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

P. G. H. Nichols[A,B,H,J], *M. E. Rogers*[C,H], *A. D. Craig*[D,H], *T. O. Albertsen*[E,H], *S. M. Miller*[D,H,I], *D. R. McClements*[A,H], *S. J. Hughes*[F,H], *M. F. D'Antuono*[A] *and B. S. Dear*[G,H]

[A]Department of Agriculture and Food Western Australia, Locked Bag 4, Bentley Delivery Centre WA 6983, Australia.
[B]School of Plant Biology, Faculty of Natural and Agricultural Sciences, The University of Western Australia, Crawley WA 6009, Australia.
[C]Primary Industries Research Victoria, Department of Primary Industries Victoria, Tatura, Vic 3616, Australia.
[D]South Australian Research and Development Institute, Struan Research Centre, PO Box 618, Naracoorte, SA 5271, Australia.
[E]Department of Agriculture and Food Western Australia, Great Southern Agricultural Research Institute, Katanning, WA 6317, Australia.
[F]South Australian Research and Development Institute, Plant Research Centre, Waite Campus, Adelaide, SA 5001, Australia.
[G]EH Graham Centre for Agricultural Innovation (Alliance between New South Wales Department of Primary Industries and Charles Sturt University), Pine Gully Road, Wagga Wagga, NSW 2650, Australia.
[H]Cooperative Research Centre for Plant-based Management of Dryland Salinity, The University of Western Australia, 35 Stirling Highway, Crawley, WA 6009, Australia.
[I]Current address: South East Natural Resources Management Board, Mount Gambier, SA 5290, Australia.

[J]Corresponding author: email: pnichols@agric.wa.gov.au

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

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

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

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

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

Real *et al.* (2007 this issue) demonstrated high waterlogging tolerance of *Lotus tenuis* Waldst. & Kit. ex Willd., *L. corniculatus* L. and *L. uligonosis* Schkuhr, with 44 – 109% mean daily growth rates of drained controls following 6 weeks of inundation. Schachtman and Kelman (1991) found *L. tenuis* and *L. corniculatus* to have similar or greater salinity tolerance than lucerne, on the basis of growth reductions at 120 mol/m^3 NaCl, while *Lotus uligonosis* had a greater reduction. Recently Teakle *et al.* (2007) demonstrated greater tolerance of L. *tenuis* than *L. corniculatus* to the interactive effects of salinity and waterlogging. Among other perennial legumes, Le Houérou (1986) suggested that sulla (*Hedysarum coronarium* L.) 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 2003*b*), 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), while Cranbrook and Girgarre were moderately saline (EC_e 4 - 8 dS/m). However, in winter Duranillin had moderate salinity, Tammin and Cranbrook had low salinity (EC_e 2 - 4 dS/m) and Girgarre and Keith were non-saline (EC_e < 2 dS/m). Additional site information is given in Nichols *et al.* (2007 this issue).

Insert Table 1 near here

Species evaluated

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

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

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

Data analysis

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

In order to ascertain whether species success could be related to site differences, Pearson correlations (n = 5) were conducted between mean plant measurements (transformed) and either soil attributes (Table 1) or rainfall data (Table 3 from Nichols *et al.* 2007 this issue) for species common to at least 4 sites. Five perennial legumes (*Hedysarum carnosum, Lotus 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. pentaphylum* 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/m^2 (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.

Insert Table 11 near here

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

Insert Table 12 near here

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

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

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

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

In southern Australia perennials also need to cope with the stress of summer drought typical of mediterranean-type climates. Few commercial perennial pasture species are well adapted, particularly to the low and medium rainfall parts of this zone, largely due to their temperate origin (Lolicato and Rogers 1997; Cocks 2001; Dear *et al.* 2003; Dear and Ewing 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 perennial legume at Tammin, herbage production was very low and very few plants remained after 3 years. Modelling by Hill (1996) suggests unreliable lucerne persistence in WA north of a transect from Perth to Esperance. Tammin lies north of such a line, suggesting its lack of persistence could have been due to the relatively harsh climate, in addition to the effects of salinity.

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

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

Sulla is a widely cultivated species in parts of the Mediterranean basin, but is a relatively new species to agriculture in Australia (Dear *et al.* 2003; Yates *et al.* 2006). These experiments support the observations of Le Houérou (1986), who suggests it has some salinity tolerance. Its performance at the moderately saline site of Girgarre, where it was the most 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 2003*b*). 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

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

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

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

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

The performance of the 2 tall wheatgrass cultivars was remarkably similar across all 5 sites. Dundas and Tyrell also performed similarly on a range of saline soils in western Victoria (Nichols 1998), while Zhang *et al.* (2005) found them to have similar seedling tolerance to salt stress. These results are not surprising, as Dundas is a selection from within Tyrell for enhanced leafiness and quality (Smith 2000).

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

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

There was a marked difference in performance between the 2 tall fescue cultivars at Tammin, with Triumph failing to persist beyond the first summer. This is probably more a reflection of the difference in seasonal growth pattern of the 2 genotypes, rather than any difference in salinity tolerance. Fraydo is an early flowering Mediterranean type with high summer dormancy (Reed *et al.* 2004). Such types generally perform better in the mediterranean climate of south-western Australia than the more winter-active Triumph types (Sanford 2006; Reed *et al.* 2007 this issue).

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

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

Species recommendations for different saline environments

In order to reliably determine the suitability of perennial pasture species for different classes of saline land, consideration needs to be given to the time of year and depth of soil for obtaining salinity measurements that are meaningful to their growth. These experiments measured salinity levels in the surface 10 cm in winter and summer and did not consider salinity levels at greater depths, which have been shown by Smith and Stoneman (1970) to vary much less during the year. Nichols *et al.* (2007 this issue) argued that the critical site salinity measurement for annual pasture legume species recommendations in southern Australia is in the surface 10 cm during early autumn, reflecting the highest levels regenerating pasture seeds could be subjected to following germination, and that summer EC_e levels also approximated these. However, the ability of tall wheatgrass (Bleby *et al.* (1996) and *Melaleuca halmaturorum* (Mensworth and Walker (1996) to access less saline water from depths greater than 0.5 m over summer and early autumn suggests this time and soil depth may not be the most appropriate for perennial plants. Further work is needed to more accurately define the optimal time and soil depth for determining perennial plant suitability on saline land.

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

Insert Table 16 near here

For non-saline sites (summer EC_e <2 dS/m), salinity-tolerance is not required and a wide range of pasture and crop species can be grown. For medium and high rainfall areas (typically greater than 450 mm mean annual rainfall) with low salinity (summer EC_e 2 - 4 dS/m), there are several options for both well-drained and poorly drained sites. Tall 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. uligonosis* and *L. tenius* 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. uligonosis* 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 2003*b*). 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 2003*b*) 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 Tyrrell (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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Table 1. Experimental site locations, mean annual rainfall (data from Bureau of 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] Winter	Summer	Drainage rating[B]	Soil texture rating[C]
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

[A] Mean salinity values at each site in winter (minimum) and summer (maximum)

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

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

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

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

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

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

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

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

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

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

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

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

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

[A] 0 = no nodules, 1 = small white nodules only, 2 = less than 5 pink nodules and 3 = at least 5 pink nodules.

[B] 0 = all plants dead, 5 = all plants green and healthy.

[C] Likely to be over-estimated due to a limited number of surviving plants

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

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

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

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

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

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

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

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

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

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

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

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

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

Species	Site							
	Tammin		Duranillin		Cranbrook		Keith	
Dactylis marina PI229472	1.00	(0)	1.48	(2)			1.00	(0)
D. marina PI237604	1.29	(1)	1.00	(0)			1.00	(0)
Eleusine indica PI408802					1.00	(0)		
Festuca arundinacea cv. Triumph	1.00	(0)	1.00	(0)				
F. arundinacea cv. Fraydo	4.22	(21)	1.00	(0)				
Lolium perenne PI170521							1.00	(0)
L. perenne PI197270							1.00	(0)
L. perenne PI201185					1.46	(2)	1.00	(0)
L. perenne cv. Victorian							1.00	(0)
Phalaris aquatica cv. Sirolan	3.27	(11)	1.00	(0)	4.92	(24)	1.00	(0)
Puccinellia ciliata cv. Menemen	5.37	(34)	5.01	(24)	3.00	(10)	9.36	(87)
P. ciliata SA39293					2.89	(11)		
P. distans PI502581					2.72	(7)		
Thinopyrum ponticum cv. Dundas	4.47	(21)	1.89	(3)	5.49	(31)	6.65	(43)
T. ponticum 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	

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

Species	Site							
	Tammin		Duranillin		Cranbrook		Girgarre	
Austrodanthonia richardsonii cv.Hume							0.00	(0)
Dactylis marina PI229472	0.00	(0)	0.80	(50)			2.86	(764)
D. marina PI237604	0.25	(4)	0.00	(0)			2.84	(1392)
Eleusine indica PI408802					0.00	(0)		
Festuca arundinacea cv. Triumph	0.00	(0)	0.00	(0)				
F. arundinacea cv. Fraydo	1.00	(34)	0.00	(0)				
Lolium perenne PI170521							0.00	(0)
L. perenne PI201185					0.00	(0)		
L. perenne cv. Victorian							3.46	(4129)
Phalaris aquatica cv. Australian							3.27	(2220)
P. aquatica cv. Sirolan	1.51	(35)	0.00	(0)	2.02	(179)	3.79	(8486)
P. aquatica x *P. arundinacea* hybrid							3.20	(1906)
Puccinellia ciliata cv. Menemen	2.32	(352)	2.58	(460)	0.25	(3)	0.00	(0)
P. ciliata SA39293					1.37	(129)		
P. distans PI502581					0.00	(0)		
Thinopyrum ponticum cv. Dundas	2.00	(134)	1.46	(60)	2.29	(256)	3.43	(3241)
T. ponticum Tas1499							3.69	(5620)
T. ponticum 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	

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

Species	Site					
	Tammin		Duranillin		Cranbrook	
Dactylis marina PI229472	1.00	(0)	1.00	(0)		
D. marina PI237604	1.00	(0)	1.00	(0)		
Eleusine indica PI408802					1.00	(0)
Festuca arundinacea cv. Triumph	1.00	(0)	1.00	(0)		
F. arundinacea cv. Fraydo	2.96	(11)	1.00	(0)		
Lolium perenne PI201185					1.00	(0)
Phalaris aquatica cv. Sirolan	1.64	(2)	1.00	(0)	5.98	(38)
Puccinellia ciliata cv. Menemen	3.25	(14)	5.22	(27)	3.08	(11)
P. ciliata SA39293					4.05	(17)
P. distans PI502581					1.00	(0)
Thinopyrum ponticum cv. Dundas	3.48	(14)	2.04	(4)	8.69	(75)
T. ponticum 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	

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

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

Table 16. Suitability of temperate perennial legume and grass species for southern Australian sites differing in soil salinity, drainage and annual rainfall. Electrical conductivities (EC_e) are for maximum (summer-autumn) levels in the 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 (prone to winter waterlogging)	*>450 mm mean annual rainfall*		
	Tall wheatgrass	Puccinellia	Puccinellia
	Phalaris	Tall wheatgrass	
	Strawberry clover	Phalaris	
	Lotus corniculatus	Strawberry clover	
	L. tenuis	*Lotus corniculatus*	
	L. uligonosis	*L. tenuis*	
	<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	