURICHT, G.C. (2008) Persistence of diverse lucerne (*Medicago sativa* sspp.) germplasm under farmer management across a range of soil types in southern Australia. *Australian Journal of Agricultural Research,* **59**, 139–148.

IRWIN, J.A.G. (1974) Crown rot of lucerne in Queensland caused by *Colletotrichum trifolii*. *Australian Journal of Experimental Agriculture and Animal Husbandry,* **14**, 197–200.

Irwin, J.A. (1977) Factors contributing to poor lucerne persistence in southern Queensland. *Australian Journal of Experimental Agriculture and Animal Husbandry,* **17**, 998–1003.

Irwin, J.A.G. (2000) UQL-1. *Plant Varieties Journal,* **13 (1)**, 41–42.

Irwin, J.A.G., Lloyd, D.L., Bray, R.A. and Langdon, P.W. (1980) Selection for resistance to *Colletotrichum trifolii* in the lucerne cultivars Hunter River and Siro Peruvian. *Australian Journal of Experimental Agriculture and Animal Husbandry,* **20**, 447–451.

Irwin, J.A.G., Lloyd, D.L. and Lowe, K.F. (2001) Lucerne biology and genetic improvement - an analysis of past activities and future goals in Australia. *Australian Journal of Agricultural Research,* **52**, 699–712.

Irwin, J.A.G., Mackie, J.M., Marney, T.S., Musial, J.M. and Roberts, S. (2004) Incidence of *Stagonospora meliloti* and *Acrocalymma medicaginis* in lucerne crowns and roots in eastern Australia, their comparative aggressiveness to lucerne and inheritance of reaction to *S. meliloti* in lucerne. *Australasian Plant Pathology,* **33**, 61–67.

Irwin, J.A.G., Pepper, P.M., Armour, D., Mackie, J.M. and Lowe, K.F. (2008) Use of single cross hybrids to measure heterosis for yield in diverse lucerne genotypes growing in a subtropical environment. *Australian Journal of Agricultural Research,* **59**, 999–1009.

Kelly, K.B., Stockdale, C.R. and Mason, W.K. (2006) The productivity of irrigated legumes in northern Victoria. 1. Effect of irrigation interval. *Australian Journal of Experimental Agriculture,* **45**, 1567–1576.

Kobelt, E. (1997) Sceptre. *Plant Varieties Journal,* **10 (2)**, 57.

Kobelt, E. (2002) SARDI Seven. *Plant Varieties Journal,* **15 (2)**, 43–45.

Kobelt, E. (2006) SARDI Ten. *Plant Varieties Journal,* **19 (3)**, 188–194.

Kobelt, E. and Humphries, A.W. (2007) SARDI Five. *Plant Varieties Journal,* **20 (1)**, 254–259.

Lloyd, D.L., Gramshaw, D., Hilder, T.B., Ludke, D.H. and Turner, J.W. (1985) Performance of North American and Australian lucernes in the Queensland subtropics. 3. Yield, plant survival and aphid populations in raingrown stands. *Australian Journal of Experimental Agriculture,* **25**, 91–99.

Lowe, K.F., Gramshaw, D., Bowdler, T.M. and Ludke, D.H. (1985) Performance of North American and Australian lucernes in the Queensland subtropics 2. Yield and plant survival in irrigated stands. *Australian Journal of Experimental Agriculture,* **25**, 82–90.

Lowe, K.F., Gramshaw, D., Bowdler, T.M., Clem, R.L. and Collyer, B.G. (1987a) Yield, persistence and field disease assessment of lucerne cultivars and lines under irrigation in the Queensland sub-tropics. *Tropical Grasslands,* **21**, 168–181.

Lowe, K.F., Langdon, P.W. and Bowdler, T.M. (1987b) Combined effects of leaf spot diseases caused by *Stemphylium vesicarium* (Wallr.) Simmons and *Leptosphaerulina trifolii* (Rostr.) Petr. on lucerne cultivars, and the efficacy of some fungicidal control methods. *Australian Journal of Experimental Agriculture,* **27**, 59–65.

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

Lowe, K.F., Bowdler, T.M., Casey, N.D., Lowe, S.A., White, J.A. and Pepper, P.M. (2008) Evaluating temperate species in the subtropics. 2. Perennial grasses. *Tropical Grasslands,* **42**, 1–27.

Mackie, J.M. and Irwin, J.A.G. (1998) The proportion of individual lucerne plants resistant to *Phytophthora medicaginis* and *Colletotrichum trifolii* in Australian cultivars. *Australian Journal of Experimental Agriculture,* **38**, 41–44.

Mackie, J.M., Musial, J.M., O'Neill, N.R. and Irwin, J.A.G. (2003) Pathogenic specialisation within *Colletotrichum trifolii* in Australia, and lucerne cultivar reactions to all known Australian pathotypes. *Australian Journal of Agricultural Research,* **54**, 829–833.

Mackie, J.M., Pepper, P.M., Lowe, K.F., Musial, J.M. and Irwin, J.A.G. (2005) Potential to increase yield in lucerne (*Medicago sativa* subsp. *sativa*) through introgression of *Medicago sativa* subsp. *falcata* into Australian adapted material. *Australian Journal of Agricultural Research,* **56**, 1365–1372.

Musial, J.M., Aitken, K.S., Mackie, J.M. and Irwin, J.A.G. (2005) A genetic linkage map in autotetraploid lucerne adapted to northern Australia, and the use of the map to identify DNA markers linked to resistance to *Phytophthora megicaginis. Australian Journal of Agricultural Research,* **56**, 333–344.

Musial, J.M., Lowe, K.F., Mackie, J.M., Aitken, K.S. and Irwin, J.A.G. (2006) DNA Markers linked to yield, yield components, and morphological traits in autotetraploid lucerne (*Medicago sativa* L.). *Australian Journal of Agricultural Research,* **57**, 801–810.

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

Oram, R.N. (1990) *Register of Australian herbage plant cultivars*. (CSIRO: Melbourne, Australia).

Othieno Abbo, E. and Irwin, J.A.G. (1990) *Aphanomyces eutiches*, a possible cause of poor lucerne establishment in Queensland. *Australian Journal of Experimental Agriculture,* **30**, 361–364.

Palmer, T.P. and Wynn-Williams, R.B. (1976) Relationships between density and yield of lucerne. *New Zealand Journal of Experimental Agriculture,* **10**, 71–77.

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).

Peace, C. (2007) Australian fodder production by year. In: (Copyright © 2002 Australian Fodder Industry Association Inc. http://www.afia.org.au/information/statistics/, Updated 1 March 2005, Accessed 28/9/2007)

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)

Stovold, G.E. and Francis, A. (1988) Incidence of *Colletotrichum trifolii* on lucerne in New South Wales, its host range and reaction of lucerne cultivars to inoculation. *Australian Journal of Experimental Agriculture,* **28**, 203–210.

Waterhouse, D.B., Williams, R.W. and Oram, R.N. (1993) Register of Australian Herbage Plant cultivars. b. Legumes 8. Lucerne (a) *Medicago sativa* L. (lucerne) cv. Aquarius. *Australian Journal of Experimental Agriculture,* **33**, 257–258.

Williams, R.W. (2003) Venus. *Plant Varieties Journal,* **16 (3)**, 43–45.

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