Production and persistence of temperate perennial grasses and legumes at five saline sites in southern Australia

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Short title: Perennial legumes and grasses on saline land

Abstract. Herbage production and persistence of 24 perennial legumes from 20 species and 19 perennial grasses from 10 species were measured at 5 sites across southern Australia that differed in annual rainfall and extent of salinity and waterlogging. Strawberry clover (*Trifolium fragiferum* L.), *Lotus uliginosis* Schkuhr, *L. tenuis* Waldst. & Kit. ex Willd., *L. corniculatus* L. and tall wheatgrass (*Thinopyrum ponticum* (Podp.) Z.-W. Liu & R.-C. Wang) were the most productive and persistent at Cranbrook, Western Australia (WA), a site with occasional waterlogging and a summer EC_e of 6.9 dS/m in the surface 10 cm, while phalaris (*Phalaris aquatica* L.), tall wheatgrass, perennial ryegrass (*Lolium perenne* L.) and sulla (*Hedysarum coronarium* L.) were the best performers at Girgarre, Victoria, another site with occasional waterlogging and a summer EC_e of 8.0 dS/m. At Duranillin (WA) and Keith (South Australia), which both experienced extensive winter waterlogging and had summer $EC_e > 30$ dS/m, puccinellia (*Puccinellia ciliata* Bor) and tall wheatgrass were the only species that persisted. No perennial grasses or legumes were persistent or productive at Tammin (WA), the lowest rainfall site (330 mm mean annual rainfall) with summer EC_e of 10.9 dS/m. Genetic variation for adaptation to saline soils was observed for several species, suggesting opportunities to develop better adapted cultivars.

Additional keywords: waterlogging, establishment, biomass, plant evaluation, plant breeding

Introduction

The clearing of deep-rooted native perennial vegetation for agriculture and the subsequent rise of water-tables has resulted in large areas of southern Australia being seriously affected by dryland salinity. Currently 5.7 million hectares of agricultural land in Australia are estimated to be affected by dryland salinity or at risk from shallow water-tables, with this area expected

1 to rise to 17 million hectares by 2050 (Dolling *et al.* 2001). The presence of shallow water-
2 tables in many areas affected by dryland salinity can result in additional plant stresses, due to
3 waterlogging and inundation during the winter months (Barrett-Lennard 2003a). Saline lands
4 also tend to have high spatial variability for salinity, which can vary up to 10-fold within a
5 square metre (Semple *et al.* 2003; Rogers *et al.* 2005; Nichols *et al.* 2007 this issue).

6 Salt-tolerant grasses can form an important component of saltland pastures, either on
7 their own, or as under-storey species with saltbush (*Atriplex* species) or bluebush (*Maireana*
8 species) (Barrett-Lennard 2003b). Saline landscapes are generally infertile, due to nitrogen
9 deficiency resulting from denitrification and the lack of a legume base (Rogers *et al.* 2005).
10 Identification of legumes that can increase the supply of nitrogen to salt tolerant grasses, and
11 hence increase their nutritive value to livestock, is a high priority (Dear *et al.* 2003; Dear and
12 Ewing 2007 this issue). Nichols *et al.* (2007 this issue) report on the field performance of a
13 range of annual legumes at saline sites in southern Australia. Perennial legumes and grasses
14 have the potential advantages over annuals of providing out-of-season feed, increasing
15 carrying capacity and reducing the need for supplementary feeding in autumn (Moore 2006a).

16 Several glasshouse studies have identified differences in salinity tolerance between
17 perennial pasture plants (Russell 1976; Kapulnik *et al.* 1989; Schachtman and Kelman 1991;
18 Rumbaugh *et al.* 1993; Rogers *et al.* 1996, 2006, 2007; Downes 2000; Peel *et al.* 2004; Zhang
19 *et al.* 2005). However, there is no quantitative information directly linking the impacts of
20 salinity and waterlogging to plant growth and agronomic performance (Barrett-Lennard
21 2003b). Two studies describe the field performance of perennial grasses and legumes on
22 saline land in southern Australia. Rogers and Bailey (1963) published salinity tolerance
23 ratings for a range of forage legumes and grasses based on observations at one field site in
24 Western Australia (WA), but presented no data to support their claims. Semple *et al.* (2003)
25 related plant height and persistence of 30 perennial grasses to soil characteristics at 6 high

rainfall saline sites (EC_e range 4.3 - 52.2) in New South Wales (NSW), but did not measure herbage production. There is clearly a need for quantitative information on field performance of pasture plants on saline sites to enable farmers to make better informed choices.

Of the temperate perennial grasses studied to date, puccinellia (*Puccinellia ciliata* Bor) and tall wheatgrass (*Thinopyrum ponticum* (Podp.) Z.-W. Liu & R.-C. Wang) have the highest salinity tolerance, able to grow in soils with EC_e levels up to 40 dS/m (Nichols 1998; Semple *et al.* 2003), with the former also tolerating brief periods of inundation (Barrett-Lennard 2003b). Zhang *et al.* (2005) showed that salinity tolerance of seedlings was greater in tall wheatgrass, with the concentrations for a 50% reduction of the germination rates in distilled water being 179, 301 and 297 mmol/L NaCl for Menemen puccinellia, Tyrell tall wheatgrass and Dundas tall wheatgrass, respectively. Both grasses have been widely promoted for saline land (Barrett-Lennard, 2003b) and optimal management conditions are understood (Nichols 1998), although some concerns have been expressed about the weed potential of tall wheatgrass (Virtue and Melland 2003).

Rogers and Bailey (1963) considered perennial ryegrass (*Lolium perenne* L.), *Puccinellia distans* (Jacq.) Parl. and annual ryegrass (*Lolium rigidum* Gaudin) as being moderately tolerant of salinity, while Oram *et al.* (2002) and Semple *et al.* (2003) suggested that phalaris (*Phalaris aquatica* L.) and tall fescue (*Festuca arundinacea* Schreb.) may have a role to play in mildly salinised land. A phalaris population derived from a hybrid between a Na^+ -excluding accession of *P. aquatica* and a waterlogging tolerant *P. arundinacea* L. population performed better than other phalaris lines and was no different to tall wheatgrass on a low-moderately saline gradient (EC_e 0.7 – 5.2) in southern NSW (Oram *et al.* 2002). Rogers *et al.* (1996) and Rogers (2007) also suggest that the native Australian wallaby grass (*Austrodanthonia richardsonii* (Cashmore) HP Lindner) may have some salt tolerance.

1 Lucerne (*Medicago sativa* L.) is the most widely sown perennial legume in Australia,
2 performing best on well-drained, neutral to alkaline soils (Cocks 2001; Dear *et al.* 2003).
3 Russell (1976) reported a 50% decrease in growth at EC_e values of 8.8 - 10.2 dS/m, placing it
4 in the moderately sensitive category of Maas and Hoffman (1977). Lucerne is very sensitive
5 to waterlogging, limiting its use on many soils affected by dryland salinity. Real *et al.* (2007
6 this issue) showed a mean daily growth rate of 7% of a drained control, following 6 weeks of
7 inundation, while Rogers *et al.* (2006) showed a growth reduction, relative to aerated controls,
8 of 69% after 4 weeks in stagnant water.

9 Strawberry clover (*Trifolium fragiferum* L.) has a lower salinity tolerance (Russell
10 1976; Rogers *et al.* 1997, 2006), but greater waterlogging tolerance (Rogers and West 1993;
11 Rogers *et al.* 2006), than lucerne. It has been widely sown in poorly drained high rainfall
12 areas (Dear *et al.* 2003; McDonald *et al.* 2005) and in irrigation areas prone to waterlogging
13 that are too saline for white clover (*T. repens*) (Rogers *et al.* 1997). Rogers and Bailey (1963),
14 however, were unable to establish stands of strawberry clover from seed under the salinity and
15 waterlogging conditions of their experimental site.

16 Real *et al.* (2007 this issue) demonstrated high waterlogging tolerance of *Lotus tenuis*
17 Waldst. & Kit. ex Willd., *L. corniculatus* L. and *L. uliginosis* Schkuhr, with 44 – 109% mean
18 daily growth rates of drained controls following 6 weeks of inundation. Schachtman and
19 Kelman (1991) found *L. tenuis* and *L. corniculatus* to have similar or greater salinity tolerance
20 than lucerne, on the basis of growth reductions at 120 mol/m³ NaCl, while *Lotus uliginosis*
21 had a greater reduction. Recently Teakle *et al.* (2007) demonstrated greater tolerance of *L.*
22 *tenuis* than *L. corniculatus* to the interactive effects of salinity and waterlogging. Among
23 other perennial legumes, Le Houérou (1986) suggested that sulla (*Hedysarum coronarium* L.)
24 and *H. carnosum* Desf. have salt tolerance. Rogers *et al.* (2006) also showed that several

members of the *Melilotus* genus had similar waterlogging tolerance to strawberry clover and greater salinity tolerance than lucerne.

Farmers have become increasingly interested in improving the productivity of salt-affected land (Barrett-Lennard 2003b), while O'Connell *et al.* (2005) have demonstrated positive economic outcomes from incorporating saltland pastures into a farming system. In view of this interest and the paucity of field data on the comparative performance of grasses and legumes on saline land, a series of experiments was established as an initiative of the Cooperative Research Centre for Plant-based Management of Dryland Salinity (Dear and Ewing 2007 this issue). This paper details the herbage production and persistence of a range of commercially available and experimental temperate perennial grasses and legumes at 5 saline sites across southern Australia. A companion paper (Nichols *et al.* 2007 this issue) reports the results for annual legumes at the same sites, while another paper (Boschma *et al.* 2007 this issue) discusses the performance of legumes and grasses in the summer-dominant rainfall environment of northern NSW.

Materials and methods

Experimental locations

Experiments were located adjacent to the annual legume experiments at the 5 sites described in Nichols *et al.* (2007 this issue). Site details and general soil descriptions are given in Table 1. Four sites were sown in 2003, comprising Tammin (4 km NW of Tammin) and Duranillin (26 km S of Darkan) in WA, Keith (17 km W of Keith) in South Australia and Girgarre (3 km N of Girgarre) in Victoria. An additional site was sown in 2004 at Cranbrook (40 km NW of Cranbrook), WA. Mean annual rainfall is 330 mm at Tammin, 450 mm at Girgarre, 465 mm at Keith and 530 mm at both Duranillin and Cranbrook. Using the broad categories of Rogers *et al.* (2005), Duranillin, Keith and Tammin were highly saline in summer ($EC_e > 8$ dS/m),

1 while Cranbrook and Girgarre were moderately saline (EC_e 4 - 8 dS/m). However, in winter
2 Duranillin had moderate salinity, Tammin and Cranbrook had low salinity (EC_e 2 - 4 dS/m)
3 and Girgarre and Keith were non-saline ($EC_e < 2$ dS/m). Additional site information is given
4 in Nichols *et al.* (2007 this issue).

5 Insert Table 1 near here

7 *Species evaluated*

8 Twenty four perennial legumes from 21 species (Table 2) and 19 perennial grasses from 11
9 species (Table 3) were evaluated. Entries consisted of either single genotypes or composites
10 of 2 - 4 genotypes mixed in equal proportions. For simplicity, composites of genotypes are
11 referred to by the species name in the text, while single genotypes are referred to by species
12 and genotype name. Species were selected either on the basis of purported salinity tolerance
13 (Rogers *et al.* 2005) or on the basis of being new or important pasture cultivars used in
14 southern Australian agriculture for which little or no information on relative salinity tolerance
15 was known.

16 The same seed source was used for all experiments. Seeds of most legumes were
17 obtained from the Australian Medicago Genetic Resource Centre, operated by the South
18 Australian Research and Development Institute, while the grasses and the white clover
19 (*Trifolium repens* L.) composite were obtained from the Department of Primary Industries
20 Victoria. Seeds were tested for viability and sowing rates were adjusted to ensure an
21 equivalent of at least 80% germinability. Legume seeds were slurry inoculated immediately
22 prior to sowing with the appropriate strain of *Rhizobium*, where known, or with a mixture of
23 best-bet strains.

24 Insert Tables 2 and 3 near here

Some species (identified in Tables 2 and 3) that were included in this study are now prohibited from general importation into Australia or from specific importation into Western Australia. At the commencement of the evaluation program, these species were already held in Australian Genetic Resource Centre collections and were available for evaluation under regulations existing at the time. New protocols subsequently developed by the CRC for Plant-based Management of Dryland Salinity (Stone 2007 this issue) will ensure distributions of these species will not occur in the future.

Perennial legumes. Four perennial legumes, comprising *H. carnosum*, lucerne cv. Salado, *L. tenuis* and strawberry clover cv. Palestine, were sown at all 5 sites (Table 2). Sulla, consisting of either a strain from Lake Grace, WA or the accession SA26218, was sown at 4 sites. *Lotus creticus* L., *L. corniculatus* (birdsfoot trefoil), consisting either of cv. Goldie or a composite, and *L. uliginosus*, consisting either of cv. Maku or a composite, were sown at 3 sites. Other species and genotypes of local interest were sown at each site, while at Keith 8 perennial *Melilotus* species were sown as part of a wider examination of the genus.

Perennial grasses. Four common species (tall wheatgrass cultivars Dundas and Tyrell, puccinellia cv. Menemen and phalaris cv. Sirolan) were sown at each site (Table 3). *Dactylis marina* Borrill accessions PI229472 and PI237604 were sown at 4 sites, while perennial ryegrass, consisting of either cv. Victorian or one of the accessions PI170521, PI197270 and PI201185, was sown at 3 sites. Other species and genotypes of local interest were sown at each site.

Experimental design and management

Grasses and legumes were sown as separate experiments at each site, in order to apply appropriate herbicide and management treatments. Experimental designs and management were the same as described in Nichols *et al.* (2007 this issue). Each experiment consisted of a

row-column design with 5 replicates. Plot dimensions at Tammin, Duranillin, Girgarre and Keith were 2 m x 1 m, with 1.5 m buffers between plots, while at Cranbrook they were 5 m x 2 m with no buffer strips between plots.

The Cranbrook and Girgarre plots were drilled in by cone seeder, while seeds at the other sites were hand broadcast onto plots and lightly raked. Sowing dates were 20 May (Duranillin), 27 May (Tammin), 5 June (Girgarre) and 24 June (Keith) in 2003 and 10 June (Cranbrook) in 2004. A standard sowing rate of 10 kg/ha was used for all species. Site preparation, general maintenance and insect and weed control were by and large the same as for the adjacent annual legume experiments described in Nichols *et al.* (2007 this issue). However, the grass experiments had some different treatments to the legumes. At Keith, trifluralin (480 g a.i./L) was applied pre-sowing and incorporated into the perennial legume experiment at a rate of 1.5 L/ha. Broadleaf weeds in the grass plots at Girgarre were controlled using dicamba (200 g a.i./L). No herbicides were available to remove grass weeds from perennial grasses, resulting in poor weed control of annual grasses in the grass plots at Tammin and Cranbrook. Urea was applied at a rate of 200 kg/ha to grass plots at Tammin in winter each year, but not at Duranillin, Cranbrook or Girgarre.

Plots remained undefoliated during each autumn-spring period but were generally grazed by sheep each summer. The Girgarre site, however, remained ungrazed while the Cranbrook site was ungrazed over the second summer. There was generally little growth of consequence at any site over the summer- early autumn periods.

Plant measurements

Plant establishment was determined by counting the number of emerged seedlings in random quadrats 4 - 6 weeks after sowing. Densities of any regenerating seedlings were measured in early winter of each year 4 - 6 weeks after the opening rains to the season, using the methods

of Nichols *et al.* (2007 this issue). Spring biomass production of sown species was estimated using the methodology of Nichols *et al.* (2007 this issue). First year biomass was measured on legume plots at Tammin, Keith, Cranbrook, Duranillin and Girgarre on 18 Sept., 17 Oct., 19 Oct., 20 Oct. and 23 Oct., respectively, while grass plots were only measured at Tammin and Cranbrook. Second year biomass of both legumes and grasses was measured on 23 Aug., 21 Sept. and 19 Oct. at Cranbrook, Tammin and Girgarre, respectively, while grasses were also measured at Duranillin on 16 Sept. Third year grass biomass was measured on 16 Sept. at Duranillin and 19 Sept. at Tammin. Separate calibrations were made for legumes and grasses for each assessment. Third year non-calibrated visual biomass ratings, using a 0 - 10 scale, were also conducted on grasses at Girgarre on 10 Oct.

Persistence was monitored in the second and third winters using a single permanent quadrat (0.5 m x 0.5 m, divided into 10 cm x 10 cm squares) in each plot. Quadrat positions were selected as the area in each plot with the best establishment. Persistence was measured in terms of plant frequency, by counting the presence or absence of live crown material in individual grid squares, expressed as a percentage of the total number of squares. In year 2, frequency measurements were conducted on perennial legumes and grasses at Cranbrook, Tammin and Duranillin, on legumes at Girgarre and on grasses at Keith. Frequency counts in year 3 were conducted on perennial legumes and grasses at Cranbrook, Tammin and Duranillin. Third year non-calibrated density ratings, using a 0 - 10 scale, were also conducted on legumes at Girgarre on 10 Oct.

The plots at Keith were rated on 16 Sept. (11 weeks after sowing) for healthiness and survival, as a measure of waterlogging tolerance, following 7 weeks of inundation. EC_e levels of less than 2 dS/m during this period (Nichols *et al.* 2007 this issue) allowed this assessment to be conducted without major confounding effects of salinity. A graded scale of 0 - 5 was used for plant survival and health, where 0 = all plants dead and 5 = all plants green and

1 healthy. Scores for the presence and effectiveness of rhizobial nodulation were also made at
2 Keith on the same day. Two plants were randomly selected from each plot. Individual plants
3 were carefully dug up to avoid nodules being knocked off the roots and immediately washed
4 in water. The total root system was removed and scored for nodulation on the tap and lateral
5 roots using a 0 - 3 rating scale, where 0 = no nodules, 1 = small white nodules only, 2 = less
6 than 5 pink nodules and 3 = at least 5 pink nodules per plant.

7 *Data analysis*

9 Data analysis is described in Nichols *et al.* (2007 this issue). Following examination of
10 residuals of all measurements, the most appropriate transformations to stabilise the variance
11 were $\log_{10}$ for seedling density and herbage production data and square root for frequency
12 measurements. These conventions were also used by Li *et al.* (2007, this issue). In both cases,
13 the value 1 was added to the data prior to transformation. Transformations were not made for
14 nodulation and waterlogging tolerance ratings or for year 3 herbage production ratings at
15 Girgarre. Outliers which were more than 3 standard deviations from the mean were removed
16 from the data. This ranged from 0 - 3 measurements per variable at each site. For simplicity,
17 perennial legume performance is compared with Palestine strawberry clover and perennial
18 grasses are compared with Menemen puccinellia, unless otherwise stated. Raw data is also
19 presented to give biological meaning to the results.

20 In order to ascertain whether species success could be related to site differences,
21 Pearson correlations ($n = 5$) were conducted between mean plant measurements (transformed)
22 and either soil attributes (Table 1) or rainfall data (Table 3 from Nichols *et al.* 2007 this issue)
23 for species common to at least 4 sites. Five perennial legumes (*Hedysarum carnosum*, *Lotus*
24 *tenuis*, Salado lucerne, Palestine strawberry clover and sulla (Lake Grace and SA26218

combined)) and 6 perennial grasses (*Dactylis marina* P1229472 and PI237604, Dundas and Tyrell tall wheatgrasses, Sirolan phalaris and Menemen puccinellia) were examined.

All analyses were conducted using GENSTAT (9th edition). Analyses of Variance (ANOVA) and spatial analyses (using several models with REML) were attempted on transformed variables, with the latter analyses used to account for measurable trends or spatial variability within sites. As was the case with the annual legumes (Nichols *et al.* 2007 this issue), comparisons between species did not change substantially when using a spatial model compared with a simple randomised block model (with the terms Blocks = replicates and Treatment = species). Consequently, randomised block analyses are presented for all data. Least significant differences (l.s.d.s) at the 5% probability level were also calculated. Multiple zero values at a site were included in the analysis, even though it was recognised that this may artificially lower l.s.d.s.

Formal genotype x environment (G x E) analyses were not attempted. The purpose of such analyses is usually to identify genotypes adapted to a wide range of environments. In this case, the expectation was that sizeable G x E effects would occur, due to large differences in site characteristics and levels of salinity and waterlogging tolerances.

Results

Growing conditions

Long-term mean annual rainfall data are shown in Table 1, while rainfall recorded at each site during the experimental period is shown in Table 3 of Nichols *et al.* (2007 this issue). At Duranillin, the soil surface remained wet with extended periods of inundation from mid-June to mid-October in 2003 and 2004 and from early May to mid-October in 2005, while Keith was inundated in 2003 for 7 weeks from early August and for 3-4 weeks during winter and early spring in 2004 and 2005. At Cranbrook plots were waterlogged in August 2005,

including a 7 day period of inundation, but were free draining at other times, while waterlogging, with 7-10 day periods of inundation, occurred at Girgarre in late August in both 2004 and 2005. No inundation or surface waterlogging was apparent at Tammin. Further details of growing conditions during the experimental period are given in Nichols *et al.* (2007 this issue). Soil surface (0 - 10 cm) electrical conductivities in winter and summer are given in Table 1 and described in more detail in Nichols *et al.* (2007 this issue).

Perennial legumes

Establishment densities following sowing varied widely between sites and between species within sites (Table 4). No species established successfully at Duranillin, while densities were low at Tammin and Girgarre. Establishment of Palestine strawberry clover was among the best at each site, although sulla had better establishment at both Duranillin and Girgarre. Establishment densities of *L. tenuis* were similar to Palestine at all sites, while Salado lucerne had similar establishment densities to Palestine at Duranillin, Cranbrook and Girgarre, but lower densities at Tammin and Keith. *Hedysarum carnosum* densities were similar to Palestine at Tammin, Duranillin and Girgarre, but lower at Cranbrook and Keith. All other species, including all the perennial *Melilotus* species, had significantly poorer establishment than Palestine at Keith. Establishment densities of *Dorycnium graecum* (L.) Ser., *D. pentaphyllum* Scop., *L. creticus* and *L. cytisoides* L. were poor at Cranbrook, while those of *L. corniculatus* and *L. uliginosus* were no different to Palestine.

Insert Table 4 near here

Prolonged inundation during the first winter at Keith had a major impact on plant health and survival of all species, apart from *L. tenuis* (Table 5). Even Palestine strawberry clover, noted for its waterlogging tolerance (Rogers *et al.* 2006), suffered symptoms of stress

and 9 species were rated as significantly less healthy than it. Plant death occurred subsequently in all species, with the exception of *L. tenuis*, as a result of this inundation.

Most species appeared to have effective rhizobial nodulation (rating of at least 2) in the first spring at Keith (Table 5). However, *Melilotus polonicus* (L.) Pall. failed to form effective rhizobial symbioses. It needs to be noted that scoring for nodulation was difficult, as few plants survived the winter and consequently, the ratings can only be taken as indicative. The ratings for *H. carnosum* and *M. wolgicus* Poir., in particular, were only conducted on a single replicate and are likely to be over-estimates.

Insert Table 5 near here

Very little herbage was produced by the perennial legumes in the first spring at any site (Table 6). No perennial legumes, including *L. tenuis*, survived to mid-spring at Keith and only 4 survived at Duranillin. Sulla produced more than all other species at Duranillin and Girgarre, while *L. tenuis* was the only other species to produce significantly more herbage than zero at Duranillin. No other species produced more herbage than Palestine at any site, although production of Salado lucerne was similar. At Cranbrook, Palestine and Salado produced much more biomass than all other species. Where the 2 lucernes were compared, Sceptre produced more herbage than Salado at Tammin but not significantly more at Duranillin.

Insert Table 6 near here

No perennial legumes survived the first summer at Duranillin, while Sceptre lucerne and *L. tenuis* were the only species in the second year at Tammin with plant frequencies significantly greater than zero (Table 7). At Girgarre sulla had the highest frequency, with new seedling recruits contributing an additional 9 plants/m² (Table 7). Palestine strawberry

clover was the only other legume to have a plant frequency significantly greater than zero. Perennial legume frequencies were much higher at Cranbrook (Table 7). Here, Palestine strawberry clover and *L. tenuis* had the highest frequencies, while *L. uliginosus*, *L. corniculatus* and Salado lucerne also persisted.

Insert Table 7 near here

Mean herbage production of the perennial legumes in the second spring was modest at Cranbrook and Girgarre and very low at Tammin (Table 8). Some genotypes at Cranbrook, however, responded to the extended growing season and were very productive. Palestine strawberry clover and *L. uliginosus* produced more than 2.7 t/ha, while biomass production of *L. tenuis* and *L. corniculatus* was not significantly less. The inundation at Cranbrook resulted in a marked reduction in biomass production of Salado lucerne, relative to other species, although few plants died. At Girgarre sulla was the only species to produce more than 1 t/ha.

Insert Table 8 near here

Plant frequency declined markedly at Tammin by the third year, with all species having effectively disappeared (Table 9). By contrast, frequency of the most successful perennial legumes increased at Cranbrook from the previous year (Table 9). Palestine strawberry clover crowns occupied 89% of all grid squares, while the frequency of *L. uliginosus* was not significantly less. *Lotus tenuis*, *L. corniculatus* and Salado lucerne also persisted well, but at lower frequencies than Palestine, while frequencies of the other species declined to zero or very low levels. At Girgarre sulla had the highest frequency ratings, with lower ratings for Palestine and the other surviving plants (Table 9). Further observations at Girgarre indicated that sulla and *L. tenuis* were the most persistent species after 5 years (M. Rogers, data not presented).

Insert Table 9 near here

Perennial grasses

Mean grass establishment densities were low at Tammin, Duranillin and Girgarre and high at Keith and Cranbrook (Table 10). Density of Menemen puccinellia was lower than most species at Duranillin, Cranbrook and Girgarre, but was among the highest at Keith and Tammin. Densities of the 2 tall wheatgrass cultivars were significantly greater than Menemen at Duranillin and Girgarre, no different at Cranbrook and significantly lower at Tammin and Keith. Phalaris and perennial ryegrass at Cranbrook and Girgarre also established more densely than Menemen, while 2 of the 4 perennial ryegrasses (PI170521 and PI197270) at Keith had lower densities. No plants of *Dactylis marina* established at Duranillin, while establishment density was very low at Girgarre. The native Australian wallaby grass (*A. richardsonii*) cv. Hume also established poorly at Girgarre.

Insert Table 10 near here

Mean spring herbage production in the year of establishment was very low at all sites and was only measured at Tammin and Cranbrook (Table 11). At Tammin no grasses produced more than 340 kg/ha. At Cranbrook PI201185 perennial ryegrass produced the most biomass (1.5 t/ha), while Sirolan phalaris (1.0 t/ha) production was not significantly lower. Biomass production of all other species was less than 340 kg/ha. It is worth noting that herbage production of the perennial grasses at Tammin and Cranbrook was compromised by invasion of annual grasses, particularly annual ryegrass, which could not be controlled by herbicides. This was also the case in subsequent years. At Cranbrook this is likely to have inflated the first year biomass estimate for perennial ryegrass. In subsequent years perennial ryegrass was distinguishable from annual ryegrass.

1 Insert Table 11 near here

2
3 Few grasses persisted into the second year at any site, but there were major site
4 differences in those that did persist (Table 12). At the waterlogged and most saline sites of
5 Duranillin and Keith, Menemen puccinellia was the outstanding entry, with significantly
6 greater plant frequencies than all other species. Frequencies of Dundas and Tyrell tall
7 wheatgrasses were also high at Keith, but low at Duranillin. No other species survived at
8 Keith, and given this clear result, no further measurements were taken at this site. At
9 Cranbrook, Dundas and Tyrell tall wheatgrasses and Sirolan phalaris had significantly higher
10 frequencies than Menemen and all other species. Tammin plant frequencies for Fraydo tall
11 fescue and both tall wheatgrasses were similar to Menemen and lower for Sirolan phalaris,
12 while the other species did not persist.

13 Insert Table 12 near here

14
15 Mean biomass production in the second spring was very low at Duranillin, Tammin
16 and Cranbrook, with no species producing more than 0.5 t/ha at any site (Table 13). However,
17 at Girgarre Sirolan phalaris produced 8.5 t/ha, while production of Victorian perennial
18 ryegrass and the tall wheatgrasses, Tas1499 and Dundas, were not significantly less (Table
19 13). There were no differences between the 3 tall wheatgrass genotypes at Girgarre but there
20 were marked genotype differences for other species. In contrast to cv. Victorian, PI170521
21 perennial ryegrass disappeared from the site, while Sirolan phalaris produced more than 3
22 times that of cv. Australian and nearly 4 times more than the *Phalaris aquatica* x *P.*
23 *arundinacea* hybrid.

24 Insert Table 13 near here

Mean plant frequency into the third year declined from the previous year at Tammin (Table 14). There were no differences between Tyrell and Dundas tall wheatgrasses, Menemen puccinellia or Fraydo tall fescue, with Sirolan phalaris being the only other grass present. At Duranillin Menemen puccinellia frequency increased slightly, due to broader crown development, while Dundas and Tyrell tall wheatgrasses were the only other surviving grasses (Table 14). Mean plant frequencies of the 5 most frequent grasses at Cranbrook increased from the previous year (Table 14). For example, the frequency of Dundas (74%), the densest grass, was 2.6 times greater than the previous year, but was not significantly different to Tyrell, with both tall wheatgrasses having a higher frequency than Sirolan phalaris. Frequencies of Menemen and SA39293 puccinellias were lower, while *P. distans* disappeared from the experiment.

Insert Table 14 near here

Menemen puccinellia (1.0 t/ha) was the only grass that produced useful quantities of biomass at Duranillin in the third spring (Table 15). At Tammin, Tyrell and Dundas tall wheatgrasses and Fraydo tall fescue produced the most biomass, but at very low levels. At Girgarre, the phalaris and tall wheatgrass genotypes produced similar amounts of biomass, while Menemen puccinellia did not produce any herbage.

Insert Table 15 near here

Relationships between plant performance and site attributes

In order to ascertain whether variety success could be related to site differences, relationships were examined between a range of plant measurements and either site characteristics (Table 1) or rainfall measurements (Table 3 from Nichols *et al.* 2007 this issue). In spite of the small 5-site dataset, some statistically significant correlations were found. Among the perennial

legumes year 1 spring herbage production was correlated with winter EC_e levels for both sulla ($r = 0.97$, $P < 0.05$) and *L. tenuis* ($r = 0.98$, $P < 0.05$) and surprisingly to drainage rating for Palestine strawberry clover ($r = 0.99$, $P < 0.01$). Year 2 spring herbage production increased as clay content increased for both *L. tenuis* ($r = 0.95$, $P < 0.05$) and Salado lucerne ($r = 0.97$, $P < 0.05$). Year 2 plant frequency was correlated with drainage rating for both *L. tenuis* ($r = 0.99$, $P < 0.01$) and Salado lucerne ($r = 0.97$, $P < 0.05$) and negatively correlated with both summer EC_e levels ($r = -0.96$, $P < 0.05$) and unexpectedly to May-November rainfall in the year of establishment ($r = -0.96$, $P < 0.05$) for Salado. Year 3 plant frequency was correlated with increasing clay content for Salado ($r = 0.98$, $P < 0.05$). Among the perennial grasses, the only statistically significant correlation was establishment density of Menemen puccinellia with topsoil pH ($r = 0.97$, $P < 0.05$).

There were no significant correlations between topsoil salinity levels in August or September and any plant measurement for either the perennial legumes or perennial grasses at Tammin.

Discussion

Ecological requirements for coping with saline environments

For perennial species to be of commercial value, they need to persist and remain productive for at least 3 years, the minimum time frame for evaluation in these experiments. For this to occur in dryland saline environments they need to cope with varying salinity levels throughout the year, the potential for waterlogging in winter and summer drought.

Smith and Stoneman (1970) showed that while salinity levels in the surface 10 cm fluctuated markedly during the year, ranging from relatively low in winter and early spring to reach maximum levels from late spring to mid autumn, there was little seasonal variation below 25 cm depth. Annual plants avoid high surface salinity over the summer-autumn period

1 by senescing in spring. Perennial plants, however, must either have mechanisms to cope with
2 high salinity loads (reviewed by Rogers *et al.* 2005), or have some form of salinity avoidance
3 mechanism, such as summer dormancy. Some perennial plants, including tall wheatgrass
4 (Bleby *et al.* (1996) and *Melaleuca halmaturorum* (Mensworth and Walker (1996), have been
5 shown to avoid salinity stress by accessing less saline water from depths greater than 0.5 m
6 over summer and relatively fresh water in the surface 10 cm during winter.

7 Seedling tolerance to salinity is useful for reliable plant establishment, but may be less
8 important in perennial plants than mature plant tolerance, provided that pasture sowing occurs
9 following sufficient flushing of salts from the topsoil. Seedling tolerance to salinity in
10 perennials is also less likely to be important than in annual plants, which must germinate each
11 year, often when leaching of salts from the topsoil is incomplete (Nichols *et al.* 2007 this
12 issue).

13 Waterlogging and inundation pose additional stresses on many saline sites. Plant
14 growth and survival at such sites is compromised by the lack of oxygen to the roots and by
15 interactions with salinity to further increase shoot concentrations of Na⁺ and Cl⁻ (Barrett-
16 Lennard 2003a; Rogers *et al.* 2005; Teakle *et al.* 2007). Plants adapted to such waterlogged,
17 saline environments, therefore require additional mechanisms to cope with waterlogging.

18 In southern Australia perennials also need to cope with the stress of summer drought
19 typical of mediterranean-type climates. Few commercial perennial pasture species are well
20 adapted, particularly to the low and medium rainfall parts of this zone, largely due to their
21 temperate origin (Lolicato and Rogers 1997; Cocks 2001; Dear *et al.* 2003; Dear and Ewing
22 2007 this issue).

Perennial legume performance

In general the perennial legumes in these experiments were less persistent and productive than the perennial grasses and also the annual legumes in Nichols *et al.* (2007 this issue). This was particularly evident at the most waterlogged and saline sites of Duranillin and Keith, where no perennial legumes survived into the second year. This result makes it clear that no perennial legumes are currently available for highly saline, waterlogged soils.

The performance of Palestine strawberry clover at Cranbrook was consistent with previous findings of adaptation to soils in high rainfall environments prone to waterlogging, in the absence of high salinity levels (McDonald *et al.* 2005; Li *et al.* 2007 this issue). Its failure at the waterlogged, highly saline sites of Duranillin and Keith supports the field observations of Rogers and Bailey (1963). These experiments also support Russell (1976), whose glasshouse results indicate a moderately sensitive rating for strawberry clover, according to the scale of Maas and Hoffman (1977). The failure of Palestine to survive the first summer at Tammin was not surprising, as strawberry clover generally fails to persist in low rainfall sites, due to inadequate drought tolerance (Lolicato and Rogers 1997; Dear *et al.* 2003).

Lucerne has been widely reported as having some tolerance to salinity (Russell 1976; Noble *et al.* 1984; Schachtman and Kelman 1991). However, these experiments were unable to confirm this, due to confounding effects of either waterlogging or low rainfall. Lucerne is widely reported as being susceptible to waterlogging (Cocks 2001; Real *et al.* 2007 this issue). This was evident at Duranillin and Keith, where it failed to survive the first winter. Less compelling evidence for this also came from Cranbrook in the second year, where its herbage production was below that of other perennial legumes. However, the survival of these plants and subsequent frequency increase in the third year, suggests Salado lucerne tolerated the intermittent waterlogging present at the site. Although lucerne was the best performing

1 perennial legume at Tammin, herbage production was very low and very few plants remained
2 after 3 years. Modelling by Hill (1996) suggests unreliable lucerne persistence in WA north of
3 a transect from Perth to Esperance. Tammin lies north of such a line, suggesting its lack of
4 persistence could have been due to the relatively harsh climate, in addition to the effects of
5 salinity.

6 Of note was the similarity in performance of the 2 lucerne cultivars at Tammin and
7 Duranillin. Salado was selected for its salinity tolerance at germination (Downes 2000).
8 However, no advantage over Sceptre was demonstrated in these experiments. This also
9 supports the results of Boyd and Rogers (2004).

10 The results from Cranbrook, particularly following inundation in the second year,
11 support other observations (Li *et al.* 2007 this issue; Real *et al.* 2007 this issue) that *L. tenuis*,
12 *L. corniculatus* and *L. uliginosus* are able to tolerate waterlogging in the absence of high
13 salinity levels. However, they were unable to cope with the saline, waterlogged conditions at
14 Duranillin and Keith. These experiments were unable to confirm the glasshouse differences in
15 salinity tolerance between the 3 species previously found by Schactman and Kelman (1991),
16 Rogers *et al.* (1997) and Teakle *et al.* (2007), due to the confounding effects of waterlogging.
17 There was evidence of some salinity tolerance in *L. tenuis* at Tammin, where it persisted as
18 well as lucerne, and at Girgarre, where it anecdotally persisted after 5 years. However, the
19 failure of *L. corniculatus* and *L. uliginosus* to persist at Tammin is likely to be at least partly
20 attributable to their poor drought tolerance (Lolicato and Rogers 1997; Dear *et al.* 2003).

21 Sulla is a widely cultivated species in parts of the Mediterranean basin, but is a
22 relatively new species to agriculture in Australia (Dear *et al.* 2003; Yates *et al.* 2006). These
23 experiments support the observations of Le Hourou (1986), who suggests it has some salinity
24 tolerance. Its performance at the moderately saline site of Girgarre, where it was the most
25 productive perennial legume over the first 3 years, is consistent with the results of Li *et al.*

(2007 this issue) on non-saline sites. However, it was unable to cope with the combination of waterlogging and high salinity at Duranillin and Keith. The related species, *H. carnosum*, did not persist beyond the first year at any site and does not appear to have a role in saline environments in southern Australia. *H. carnosum* also failed to persist at 2 sites of low salinity in northern NSW (Boschma *et al.* 2007 this issue).

None of the perennial *Melilotus* species appear to warrant further investigation for use on saline sites, particularly those subject to waterlogging. Similarly, *Dorycnium graecum* and *D. pentaphyllum* do not have potential as species for use on saline sites.

Perennial grass performance

These experiments confirm the role of puccinellia on soils that are too hostile, in terms of both salinity and waterlogging, for other temperate grass species. Menemen puccinellia was the best performing grass at the waterlogged, highly saline sites of Duranillin and Keith, supporting previous observations on similar sites (Rogers and Bailey 1963; Barrett-Lennard 2003b). Semple *et al.* (2003) also found Menemen puccinellia performed well on some highly saline soils, but did not examine differences due to waterlogging. By contrast, Menemen production and persistence was much poorer than other grasses on the moderately saline and less waterlogged sites of Cranbrook and Girgarre and on 2 non-waterlogged sites of low salinity in northern NSW (Boschma *et al.* 2007 this issue). Rogers and Bailey (1963) also noted the poor performance of puccinellia on dryland, non-saline soils and its inability to retain a perennial habit, even when irrigated. Whether puccinellia has an innate requirement for both high salinity and waterlogging requires resolution.

The higher second year herbage production of *P. ciliata* SA39293 than Menemen at Cranbrook suggests the potential to select more productive genotypes of the species, while *P. distans* appears to offer no advantages over *P. ciliata*. However, genetic diversity within these

1 *Puccinellia* species needs to be examined at a more saline, waterlogged site before definitive
2 conclusions can be drawn.

3 The results from these experiments support previous findings that tall wheatgrass is
4 able to tolerate highly saline soils (Rogers and Bailey 1963; Rogers *et al.* 1996; Nichols 1998;
5 Semple *et al.* 2003; Barrett-Lennard 2003*b*; Rogers 2007). Tall wheatgrass was the only
6 grass, along with puccinellia, that survived at the highly saline sites of Keith and Duranillin. It
7 also produced the most herbage in the third year of all grasses at Tammin and was the most
8 persistent grass at Cranbrook.

9 Barrett-Lennard (2003*b*) suggests mature plants of tall wheatgrass have similar
10 salinity tolerance, but lower waterlogging tolerance, than puccinellia. The lower persistence
11 of tall wheatgrass than puccinellia at the waterlogged sites of Keith and Duranillin supports
12 this theory. Conversely, at the better drained sites tall wheatgrass persisted and produced more
13 herbage than puccinellia. Dundas and Tyrell wheatgrasses also produced and persisted better
14 than Menemen puccinellia on 2 non-waterlogged sites of low salinity in northern NSW
15 (Boschma *et al.* 2007 this issue). The lack of correlations between performance measurements
16 of tall wheatgrass with topsoil pH in this study is consistent with Nichols (1998) and Semple
17 *et al.* (2003), indicating adaptation to a wide pH range.

18 The result of Zhang *et al.* (2005) that germinating seedlings of tall wheatgrass have
19 greater salinity tolerance than puccinellia, was not confirmed in these experiments.
20 Establishment densities of Tyrell and Dundas tall wheatgrasses were greater than Menemen
21 puccinellia at Duranillin and Girgarre, lower at Tammin and Keith and no different at
22 Cranbrook.

23 The performance of the 2 tall wheatgrass cultivars was remarkably similar across all 5
24 sites. Dundas and Tyrell also performed similarly on a range of saline soils in western
25 Victoria (Nichols 1998), while Zhang *et al.* (2005) found them to have similar seedling

1 tolerance to salt stress. These results are not surprising, as Dundas is a selection from within
2 Tyrell for enhanced leafiness and quality (Smith 2000).

3 These experiments confirmed previous studies showing the unsuitability of phalaris to
4 highly saline sites (Rogers and Bailey 1963; Rogers *et al.* 1996; Semple *et al.* 2003). Sirolan
5 phalaris failed to persist beyond the first summer at Keith and Duranillin. However, it was
6 highly productive and persistent at the moderately saline site of Girgarre, supporting the
7 assertions of Oram *et al.* (2002) and Semple *et al.* (2003) that phalaris may have a role as a
8 pasture component on less severely salinised sites in southern Australia. This contrasts with
9 Boschma *et al.* (2007 this issue), who suggest that phalaris may not be suited to saline
10 environments in northern NSW. The significantly higher second year herbage production of
11 Sirolan, compared with phalaris cultivar Australian at Girgarre, supports claims by Oram *et*
12 *al.* (2002) that selection of phalaris for improved adaptation to saline environments may be
13 possible. However, the *Phalaris aquatica* x *P. arundinacea* hybrid offered no advantages over
14 Sirolan at Girgarre, in contrast to previous results of Oram *et al.* (2002).

15 Few firm conclusions can be drawn about the adaptation of tall fescue to saline
16 environments from the experiments at Tammin and Duranillin. Neither Fraydo nor Triumph
17 tall fescue survived beyond the first summer at Duranillin. This may have been due to an
18 inability to cope with waterlogging conditions in winter, high salinity over summer, or a
19 combination of both factors. At Tammin Fraydo frequency was equal to the most persistent
20 grass after 3 years, although herbage production was poor in each year. These results do not
21 disagree with the conclusions of Rogers and Bailey (1963), Rogers *et al.* (1996), Oram *et al.*
22 (2002) and Semple *et al.* (2003) that tall fescue is only likely to have a role as a pasture
23 component on sites of relatively low salinity.

24 There was a marked difference in performance between the 2 tall fescue cultivars at
25 Tammin, with Triumph failing to persist beyond the first summer. This is probably more a

1 reflection of the difference in seasonal growth pattern of the 2 genotypes, rather than any
2 difference in salinity tolerance. Fraydo is an early flowering Mediterranean type with high
3 summer dormancy (Reed *et al.* 2004). Such types generally perform better in the
4 mediterranean climate of south-western Australia than the more winter-active Triumph types
5 (Sanford 2006; Reed *et al.* 2007 this issue).

6 These experiments were unable to confirm the rating of moderate tolerance to salinity
7 given to perennial ryegrass by Rogers and Bailey (1963), Rogers *et al.* (1996) and Rogers
8 (2007), due to the confounding effects of salinity, waterlogging and summer drought. It failed
9 to survive the first summer at Keith and Cranbrook. At Girgarre second year herbage
10 production of cultivar Victorian was equal to Sirolan phalaris, although its herbage rating in
11 year 3 was significantly less. Perennial ryegrass is noted for its low drought tolerance and is
12 not generally recommended for areas receiving less than 600 mm annual rainfall (Sanford
13 2006). As the experimental sites received less than this amount (Nichols *et al.* 2007 this
14 issue), its failure to persist was not unexpected. Of interest was the difference in performance
15 between the 2 perennial ryegrass genotypes at Girgarre, suggesting the potential to select for
16 more saline tolerant genotypes.

17 None of the other grasses studied appeared to hold promise for use on saline land.

18 19 *Species recommendations for different saline environments*

20 In order to reliably determine the suitability of perennial pasture species for different
21 classes of saline land, consideration needs to be given to the time of year and depth of soil for
22 obtaining salinity measurements that are meaningful to their growth. These experiments
23 measured salinity levels in the surface 10 cm in winter and summer and did not consider
24 salinity levels at greater depths, which have been shown by Smith and Stoneman (1970) to
25 vary much less during the year. Nichols *et al.* (2007 this issue) argued that the critical site

1 salinity measurement for annual pasture legume species recommendations in southern
2 Australia is in the surface 10 cm during early autumn, reflecting the highest levels
3 regenerating pasture seeds could be subjected to following germination, and that summer EC_e
4 levels also approximated these. However, the ability of tall wheatgrass (Bleby *et al.* (1996)
5 and *Melaleuca halmaturorum* (Mensworth and Walker (1996) to access less saline water from
6 depths greater than 0.5 m over summer and early autumn suggests this time and soil depth
7 may not be the most appropriate for perennial plants. Further work is needed to more
8 accurately define the optimal time and soil depth for determining perennial plant suitability on
9 saline land.

10 In the absence of the above information, summer-autumn salinity levels (designated
11 by summer EC_e) in the surface 10 cm are used in Table 16 to make crude recommendations
12 for perennial legume and grass suitability, using the soil salinity classifications of Rogers *et*
13 *al.* (2005) and a broad drainage classification of well or poorly drained. Soil pH and texture
14 preferences and minimum rainfall requirements for different species also need to be
15 considered before making full recommendations and are described in more detail by Barrett-
16 Lennard (2003b), Li *et al.* (2007 this issue), Reed *et al.* (2007 this issue) and Nie *et al.* (2007
17 this issue).

18
19

Insert Table 16 near here

20

21 For non-saline sites (summer $EC_e < 2$ dS/m), salinity-tolerance is not required and a
22 wide range of pasture and crop species can be grown. For medium and high rainfall areas
23 (typically greater than 450 mm mean annual rainfall) with low salinity (summer EC_e 2 - 4
24 dS/m), there are several options for both well-drained and poorly drained sites. Tall
25 wheatgrass and phalaris can be grown across both drainage categories, with tall fescue and

perennial ryegrass being suited to well-drained sites. Strawberry clover, *L. corniculatus*, *L. uliginosis* and *L. tenuis* are suited to poorly drained sites, while lucerne and sulla are suited to well drained sites. Most of these options are also applicable to soils with moderate salinity levels (summer EC_e 4- 8 dS/m) in medium and high rainfall areas. However, puccinellia is an additional option and *L. uliginosis* is not recommended for poorly drained sites, while tall fescue and perennial ryegrass are not recommended for well-drained sites.

In highly saline (summer $EC_e > 8$ dS/m) medium and high rainfall environments, puccinellia is clearly the best option for poorly drained sites, while tall wheatgrass is suited to well-drained sites. *L. tenuis* and sulla may also be suited to some soils with high salinity, but further research with these species is required to determine their upper limits of salinity tolerance. The “highly saline” classification of Rogers *et al.* (2005) is very conservative and these experiments suggest both puccinellia and tall wheatgrass will tolerate soils with summer EC_e levels > 30 dS/m, consistent with claims by Nichols (1998) and Semple *et al.* (2003).

For environments receiving less than 450 mm mean annual rainfall, current perennial options are more limited. Tall wheatgrass is suited to all salinity categories, except highly saline areas (summer $EC_e > 8$ dS/m) prone to waterlogging. In these situations puccinellia is the best grass option. Lucerne is the best perennial legume for well-drained soils with low or moderate salinity (summer EC_e 2-8 dS/m), while sulla may have a role on some of these soils. However, there is little information on the ability of any of these species to cope with saline environments in areas with less than 330 mm mean annual rainfall.

This paper has discussed the performance of individual species in isolation. However, species mixtures should be employed to take account of different seasonal factors and the high spatial variability of saline sites for salinity and waterlogging. Such mixtures should contain suitable grasses and legumes and may also contain halophytic shrubs, notably *Atriplex* and *Maireana* species (Barrett-Lennard 2003b). Nichols *et al.* (2007) make suggestions for

suitable annual legumes for different classes of saline land. These should be included with mixtures of perennial grasses and legumes. Work is also required to develop grazing management strategies that optimise persistence and productivity of each of the desirable pasture components.

Further research

Several other species with purported salinity tolerance need to be studied further to define their suitability for saline environments in southern Australia. This includes the warm-season perennial grasses kikuyu (*Pennisetum clandestinum* Hochst. ex Chiov.), Rhodes grass (*Chloris gayana* Kunth), Bambatsi panic (*Panicum coloratum* L.) and couch grass (*Cynodon dactylon* (L.) Pers.), noted by Russell (1976) and Semple *et al.* (2003) as having some salinity tolerance. The vegetatively propagated perennial grasses saltwater couch (*Paspalum vaginatum* Sw.), marine couch (*Sporobolus virginicus* (L.) Kunth), distichlis (*Distichlis spicata* (L.) Greene) and vetiver grass (*Chrysopogon zizanioides* (L.) Roberty) are reported to have tolerance to high salinity levels (Semple *et al.* 2003; Barrett-Lennard 2003b) and need further research to determine whether they can have an economically important role on severely salinised land. Annual grasses need some consideration. Annual ryegrass was noted by Rogers and Bailey (1963) as having some salinity tolerance and it was a major weed in the perennial grass plots at Tammin and Cranbrook. Italian ryegrass (*Lolium multiflorum* Lam.) has also grown well on saline transects in WA (P. Nichols, unpublished data), although it did not persist on highly saline sites in NSW (Semple *et al.* 2003). The perennial herb chicory (*Cichorium intybus* L.), described by Boyd and Rogers (2004) as having similar salinity tolerance to lucerne, is another species requiring further examination. The opportunity also arises to explore native herbaceous plants for their potential as pasture plants on saline land.

Rogers *et al.* (2005) note there has been very limited infra-specific plant selection for adaptation to saline environments in southern Australia. Genotypic variation for salinity tolerance has been widely reported in lucerne (Kapulnik *et al.* 1989; Downes 2000; Peel *et al.* 2004), strawberry clover (Schachtman and Kelman 1991; Rumbaugh *et al.* 1993), *L. tenuis* (Schachtman and Kelman 1991; Rogers *et al.* 1997) and *L. corniculatus* (Schachtman and Kelman 1991), while variation for waterlogging tolerance has been reported in *L. tenuis*, *L. corniculatus* and *L. uliginosus* (Real *et al.* 2007 this issue). Selection for increased salinity and waterlogging tolerance is likely to result in better adapted and more productive genotypes of these species for saline land. McDonald *et al.* (2005) also suggest gains in waterlogging and salinity tolerance could be made by selection within naturalised populations.

Tall wheatgrass and puccinellia warrant special attention for plant improvement. Tyrell tall wheatgrass and Menemen puccinellia were selected over 40 years ago for high rainfall environments, on the basis of Rogers and Bailey's (1963) experiments. Dundas tall wheatgrass is a recent release but was selected from within populations of Tyrell (Smith 2000). A strong case can be made for developing cultivars of both species better adapted to low saline rainfall areas. Selection for low weed potential in tall wheatgrass, possibly by increasing palatability, would also help allay weed risk concerns about the species (Virtue and Melland 2003). Improved grasses could be selected by exploiting genetic diversity within old tall wheatgrass and puccinellia stands. Alternatively, a wider range of accessions from their centres of origin could be acquired to boost the limited range of germplasm available in Australia. Cocks (2001) and Rogers *et al.* (2005) suggest dedicated collection missions to target salinity tolerance are likely to be rewarding.

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References

- Barrett-Lennard EG (2003a) The interaction between waterlogging and salinity in higher plants: causes, consequences and implications. *Plant and Soil* **253**: 35-54.
- Barrett-Lennard EG (2003b) Saltland Pastures in Australia - A Practical Guide (2nd edition). Department of Agriculture Western Australia, South Perth, Australia.
- Bleby TM, Aucote N, Kennett-Smith AK, Walker GR, Schachtman DP (1997) Seasonal water use characteristics of tall wheatgrass [*Agropyron elongatum* (Host) Beauv.] in a saline environment. *Plant, Cell and Environment* **20**, 1361-1371.
- Boschma SP, Lodge GM, Harden S (2007) Performance and persistence of pasture legumes and grasses in saline and/or waterlogged soils in northern New South Wales. *Australian Journal of Experimental Agriculture* **47**, this issue.
- Boyd DC, Rogers ME (2004) The effect of salinity on the growth of chicory (*Cichorium intybus* cv. Puna) – a potential dairy forage species for irrigation areas. *Australian Journal of Experimental Agriculture* **44**, 189-192.
- Cocks PS (2001) Ecology of herbaceous perennial legumes: a review of characteristics that may provide management options for the control of salinity and waterlogging in dryland cropping systems. *Australian Journal of Agricultural Research* **52**, 137-151.

- Dear BS and Ewing MA (2007) The search for new pasture plants to achieve more sustainable production systems in southern Australia *Australian Journal of Experimental Agriculture* **47**, this issue.
- Dear BS, Moore GM, Hughes SJ (2003) Adaptation and potential contribution of temperate perennial legumes to the southern Australian wheatbelt: a review. *Australian Journal of Experimental Agriculture* **43**, 1-18.
- Dolling PJ, Moody P, Noble A, Helyar KR, Hughes B, Reuter D, Sparrow L (2001) 'National Land and Water Resources Audit.' National Land and Water Resources Audit, Commonwealth of Australia.
- Downes R (2000) Salado lucerne. *Plant Varieties Journal* **13**, 52-53.
- Hill MJ (1996) Potential adaptation zones for temperate pasture species as constrained by climate: a knowledge-based logical modelling approach. *Australian Journal of Agricultural Research* **47**, 1095-1117.
- Kapulnik Y, Tueber LR, Phillips DA (1989) Lucerne (*Medicago sativa* L.) selected for vigour in a nonsaline environment maintained growth under salt stress. *Australian Journal of Agricultural Research* **40**, 1253-1259.
- Le Hourou HN (1986) Salt tolerant plants of economic value in the Mediterranean basin. In 'Forage and fuel production from salt-affected wasteland'. (Eds EG Barrett-Lennard, CV Malcolm, WR Stern, SM Wilkens) pp. 319-341. (Elsevier: The Netherlands).
- Li GD, Lodge GM, Moore GA, Craig AD, Dear BS, Boschma SP, Albertsen TO, Miller SM, Harden S, Hayes RC, Hughes SJ, Snowball R, Smith AB, Cullis BC (2007) Comparative evaluation of perennial pasture legumes and herbs to identify species with high herbage mass and persistence for southern Australia. *Australian Journal of Experimental Agriculture* **47**, this issue
- Lolicato SJ, Rogers ME (1997) Adaptation of pasture legumes to acid, shallow soils in central Victoria. *Australian Journal of Experimental Agriculture* **37**, 779-791.
- Maas EV, Hoffman GJ (1977) Crop salt tolerance – current assessment. *Journal of the Irrigation and Drainage Division, American Society of Civil Engineers* **103**, 115–134.
- McDonald KS, Cocks PS, Ewing ME (2005). Genetic variation in five populations of strawberry clover (*Trifolium fragiferum* cv. Palestine) in Western Australia. *Australian Journal of Experimental Agriculture* **45**, 1445-1451.
- McDonald RC, Isbell RF, Speight JG, Walker J, Hopkins MS (1990) Australian soil and land survey field handbook (2nd edition). Inkata Press Melbourne

- Mensforth LJ, Walker GR (1996) Root dynamics of *Melaleuca halmaturorum* in response to fluctuating saline groundwater. *Plant and Soil* **184**, 75-84.
- Moore GA (2006a) Introduction – why perennial pastures? In ‘Perennial pastures for Western Australia’, Bulletin 4690. (Eds GA Moore, P Sanford, T Wiley), pp. 8-11. (Department of Agriculture and Food Western Australia: South Perth, Australia).
- Moore GA (2006b) Sub-tropical grasses. In ‘Perennial pastures for Western Australia’, Bulletin 4690. (Eds GA Moore, P Sanford, T Wiley), pp. 124-166. (Department of Agriculture and Food Western Australia: South Perth, Australia).
- Nichols CW (1998) Establishing and managing tall wheatgrass in saline soils for productivity. In ‘Proceedings of the 5th workshop on Productive Use and Rehabilitation of Saline Land (PUR\$L)’ Tamworth, New South Wales, pp. 165-167.
- Nichols PGH, Craig AD, Rogers ME, Albertsen TO, Miller S, McClements DR, Hughes SJ, D’Antuono MF, Dear BS (2007) Production and persistence of annual legumes at five saline sites in southern Australia. *Australian Journal of Experimental Agriculture* **47**, this issue
- Nie ZN, Miller S, Moore GA, Hackney BF, Boschma S, Reed KFM, Mitchell M, Albertsen TO, Clark SG, Craig AD, Kearney G, Li GD, Dear BS (2007) Field evaluation of perennial grasses and herbs in southern Australia. 2. Persistence, root characteristics and summer activity. *Australian Journal of Experimental Agriculture* **47**, this issue
- Noble CL, Halloran GM, West, DW (1984) Identification and selection for salt tolerance in lucerne (*Medicago sativa* L.). *Australian Journal of Agricultural Research* **35**, 239-252.
- O’Connell M, Young J, Kingwell R (2005) The economic value of saltland pastures in a mixed enterprise farming system in a heterogeneous landscape experiencing a mediterranean climate. *Agricultural Systems* **89**, 371–389.
- Oram RN, Edlington JP, Gardner PA (2002) Selection for resistance to salinity and waterlogging in *Phalaris aquatica* L. *Australian Journal of Agricultural Research* **53**, 391-399.
- Peel MD, Waldron BL, Jensen KB, Chatterton NJ, Korton H, Dudley LM (2004) Screening for salinity tolerance in alfalfa: a repeatable method. *Crop Science* **44**, 2049-2053.
- Real D, Warden J, Sandral GA, Colmer T (2007) Waterlogging tolerance and recovery of 10 perennial forage legume species of *Lotus*. *Australian Journal of Experimental Agriculture* **47**, this issue

- 1 Reed KFM, Lee CK, Jahufer MZZ, Anderson MW (2004) Fraydo tall fescue (*Festuca*
2 *arundinacea* L.). *Australian Journal of Experimental Agriculture* **44**, 955–957.
- 3 Reed KFM, Nie ZN, Miller S, Hackney BF, Boschma S, Mitchell M, Albertsen TO, Moore
4 GA, Clark SG, Kearney G, Li GD, Dear BS (2007) Field evaluation of perennial
5 grasses and herbs in southern Australia. 1. Establishment and herbage production.
6 *Australian Journal of Experimental Agriculture* **47**, this issue
- 7 Rogers AL, Bailey ET (1963) Salt tolerance trials with forage plants in south-western
8 Australia. *Australian Journal of Experimental Agriculture and Animal Husbandry* **3**,
9 125-130.
- 10 Rogers ME (2007). The response of four perennial grass species to sodium chloride salinity
11 when irrigated with saline waters. *Australian Journal of Experimental Agriculture* **58**,
12 225-232.
- 13 Rogers M, Colmer T, Frost K, Henry D, Cornwall D, Hulm E, Hughes S, Craig A (2006)
14 Improving forage legume options for saline environments – *Melilotus* species. In
15 ‘Ground-breaking stuff. Proceedings of the 13th agronomy conference’. (Eds NC
16 Turner, T Acuna, RC Johnson), (Agronomy Society of Australia: Perth) Available at
17 http://www.regional.org.au/au/asa/2006/concurrent/environment/4548_rogersm.htm
18 [Verified 2 November 2007]
- 19 Rogers ME, Craig AD, Munns R, Colmer TD, Nichols PGH, Malcolm CV, Brown AJ,
20 Semple WS, Evans PM, Cowley K, Hughes SJ, Snowball RS, Bennett SJ, Sweeney
21 GC, Dear BS, Ewing ME (2005) The development of fodder plants for the salt-
22 affected areas of southern and eastern Australia: an overview. *Australian Journal of*
23 *Experimental Agriculture* **45**, 301-329.
- 24 Rogers ME, Noble CL, Pederick RJ (1996) Identifying suitable grass species for saline areas.
25 *Australian Journal of Experimental Agriculture* **36**, 197-202.
- 26 Rogers ME, West DW (1993). The effects of rootzone salinity and hypoxia on shoot and root
27 growth in *Trifolium* species. *Annals of Botany* **72**, 503-509.
- 28 Rumbaugh MD, Penderbury BM, James DW (1993) Variation in the salinity tolerance of
29 strawberry clover (*Trifolium fragiferum* L.) *Plant and Soil* **124**, 47-51.
- 30 Russell JS (1976) Comparative salt tolerance of some tropical and temperate legumes and
31 grasses. *Australian Journal of Experimental Agriculture and Animal Husbandry* **16**,
32 103-109.

- 1 Sanford P (2006) Temperate perennial grasses. In 'Perennial pastures for Western Australia',
2 Bulletin 4690. (Eds GA Moore, P Sanford, T Wiley), pp. 96-122. (Department of
3 Agriculture and Food Western Australia: South Perth, Australia).
- 4 Semple WS, Cole IA, Koen TB (2003) Performance of some perennial grasses on severely
5 salinised sites in the inland slopes of New South Wales. *Australian Journal of*
6 *Experimental Agriculture* **43**, 353-371.
- 7 Schachtman DP and Kelman WM (1991) Potential of *Lotus* germplasm for the development
8 of salt, aluminium and manganese tolerant pasture plants. *Australian Journal of*
9 *Agricultural Research* **42**, 139-149.
- 10 Smith KF (2000) Register of Australian Herbage Plant Cultivars A. Grasses 18. Wheatgrass
11 *Thinopyrum ponticum* (Podp.) Z.-W. Liu & R. R.-C. Wang (tall wheatgrass) cv.
12 Dundas. *Australian Journal of Experimental Agriculture* **40**, 119-120.
- 13 Smith ST, Stoneman TC (1970) Salt movement in bare saline soils. Technical Bulletin 4.
14 Department of Agriculture Western Australia, South Perth, Australia.
- 15 Stone L (2007) Minimising environmental weed risk in new perennial-based land-use
16 systems. *Australian Journal of Experimental Agriculture* **47**, this issue.
- 17 Teakle NL, Flowers TJ, Real D, Colmer TD (2007) *Lotus tenuis* tolerates the interactive
18 effects of salinity and waterlogging by 'excluding' Na⁺ and Cl⁻ from the xylem.
19 *Journal of Experimental Botany* **58**, 2169-2180.
- 20 Virtue JG, Melland RL (2003) The environmental weed risk of revegetation and forestry
21 plants. South Australia. Department of Water, Land and Biodiversity Conservation
22 Report DWLBC 2003/02, pp 184.
- 23 Yates R, Foster K, Nichols PGH, Ewing MA (2006) 'Flamenco' – a new variety of sulla for
24 southern Australia. In 'Ground-breaking stuff. Proceedings of the 13th agronomy
25 conference'. (Eds NC Turner, T Acuna, RC Johnson), (Agronomy Society of Australia:
26 Perth) Available at
27 http://www.regional.org.au/au/asa/2006/poster/systems/4842_yatesr.htm [Verified 2
28 November 2007]
- 29 Zhang B, Jacobs BC, O'Donnell MO, Guo J (2005) Comparative studies of salt tolerance of
30 seedlings for one cultivar of puccinellia (*Puccinellia ciliata*) and two cultivars of tall
31 wheatgrass (*Thinopyron ponticum*). *Australian Journal of Experimental Agriculture* **45**,
32 391-399.
- 33

1 **Table 1. Experimental site locations, mean annual rainfall (data from Bureau of**
2 **Meteorology) and mean soil properties (0-10 cm depth) of bulked samples.**

Site	Location	Mean annual rainfall (mm)	pH (CaCl ₂)	EC _e (dS/m) ^A		Drainage rating ^B	Soil texture rating ^C
				Winter	Summer		
Tammin	31.60°S, 117.45°E	330	6.5	2.4	10.9	6	6
Duranillin	33.57°S, 116.77°E	530	5.5	5.0	30.8	2	2
Cranbrook	34.15°S, 117.18°E	530	5.6	3.2	8.0	4	4
Girgarre	36.35°S, 144.97°E	450	5.5	1.9	6.9	4	9
Keith	36.15°S, 140.10°E	465	6.7	0.8	36.2	2	1

3 ^AMean salinity values at each site in winter (minimum) and summer (maximum)

4 ^BRating scale (1-6) from McDonald *et al.* (1990), where 2 = poorly drained (seasonally inundated), 4 =
5 moderately drained (potential for shallow waterlogging), 6 = rapidly drained (no chance of inundation
6 or waterlogging)

7 ^CRating scale (1-13) based on McDonald *et al.* (1990), where 1 = sand, 3 = clayey sand, 5 = loam, 7 =
8 clay loam, 9 = light clay, 11 = medium clay, 13 = heavy clay

1 **Table 2. Perennial legume species and genotypes sown at the 5 experimental sites. Species consisted of either single genotypes or**
2 **composites of 2-4 genotypes mixed in equal proportions.**

Species	Common name	Genotype(s)	Site				
			Tammin	Duranillin	Cranbrook	Girgarre	Keith
<i>Dorycnium graecum</i> ¹ (L.) Ser.		Composite of SA35667, SA36069			√		
<i>D. pentaphyllum</i> Scop.	prostrate canary clover	Composite of TAS 1273, SA33723, KG 35891			√		
<i>Hedysarum carnosum</i> ² Desf.		Composite of SA35358, SA34401, SA35357	√	√	√	√	√
<i>H. coronarium</i> L.	sulla	Lake Grace ecotype	√	√		√	
		SA26218					√
<i>Lotus corniculatus</i> L.	birdsfoot trefoil	cv. Goldie	√	√			
		Composite of SA34272, CPI 70533			√		
<i>L. creticus</i> L.	creta trefoil	Composite of CPI 66507, S1012, PI 287860	√	√	√		
<i>L. cytisoides</i> ¹ L.		Composite of Y LOT 52/91, 99ITA-M6CYT			√		
<i>L. tenuis</i> Waldst. & Kit. ex Willd.	narrow leaf trefoil	Composite of SA22033, SA22034, SA27790, SA32439	√	√	√	√	√
<i>L. uliginosus</i> Schkuhr	big trefoil	cv. Maku	√	√			
		Composite of SA12952, CPI 66433, CPI 67677			√		
<i>Medicago sativa</i> L.	lucerne	cv. Salado	√	√	√	√	√
		cv. Sceptre	√	√			
<i>Melilotus albus</i> Medik.	white sweet clover	Composite of SA27773, SA37094, SA1991					√
<i>M. dentatus</i> ² (Waldst. & Kit.) Pers.	small flowered melilot	Composite of SA36955, SA36946					√
<i>M. elegans</i> ² Ser.	elegant melilot	Composite of SA36962, SA36960, SA36961					√
<i>M. hirsutus</i> Lipsky		SA36963					√

<i>M. officinalis</i> (L.) Pall.	yellow sweet clover	Composite of SA37403, SA37418, SA17135						√
<i>M. polonicus</i> ² (L.) Pall.	caspian sweet clover	SA36977						√
<i>M. sauveolens</i> ² Ledeb.		Composite of SA37289, SA36991, SA37280						√
<i>M. wolgicus</i> ² Poir.		Composite of SA37000, SA37001						√
<i>Trifolium fragiferum</i> L.	strawberry clover	cv. Palestine	√	√	√	√	√	√
<i>T. repens</i> L.	white clover	Salt-tolerant selections from cvv. Haifa, Tamar, Aran					√	

1 ¹Not assessed by Australian Quarantine Inspection Services (AQIS)

2 ²Prohibited by Australian Quarantine Inspection Services AQIS and Western Australian Quarantine Inspection Services (WAQIS)

3

1 **Table 3. Perennial grass species and genotypes sown at the 5 experimental sites.**

Species	Common name	Genotype	Site				
			Tammin	Duranillin	Cranbrook	Girgarre	Keith
<i>Austrodanthonia richardsonii</i> (Cashmore) HP Linder	straw wallaby grass	cv..Hume				√	
<i>Dactylis marina</i> Borrill		PI229472	√	√		√	√
		PI237604	√	√		√	√
<i>Eleusine indica</i> (L.) Gaertn.	crab grass	PI408802			√		
<i>Festuca arundinacea</i> Schreb.	tall fescue	cv. Triumph	√	√			
		cv. Fraydo	√	√			
<i>Lolium perenne</i> L.	perennial ryegrass	PI170521				√	√
		PI197270					√
		PI201185			√		√
		cv. Victorian				√	√
<i>Thinopyrum ponticum</i> (Podp.) Z.-W. Liu & R.-C. Wang	tall wheatgrass	cv. Dundas	√	√	√	√	√
		Tas1499				√	
		cv. Tyrell	√	√	√	√	√
<i>Phalaris aquatica</i> L.	phalaris	cv. Australian				√	
		cv. Sirolan	√	√	√	√	√
<i>P. aquatica</i> x <i>P. arundinacea</i>		hybrid				√	
<i>Puccinellia ciliata</i> Bor	puccinella	cv. Menemen	√	√	√	√	√
		SA39293			√		
<i>P. distans</i> (Jacq.) Parl.	alkali grass	PI502581			√		

1 **Table 4. Perennial legume establishment densities ($\log_{10}$ transformed) at 5**
2 **experimental sites ($P < 0.001$). Raw means (plants/m²) are shown in parentheses.**

Species	Site									
	Tammin		Duranillin		Cranbrook		Girgarre		Keith	
<i>Dorycnium graecum</i>					1.56	(38)				
<i>D. pentaphyllum</i>					1.57	(38)				
<i>Hedysarum carnosum</i>	1.14	(22)	0.07	(0)	1.51	(40)	0.38	(4)	2.60	(394)
<i>H. coronarium</i>	0.96	(9)	0.57	(3)			1.27	(23)	2.48	(306)
<i>Lotus corniculatus</i>	0.57	(4)	0.00	(0)	1.95	(98)				
<i>L. creticus</i>	0.66	(5)	0.08	(0)	1.60	(40)				
<i>L. cytisoides</i>					1.44	(33)				
<i>L. tenuis</i>	1.38	(25)	0.32	(2)	2.40	(263)	0.70	(4)	2.81	(640)
<i>L. uliginosus</i>	1.49	(40)	0.00	(0)	2.28	(193)				
<i>Medicago sativa</i> cv. Salado	0.88	(7)	0.06	(0)	2.24	(178)	0.59	(3)	2.56	(372)
<i>M. sativa</i> cv. Sceptre	1.29	(22)	0.16	(1)						
<i>Melilotus albus</i>									2.61	(410)
<i>M. dentatus</i>									2.57	(368)
<i>M. elegans</i>									2.65	(450)
<i>M. hirsutus</i>									2.71	(524)
<i>M. officianalis</i>									2.61	(412)
<i>M. polonicus</i>									2.45	(282)
<i>M. sauveolens</i>									2.75	(568)
<i>M. wolgicus</i>									2.57	(378)
<i>Trifolium fragiferum</i> cv. Palestine	1.57	(56)	0.22	(1)	2.21	(173)	0.57	(4)	2.88	(768)
<i>T. repens</i>							0.62	(8)		
Site mean		(19)		(1)		(109)		(7)		(452)
l.s.d. ($P = 0.05$)	0.441		0.209		0.267		0.371		0.076	

3

1 **Table 5. Rhizobial nodulation and plant health ratings following 7 weeks of**
2 **inundation at Keith in the year of sowing ($P < 0.001$).**

Species	Nodulation rating (0-3) ^A	Plant health rating (0-5) ^B
<i>Hedysarum carnosum</i>	2.5 ^C	0.4
<i>H. coronarium</i> SA26218	2.5	1.9
<i>Lotus tenuis</i>	2.9	4.1
<i>Medicago sativa</i> cv. Salado	2.2	0.5
<i>Melilotus albus</i>	2.8	1.3
<i>M. dentatus</i>	2.5	0.5
<i>M. elegans</i>	3.0	0.8
<i>M. hirsutus</i>	2.4	1.0
<i>M. officianalis</i>	3.0	0.6
<i>M. polonicus</i>	0.9	0.5
<i>M. sauveolens</i>	2.3	0.5
<i>M. wolgicus</i>	2.8 ^C	0.5
<i>Trifolium fragiferum</i> cv. Palestine	3.0	1.8
Site mean	2.5	1.1
l.s.d. ($P = 0.05$)	0.68	0.59

3 ^A0 = no nodules, 1 = small white nodules only, 2 = less than 5 pink nodules and 3 = at least 5 pink
4 nodules.

5 ^B0 = all plants dead, 5 = all plants green and healthy.

6 ^CLikely to be over-estimated due to a limited number of surviving plants

1 **Table 6. First year spring herbage production ($\log_{10}$ transformed) of perennial**
2 **legumes at 5 experimental sites ($P < 0.001$). Raw means (kg/ha) are shown in**
3 **parentheses. All plants died at Keith.**

Species	Site									
	Tammin		Duranillin		Cranbrook		Girgarre		Keith	
<i>Dorycnium graecum</i>					0.98	(9)				
<i>D. pentaphyllum</i>					0.98	(9)				
<i>Hedysarum carnosum</i>	1.85	(88)	0.00	(0)	1.01	(9)	0.27	(4)	(0)	
<i>H. coronarium</i>	2.16	(174)	3.02	(1068)			2.07	(153)	(0)	
<i>Lotus corniculatus</i>	1.45	(28)	0.00	(0)	1.68	(78)				
<i>L. creticus</i>	1.46	(30)	0.53	(93)	1.19	(28)				
<i>L. cytisoides</i>					1.22	(31)				
<i>L. tenuis</i>	1.70	(53)	1.50	(204)	2.56	(392)	1.16	(15)	(0)	
<i>L. uliginosus</i>	1.52	(33)	0.00	(0)	2.16	(151)				
<i>Medicago sativa</i> cv. Salado	2.28	(293)	0.00	(0)	2.95	(933)	1.19	(15)	(0)	
<i>M. sativa</i> cv. Sceptre	2.66	(564)	0.54	(98)						
<i>Melilotus albus</i>										(0)
<i>M. dentatus</i>										(0)
<i>M. elegans</i>										(0)
<i>M. hirsutus</i>										(0)
<i>M. officianalis</i>										(0)
<i>M. polonicus</i>										(0)
<i>M. sauveolens</i>										(0)
<i>M. wolgicus</i>										(0)
<i>Trifolium fragiferum</i> cv. Palestine	2.60	(424)	0.00	(0)	2.94	(965)	1.17	(17)	(0)	
<i>T. repens</i>							0.82	(13)		
Site mean		(170)		(146)		(261)		(31)	(0)	
l.s.d. ($P = 0.05$)	0.321		0.827		0.363		0.445		-	

4

1 **Table 7. Second year perennial legume frequency (square root transformed) at 4**
2 **sites ($P < 0.001$ at Girgarre, $P < 0.01$ at Tammin and Cranbrook). Raw means**
3 **(percentage of 1 dm² squares with live crown material) are shown in parentheses.**
4 **All plants died at Duranillin.**

Species	Site			
	Tammin	Duranillin	Cranbrook	Girgarre
<i>Dorycnium graecum</i>			1.00 (0)	
<i>D. pentaphyllum</i>			1.00 (0)	
<i>Hedysarum carnosum</i>	1.00 (0)	(0)	1.00 (0)	1.00 (0)
<i>H. coronarium</i>	1.25 (1)	(0)		4.80 (26)
<i>Lotus corniculatus</i>	1.00 (0)	(0)	4.69 (22)	
<i>L. creticus</i>	1.92 (4)	(0)	1.52 (2)	
<i>L. cytisoides</i>			2.43 (6)	
<i>L. tenuis</i>	2.34 (7)	(0)	6.62 (44)	1.78 (2)
<i>L. uliginosus</i>	1.00 (0)	(0)	5.51 (30)	
<i>Medicago sativa</i> cv. Salado	2.02 (4)	(0)	4.10 (16)	1.87 (3)
<i>M. sativa</i> cv. Sceptre	3.44 (14)	(0)		
<i>Trifolium fragiferum</i> cv. Palestine	1.00 (0)	(0)	6.46 (41)	3.06 (11)
<i>T. repens</i>				1.88 (6)
Site mean	(3)	(0)	(16)	(7)
l.s.d. ($P = 0.05$)	1.241	-	0.797	1.198

5

1 **Table 8. Second year spring herbage production ($\log_{10}$ transformed) of perennial**
2 **legumes at 3 sites ($P < 0.001$ at Cranbrook and Girgarre, $P < 0.01$ at Tammin).**
3 **Raw means (kg/ha) are shown in parentheses.**

Species	Site					
	Tammin		Cranbrook		Girgarre	
<i>Dorycnium graecum</i>			0.00	(0)		
<i>D. pentaphyllum</i>			0.00	(0)		
<i>Hedysarum carnosum</i>	0.00	(0)	0.00	(0)	0.00	(0)
<i>H. coronarium</i>	0.33	(9)			3.02	(1137)
<i>Lotus corniculatus</i>	0.00	(0)	3.24	(1777)		
<i>L. creticus</i>	1.09	(39)	1.05	(26)		
<i>L. cytisoides</i>			0.99	(15)		
<i>L. tenuis</i>	0.70	(22)	3.10	(1507)	2.17	(175)
<i>L. uliginosus</i>	0.00	(0)	3.44	(2768)		
<i>Medicago sativa</i> cv. Salado	0.90	(26)	2.57	(411)	2.40	(328)
<i>M. sativa</i> cv. Sceptre	1.30	(51)				
<i>Trifolium fragiferum</i> cv. Palestine	0.00	(0)	3.44	(2783)	2.54	(514)
<i>T. repens</i>					2.69	(663)
Site mean		(15)		(929)		(402)
l.s.d. ($P = 0.05$)	0.824		0.414		0.282	

4

1 **Table 9. Third year perennial legume frequency (square root transformed) at**
2 **Tammin (not significant) and Cranbrook ($P < 0.001$). Raw means (percentage of**
3 **1 dm² squares with live crown material) are shown in parentheses. Density**
4 **ratings (0 – 10) are shown for Girgarre ($P < 0.001$).**

Species	Site				
	Tammin		Cranbrook		Girgarre
<i>Dorycnium graecum</i>			1.00	(0)	
<i>D. pentaphyllum</i>			1.00	(0)	
<i>Hedysarum carnosum</i>	1.00	(0.0)	1.00	(0)	0.0
<i>H. coronarium</i>	0.99	(0.0)			4.2
<i>Lotus corniculatus</i>	1.00	(0.0)	4.77	(24)	
<i>L. creticus</i>	1.25	(0.8)	1.46	(2)	
<i>L. cytisoides</i>			2.43	(6)	
<i>L. tenuis</i>	1.00	(0.0)	7.27	(53)	1.1
<i>L. uliginosus</i>	1.00	(0.0)	9.18	(84)	
<i>Medicago sativa</i> cv. Salado	1.15	(0.4)	6.51	(43)	0.9
<i>M. sativa</i> cv. Sceptre	1.00	(0.0)			
<i>Trifolium fragiferum</i> cv. Palestine	1.00	(0.0)	9.47	(89)	1.9
<i>T. repens</i>					1.0
Site mean		(0.1)		(30)	1.3
l.s.d. ($P = 0.05$)	-		1.065		1.05

5

1 **Table 10. Perennial grass establishment densities ($\log_{10}$ transformed) at 5**
2 **experimental sites ($P < 0.001$). Raw means (plants/m²) are shown in parentheses.**

Species	Site									
	Tammin		Duranillin		Cranbrook		Girgarre		Keith	
<i>Austrodanthonia richardsonii</i> cv. Hume							0.12	(1)		
<i>Dactylis marina</i> PI229472	1.34	(34)	0.00	(0)			0.45	(3)	2.57	(375)
<i>D. marina</i> PI237604	1.32	(23)	0.00	(0)			0.17	(1)	2.45	(280)
<i>Eleusine indica</i> PI408802					1.75	(60)				
<i>Festuca arundinacea</i> cv. Triumph	1.00	(14)	1.20	(18)						
<i>F. arundinacea</i> cv. Fraydo	1.59	(44)	1.53	(37)						
<i>Lolium perenne</i> PI170521							1.13	(13)	2.22	(168)
<i>L. perenne</i> PI197270									2.20	(164)
<i>L. perenne</i> PI201185					2.46	(295)			2.48	(308)
<i>L. perenne</i> cv. Victorian							1.52	(33)	2.49	(310)
<i>Phalaris aquatica</i> cv. Australian							1.21	(18)		
<i>P. aquatica</i> cv. Sirolan	1.69	(49)	0.87	(13)	2.23	(193)	1.60	(39)	2.62	(418)
<i>P. aquatica</i> x <i>P. arundinacea</i> hybrid							1.41	(26)		
<i>Puccinellia ciliata</i> cv. Menemen	1.84	(75)	0.83	(7)	1.71	(63)	0.46	(6)	2.55	(364)
<i>P. ciliata</i> SA39293					1.82	(90)				
<i>P. distans</i> PI502581					2.07	(133)				
<i>Thinopyrum ponticum</i> cv. Dundas	1.11	(15)	1.50	(35)	1.96	(103)	1.31	(25)	2.36	(230)
<i>T. ponticum</i> Tas1499							1.61	(41)		
<i>T. ponticum</i> cv. Tyrell	1.04	(13)	1.36	(32)	1.73	(68)	1.22	(20)	2.31	(208)
Site mean		(33)		(18)		(125)		(19)		(283)
l.s.d. ($P = 0.05$)	0.249		0.329		0.361		0.398		0.112	

3

1 **Table 11. First year spring herbage production ($\log_{10}$ transformed) of perennial**
2 **grasses at Tammin ($P < 0.01$) and Cranbrook ($P < 0.001$). Raw means (kg/ha) are**
3 **shown in parentheses.**

Species	Site			
	Tammin		Cranbrook	
<i>Dactylis marina</i> PI229472	2.04	(117)		
<i>D. marina</i> PI237604	2.13	(152)		
<i>Eleusine indica</i> PI408802			0.96	(8)
<i>Festuca arundinacea</i> cv. Triumph	2.08	(134)		
<i>F. arundinacea</i> cv. Fraydo	2.23	(174)		
<i>Lolium perenne</i> PI201185			3.19	(1554)
<i>Phalaris aquatica</i> cv. Sirolan	2.49	(340)	2.99	(1026)
<i>Puccinellia ciliata</i> cv. Menemen	1.74	(67)	1.19	(30)
<i>P. ciliata</i> SA39293			2.14	(247)
<i>P. distans</i> PI502581			1.65	(75)
<i>Thinopyrum ponticum</i> cv. Dundas	2.26	(234)	2.25	(192)
<i>T. ponticum</i> cv. Tyrell	2.08	(130)	2.30	(333)
Site mean		(168)		(433)
l.s.d. ($P = 0.05$)	0.300		0.560	

4

1 **Table 12. Second year perennial grass frequency (square root transformed) at 4**
2 **sites ($P < 0.001$). Raw means (percentage of 1 dm² squares with live crown**
3 **material) are shown in parentheses.**

Species	Site							
	Tammin		Duranillin		Cranbrook		Keith	
<i>Dactylis marina</i> PI229472	1.00	(0)	1.48	(2)			1.00	(0)
<i>D. marina</i> PI237604	1.29	(1)	1.00	(0)			1.00	(0)
<i>Eleusine indica</i> PI408802					1.00	(0)		
<i>Festuca arundinacea</i> cv. Triumph	1.00	(0)	1.00	(0)				
<i>F. arundinacea</i> cv. Fraydo	4.22	(21)	1.00	(0)				
<i>Lolium perenne</i> PI170521							1.00	(0)
<i>L. perenne</i> PI197270							1.00	(0)
<i>L. perenne</i> PI201185					1.46	(2)	1.00	(0)
<i>L. perenne</i> cv. Victorian							1.00	(0)
<i>Phalaris aquatica</i> cv. Sirolan	3.27	(11)	1.00	(0)	4.92	(24)	1.00	(0)
<i>Puccinellia ciliata</i> cv. Menemen	5.37	(34)	5.01	(24)	3.00	(10)	9.36	(87)
<i>P. ciliata</i> SA39293					2.89	(11)		
<i>P. distans</i> PI502581					2.72	(7)		
<i>Thinopyrum ponticum</i> cv. Dundas	4.47	(21)	1.89	(3)	5.49	(31)	6.65	(43)
<i>T. ponticum</i> cv. Tyrell	4.86	(23)	1.99	(4)	5.54	(32)	7.30	(53)
Site mean		(14)		(4)		(14)		(18)
l.s.d. ($P = 0.05$)	1.903		0.683		1.577		0.424	

4

1 **Table 13. Second year spring herbage production ($\log_{10}$ transformed) of**
2 **perennial grasses at 4 experimental sites ($P < 0.001$). Raw means (kg/ha) are**
3 **shown in parentheses.**

Species	Site							
	Tammin		Duranillin		Cranbrook		Girgarre	
<i>Austrodanthonia richardsonii</i> cv. Hume							0.00	(0)
<i>Dactylis marina</i> PI229472	0.00	(0)	0.80	(50)			2.86	(764)
<i>D. marina</i> PI237604	0.25	(4)	0.00	(0)			2.84	(1392)
<i>Eleusine indica</i> PI408802					0.00	(0)		
<i>Festuca arundinacea</i> cv. Triumph	0.00	(0)	0.00	(0)				
<i>F. arundinacea</i> cv. Fraydo	1.00	(34)	0.00	(0)				
<i>Lolium perenne</i> PI170521							0.00	(0)
<i>L. perenne</i> PI201185					0.00	(0)		
<i>L. perenne</i> cv. Victorian							3.46	(4129)
<i>Phalaris aquatica</i> cv. Australian							3.27	(2220)
<i>P. aquatica</i> cv. Sirolan	1.51	(35)	0.00	(0)	2.02	(179)	3.79	(8486)
<i>P. aquatica</i> x <i>P. arundinacea</i> hybrid							3.20	(1906)
<i>Puccinellia ciliata</i> cv. Menemen	2.32	(352)	2.58	(460)	0.25	(3)	0.00	(0)
<i>P. ciliata</i> SA39293					1.37	(129)		
<i>P. distans</i> PI502581					0.00	(0)		
<i>Thinopyrum ponticum</i> cv. Dundas	2.00	(134)	1.46	(60)	2.29	(256)	3.43	(3241)
<i>T. ponticum</i> Tas1499							3.69	(5620)
<i>T. ponticum</i> cv. Tyrell	2.06	(135)	1.20	(70)	2.15	(283)	3.39	(2998)
Site mean		(87)		(80)		(106)		(2563)
l.s.d. ($P = 0.05$)	0.622		0.809		0.789		0.368	

4

1 **Table 14. Third year perennial grass frequency (square root transformed) at**
2 **Tammin ($P < 0.01$), Duranillin ($P < 0.001$) and Cranbrook ($P < 0.001$). Raw means**
3 **(percentage of 1 dm² squares with live crown material) are shown in parentheses.**

Species	Site					
	Tammin		Duranillin		Cranbrook	
<i>Dactylis marina</i> PI229472	1.00	(0)	1.00	(0)		
<i>D. marina</i> PI237604	1.00	(0)	1.00	(0)		
<i>Eleusine indica</i> PI408802					1.00	(0)
<i>Festuca arundinacea</i> cv. Triumph	1.00	(0)	1.00	(0)		
<i>F. arundinacea</i> cv. Fraydo	2.96	(11)	1.00	(0)		
<i>Lolium perenne</i> PI201185					1.00	(0)
<i>Phalaris aquatica</i> cv. Sirolan	1.64	(2)	1.00	(0)	5.98	(38)
<i>Puccinellia ciliata</i> cv. Menemen	3.25	(14)	5.22	(27)	3.08	(11)
<i>P. ciliata</i> SA39293					4.05	(17)
<i>P. distans</i> PI502581					1.00	(0)
<i>Thinopyrum ponticum</i> cv. Dundas	3.48	(14)	2.04	(4)	8.69	(75)
<i>T. ponticum</i> cv. Tyrell	3.23	(10)	2.00	(4)	7.80	(61)
Site mean		(6)		(4)		(25)
l.s.d. ($P = 0.05$)	1.668		0.633		1.362	

4

1 **Table 15. Third year spring herbage production ($\log_{10}$ transformed) of perennial**
2 **grasses at Tammin ($P < 0.001$) and Duranillin ($P < 0.001$). Raw means (kg/ha) are**
3 **shown in parentheses. Biomass ratings (0 – 10) are shown for Girgarre (P**
4 **< 0.001).**

Species	Site				
	Tammin		Duranillin		Girgarre
<i>Austrodanthonia richardsonii</i> cv.Hume					0.1
<i>Dactylis marina</i> PI229472	0.00	(0)	0.00	(0)	1.1
<i>D. marina</i> PI237604	0.00	(0)	0.00	(0)	1.3
<i>Festuca arundinacea</i> cv. Triumph	0.00	(0)	0.00	(0)	
<i>F. arundinacea</i> cv. Fraydo	1.24	(154)	0.00	(0)	
<i>Lolium perenne</i> PI170521					0.4
<i>L. perenne</i> cv. Victorian					1.8
<i>Phalaris aquatica</i> cv. Australian					3.3
<i>P. aquatica</i> cv. Sirolan	0.86	(21)	0.00	(0)	4.1
<i>P. aquatica</i> x <i>P. arundinacea</i> hybrid					3.1
<i>Puccinellia ciliata</i> cv. Menemen	1.23	(86)	2.98	(988)	0.0
<i>Thinopyrum ponticum</i> cv. Dundas	1.79	(227)	1.73	(84)	3.3
<i>T. ponticum</i> Tas1499					3.8
<i>T. ponticum</i> cv. Tyrell	2.18	(259)	1.87	(128)	3.0
Site mean		(93)		(150)	2.1
l.s.d. (<i>P</i> = 0.05)	1.022		0.338		1.16

5

6

1 **Table 16. Suitability of temperate perennial legume and grass species for**
2 **southern Australian sites differing in soil salinity, drainage and annual rainfall.**
3 **Electrical conductivities (EC_e) are for maximum (summer-autumn) levels in the**
4 **top 10 cm of soil. Salinity categories are those of Rogers *et al.* (2005).**

		Low salinity	Moderate salinity	High salinity
		(2 - 4 dS/m)	(4 - 8 dS/m)	(>8 dS/m)
Poorly drained		>450 mm mean annual rainfall		
(prone to winter waterlogging)	Tall wheatgrass		Puccinellia	Puccinellia
	Phalaris		Tall wheatgrass	
	Strawberry clover		Phalaris	
	<i>Lotus corniculatus</i>		Strawberry clover	
	<i>L. tenuis</i>		<i>Lotus corniculatus</i>	
	<i>L. uliginosis</i>		<i>L. tenuis</i>	
		<450 mm mean annual rainfall		
	Tall wheatgrass		Puccinellia	Puccinellia
			Tall wheatgrass	
Well-drained		>450 mm mean annual rainfall		
	Tall wheatgrass		Tall wheatgrass	Tall wheatgrass
	Phalaris		Phalaris	
	Lucerne		Lucerne	
	Sulla		Sulla	
	Tall fescue			
	Perennial ryegrass			
		<450 mm mean annual rainfall		
	Tall wheatgrass		Tall wheatgrass	Tall wheatgrass
	Lucerne		Lucerne	

5