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# Australian perennial shrub species add value to the feed base of grazing livestock in low- to medium-rainfall zones

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**Abstract.** Australian native perennial shrubs that are adapted to drought and infertile soils contribute nutrients to grazing systems that would otherwise support limited ruminant productivity. In this study, we report the nutritive value of 39 Australian shrub species of the genera *Atriplex*, *Rhagodia*, *Maireana*, *Chenopodium*, *Enchylaena*, *Acacia*, *Eremophila*, and *Kennedia*. Edible foliage was sampled in winter and summer, and there was little difference in nutritive value between seasons. The *in vitro* organic matter digestibility of most shrub species was 40–70%. Most species contained medium to high levels of crude protein (12–22% of dry matter, DM) and high concentrations of sulfur (2–8 g/kg DM). In an 8-week grazing experiment in which Merino wethers grazed a 'shrub system' containing four shrub species and a sown inter-row of annual pasture, the sheep gained weight during autumn without supplementary feeding. By comparison, sheep fed senesced volunteer pasture and supplementary cereal grain only maintained weight. The forage shrubs provided up to 50% of the total DM intake of sheep grazing the 'shrub system' and made a modest contribution to the digestible energy intake of the animals and a large contribution to their crude protein and mineral intake. Considering the timely and predictable provision of limiting nutrients and benefits such as gut health and the provision of shade and shelter, we suggest that Australian shrub species can make a valuable addition to the feed base of low- to medium-rainfall zones in southern Australia.

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## Introduction

The availability of nutritious feed for grazing livestock in southern Australia varies between seasons (Revell and Sweeney 2004), with autumn being a typical 'feed gap' where demand exceeds supply (Moore *et al*. 2009). This is particularly so in areas where there is strong reliance on annual-based pasture species that are dead during the dry, hot summer and autumn periods. During this time, both feed quantity and quality are limiting, and consequently, supplementary feeding is often required to meet animal requirements. Options for bridging the feed gap using perennial pastures have been identified (Dear and Ewing 2008; Hayes *et al*. 2010; Real *et al*. 2011), but viable options are limited for areas with low to medium rainfall (<500 mm annual rainfall), long summers, and poor-quality soil. The possible contribution of perennial shrub species to the southern Australian feed base has received some attention (e.g. saltbush, Norman *et al*. 2004; Ben Salem *et al*. 2010; and tagasaste, Tudor *et al*. 2000), but less than might be expected given the reliance on forage shrubs in many semi-arid regions in Australia (Wilson 1994) and other parts of the world (Le Houérou 2000; Estell *et al*. 2012).

Recent research has re-focussed attention on the potential of Australian perennial shrub species (Revell *et al*. 2008). In this research, a broad approach was adopted to study not only the edible biomass production of shrubs in the out-of-season period (late summer–autumn), but the effects of shrubs on rumen fermentation (Durmic *et al*. 2010), gut parasites (Kotze *et al*. 2009), and natural resource management (e.g. water use and control of wind erosion). Bio-economic analysis indicates that whole-farm profit can be increased by inclusion of perennial shrubs into the feed base (O'Connell *et al*. 2006; Monjardino *et al*. 2010), which reduces the amount of supplementary feed required and enables deferment of grazing from annual pasture species to shrub-based forages at the break of season (the end of autumn).

In this paper, we report two experiments conducted to determine the potential contribution of Australian shrub species to productive grazing systems. The first experiment quantified the contribution to ruminant production of digestible organic matter (OM) (energy), nitrogen (N) (crude protein), phosphorus (P), and other macro- and trace-minerals in Australian perennial shrubs from 39 species across eight genera. The second experiment quantified the performance of livestock in a forage system that included a mixture of native shrub species.

## Materials and methods

### *Experiment 1. Evaluation of the nutritive value of Australian perennial shrub species*

The process used for selecting perennial shrub species for inclusion in grazing systems was described by Bennell *et al.* (2010). In brief, the main selection criteria were: (i) a perennial life habit and woody growth form, which includes growth forms such as trees and creepers; (ii) species that are native to the traditional livestock–cropping zone (temperate) or the southern pastoral zone (semi-arid); (iii) evidence of palatability and no evidence of toxicity to livestock; and (iv) potential to be propagated and grown under field conditions. Consequently, 87 species were evaluated in the 'Enrich' project (Revell *et al.* 2008). In this paper, we report on 39 of these species (Table 1) from eight of the most represented genera that are widely relevant to growing conditions in southern Australia. The shrubs were planted as seedlings in 2006 at Monarto, South Australia (35.12080S, 139.13763E, sandy-loam over clay, pH ($CaCl_2$) 8.0). Leaves, stems, and petioles <3 mm in diameter were sampled in December 2007 and June 2008 for nutritive value analyses. Average annual rainfall during study period was 364 mm.

After sampling, plant samples were dried at 60°C for 48 h, ground through a 1-mm sieve using a Tecator grinder (Foss, Hillerød, Denmark), and analysed for content of OM and total ash (Faichney and White 1983), neutral detergent fibre (NDF) and acid detergent fibre (ADF) (Ankom 200/220 fibre analyser; Ankom Technology Co., Fairport, NY, USA), and mineral content (inductively coupled plasma-atomic emission spectrometry following digestion in nitric and hydrochloric acid; Waite Analytical Services, Urrbrae, S. Aust.; McQuaker *et al.* 1979). Crude protein was calculated as N × 6.25. *In vitro* OM digestibility (OMD) was estimated using the pepsin–cellulase digestion method (Klein and Baker 1993) followed by calibration to correct for the effect of salt on digestibility (Masters *et al.* 2005) and apparent systematic overestimations of *in vivo* OMD of chenopods and other shrub genera when using the pepsin–cellulase digestion method (Norman *et al.* 2010*a*). It should be noted that the calibrations developed by Norman *et al.* (2010*a*) were based on species of *Acacia*, *Atriplex*, and *Maireana*. We assumed that these correction factors were relevant to the other genera tested in our study. We believe this is a valid assumption because of linearity in the correction factors despite differences in the content of nutrients and secondary compounds between *Acacia*, *Atriplex*, and *Maireana*.

### *Experiment 2. Field evaluation of livestock performance grazing shrubs and pasture*

A field study was conducted as a proof-of-concept demonstration of a 'shrub system' consisting of sown shrubs and sown inter-row pasture compared with a 'standard system' of volunteer (unimproved) pasture and supplementation with barley grain. The shrub species studied in Expt 1 were subjected to a 'decision tree' (Emms *et al.* 2013) to identify candidates most likely to make a valuable contribution to grazing systems based on plant productivity, *in vitro* fermentation including methane production (Durmic *et al.* 2010), and anthelmintic properties (Kotze *et al.* 2009). The outcome from this decision-making process, together with the nutritive value traits from Expt 1, was used to select the species for the grazing experiment.

#### *Site details*

The study was conducted in autumn 2012 on a commercial farm at Quairading (32.1326S, 117.3797E) in a paddock with soil pH($CaCl_2$) 7.7 and soil conductivity 270 μS/cm at 0–15 cm and 630 μS/cm at 15–30 cm. Each species of shrub was planted as seedlings in three replicated plots of ~3.36 ha each in spring 2010. The shrubs were planted in double rows, 2 m apart, with shrubs at intervals of ~1.5 m within each row. For each species, five double rows were planted in 2010, with inter-row spaces of 5 m sown to a mix of annual pasture, mostly annual ryegrass and barley.

During the grazing period, a total of 20.6 mm of rainfall was recorded at the closest weather station (Bureau of Meteorology Quairading Station, 13 km away). Only 6 mm was recorded in April and three rainfall events were recorded in May (1.4, 12.4, and 0.8 mm on 4, 5, and 8 May). There was negligible germinating green pasture during the experimental period.

#### *Animal management*

Merino wethers ($n$ = 120) aged ~10 months were randomly allocated to two groups balanced for liveweight, the shrub system ($n$ = 60) and the standard system ($n$ = 60). Both groups were divided into three replicates ($n$ = 20 sheep per replicate). At the start of the experiment, the sheep weighed an average of 35.7 kg (s.e. 0.26 kg) and had an average condition score of 2.5 (1–5 scale; Suiter 1994). Liveweight gain, condition score, and feed intake were measured over an 8-week period from April to May 2012. All animals were weighed at the same time of day on each occasion (0900–1000 hours) to minimise variation associated with changes in gut fill.

Each group of 20 sheep in the shrub system grazed 20 m strips within their allocated plot, which provided an area of 0.28 ha. The width of the strips was determined so that the estimated feed on offer from both the shrubs and the inter-row pasture represented 130% of weekly requirements (maintenance plus growth; CSIRO 2007). The shrubs were grazed at a high stocking rate, equivalent to 71 sheep/ha, and the sheep were moved on a weekly basis to a new strip within their allocated paddock. Over the 8 weeks of grazing, 2.24 ha of the shrub plot was used for each group of 20 sheep, which was equivalent to a stocking rate over this period of 8.9 sheep/ha. This strip-grazing approach was taken to ensure that, in each week, there was sufficient grazing pressure to encourage consumption of the novel shrub species, and the movement to a new strip each week ensured that the sheep had access to the full range of shrub species each week. No supplementary feed (i.e. no hand-feeding) was provided to the sheep in the shrub system.

The amount of edible DM provided by the shrubs was estimated using the 'Adelaide' technique (Andrew *et al.* 1979). After grazing, the percentage of leaf removal from 50% of the shrubs in each plot was assessed visually using a 0–5 scale corresponding to 0%, 20%, 40%, 60%, 80%, and 100% removal. Shrub intake was calculated from the edible biomass on offer

**Table 1. Genera and species, taxa authorship, and plant accession numbers for 39 species of Australian native shrubs**
All species were sampled in June 2007 and again December 2008

| Botanical name | Taxa author | Accession no. | Collection time | Growth stage |
|---|---|---|---|---|
| *Acacia ligulata* | A.Cunn. ex Benth. | SA 44755 | December | Vegetative |
| | | | June | Vegetative |
| *Acacia loderi* | Maiden | SA 44513 | December | Vegetative |
| | | | June | Vegetative |
| *Acacia myrtifolia* | (Sm.) Willd. | SA 44517 | December | Vegetative |
| | | | June | Vegetative |
| *Acacia neriifolia* | A.Cunn. ex Benth. | SA 44518 | December | Vegetative |
| | | | June | Vegetative |
| *Acacia pycnantha* | Benth. | SA 45612 | December | Vegetative |
| | | | June | Vegetative |
| *Acacia saligna* | (Labill.) H. L. Wendl. | SA 44520 | December | Vegetative |
| | | | June | Vegetative |
| *Atriplex amnicola* | Paul G. Wilson | SA 41310 | December | Reproductive (fruit) |
| | | | June | Reproductive (flowering and fruit) |
| *Atriplex cinerea* | Poir. | SA 45593 | December | Reproductive (flowering and fruit) |
| | | | June | Reproductive (fruit) |
| *Atriplex isatidea* | Moq. | SA 44093 | December | Vegetative |
| | | | June | Vegetative |
| *Atriplex nummularia* | Lindl. | cv. Eyres Green | December | Reproductive (fruit) |
| | | | June | Vegetative |
| *Atriplex paludosa* | R.Br. | SA 40803 | December | Vegetative |
| | | | June | Reproductive (flowering and fruit) |
| *Atriplex rhagodioides* | F.Muell. | SA 44768 | December | Vegetative |
| | | | June | Reproductive (Fruit) |
| *Atriplex semibaccata* | R.Br. | SA 41067 | December | Reproductive (Flower) |
| | | | June | Reproductive (flowering and fruit) |
| *Atriplex vesicaria* | Heward ex Benth. | SA 44622 | December | Reproductive (flowering and fruit) |
| | | | June | Reproductive (flowering and fruit) |
| *Chenopodium gaudichaudianum* | (Moq.) Paul G.Wilson | SA 44098 | December | Reproductive (flowering and fruit) |
| | | | June | Reproductive (flowering and fruit) |
| *Chenopodium nitrariaceum* | (F.Muell.) Benth. | SA 42577 | December | Vegetative |
| | | | June | Vegetative |
| *Enchylaena tomentosa* | R.Br. | SA 41119 | December | Reproductive (flowering and fruit) |
| | | | June | Reproductive (flowering and fruit) |
| *Eremophila bignoniiflora* | (Benth.) F.Muell. | SA 45611 | December | Vegetative |
| | | | June | Vegetative |
| *Eremophila glabra* | (R.Br.) Ostenf. | SA 44440 | December | Reproductive (fruit) |
| | | | June | Reproductive (fruit) |
| *Eremophila longifolia* | (R.Br.) F.Muell. | SA 45610 | December | Vegetative |
| | | | June | Vegetative |
| *Eremophila maculata* | (Ker Gawl.) F.Muell. | SA 44715 | December | Reproductive (fruit) |
| | | | June | Vegetative |
| *Kennedia eximia* | Lindl. | SA 41699 | December | Reproductive (fruit) |
| | | | June | Vegetative |
| *Kennedia macrophylla* | Lindl. | SA 40368 | December | Vegetative |
| | | | June | Vegetative |
| *Kennedia nigricans* | Lindl. | SA 41412 | December | Vegetative |
| | | | June | Vegetative |
| *Kennedia prorepens* | (F.Muell.) F.Muell | SA 41349 | December | Reproductive (flowering and fruit) |
| | | | June | Vegetative |
| *Kennedia prostrata* | R.Br. | SA 41710 | December | Reproductive (flower) |
| | | | June | Reproductive (fruit) |
| *Maireana astrotricha* | (L.A.S.Johnson)Paul G.Wilson | SA 26084 | December | Vegetative |
| | | | June | Vegetative (post reproduction) |
| *Maireana brevifolia* | (R.Br.) Paul G.Wilson | SA 42869 | December | Vegetative |
| | | | June | Vegetative |
| *Maireana convexa* | Paul G.Wilson | SA 44114 | December | Vegetative |
| | | | June | Vegetative |

(*continued next page*)

**Table 1.** (*continued*)

| Botanical name | Taxa author | Accession no. | Collection time | Growth stage |
|---|---|---|---|---|
| *Maireana georgei* | (Diels) Paul G.Wilson | SA 42601 | December | Vegetative (post reproduction) |
| | | | June | Vegetative |
| *Maireana planifolia* | (F.Muell.) Paul G.Wilson | SA 44536 | December | Vegetative (post reproduction) |
| | | | June | Vegetative |
| *Maireana pyramidata* | (Benth.) Paul G.Wilson | SA 42717 | December | Vegetative |
| | | | June | Vegetative |
| *Maireana sedifolia* | (F.Muell.) Paul G.Wilson | SA 44717 | December | Vegetative |
| | | | June | Vegetative |
| *Maireana tomentosa* | Moq. | SA 41419 | December | Reproductive (flowering and fruit) |
| | | | June | Vegetative |
| *Rhagodia candolleana* | Moq. | SA 41409 | December | Vegetative |
| | | | June | Reproductive (flowering and fruit) |
| *Rhagodia crassifolia* | R.Br. | SA 41139 | December | Vegetative |
| | | | June | Reproductive (flowering and fruit) |
| *Rhagodia parabolica* | R.Br. | SA 41029 | December | Reproductive (flowering) |
| | | | June | Reproductive (flowering and fruit) |
| *Rhagodia preissii* | Moq. | SA 45214 | December | Reproductive (flowering) |
| | | | June | Reproductive (flowering and fruit) |
| *Rhagodia spinescens* | R.Br. | SA 41030 | December | Vegetative |
| | | | June | Vegetative |

pre-grazing and the proportion of leaf removed during grazing. Pasture biomass was assessed from 20 quadrat cuts of the inter-row during each week of grazing, and the difference in biomass between pre- and post-grazing was used to estimate pasture intake.

The amount of supplementary feed provided to sheep in the standard system was adjusted during the course of the experiment to ensure that the sheep maintained liveweight. The amount of supplementary grain fed was 100 g/head.day for the first 3 weeks, 200 g/head.day in week 4, 300 g/head.day in week 5, and 400 g/head.day in weeks 6–8.

### *Statistical analyses*

Nutritive value traits of the shrub species in Expt 1 were compared by analysis of variance (ANOVA), with genus and sampling data as the factors. In Expt 2, the intake of DM, digestible OM, crude protein, and minerals from the shrubs was analysed by ANOVA comparing intake over time (weeks). The liveweight and condition score of sheep in the shrub system was compared with that of sheep in the standard system group using ANOVA with repeated-measures (weeks). All analyses were performed using GENSTAT 15th edition (VSN International Ltd, Hemel Hempstead, UK).

## Results

### *Experiment 1. Nutritive value of Australian shrub species*

#### *Organic matter digestibility*

The predicted OMD differed significantly between genera ($P < 0.001$) but not between collection dates (December *v.* June). The least digestible genera were *Kennedia* (average OMD 38.1%, s.e. 1.88) and *Acacia* (average OMD 44.2%, s.e. 1.72), and the most digestible genera were *Eremophila* (average OMD 66.1%, s.e. 2.11) and *Rhagodia* (average OMD 63.0%, s.e. 1.88) (Table 2). The mid-ranking genera were *Chenopodium* (average OMD 59.6%, s.e. 2.98), *Enchylaena* (single species represented; average OMD 57.8%, s.e. 4.21), *Atriplex* (average OMD 51.3%, s.e. 1.49), and *Maireana* (average OMD 46.1%, s.e. 1.49). Across all species tested, there was a significant linear relationship ($P < 0.001$) between OMD and NDF and ADF, the stronger relationship being with ADF, for which about two-thirds of the variation in OMD could be accounted for by variation in the ADF content of the plants (Fig. 1).

#### *Nitrogen, phosphorus, and sulfur*

The N content of the shrub species varied between genera ($P < 0.001$) but it was not affected by the time of year that the samples were collected. With the exception of *Eremophila* (1.8% N, s.e. 0.17), the average N content of all genera exceeded 2% (Table 2). *Maireana* had the highest N content (3.6%, s.e. 0.12), the *Rhagodia*, *Enchylaena*, and *Chenopodium* genera contained ~3% N (2.8%, 3.0%, and 3.2% N; s.e. 0.15, 0.34, and 0.24, respectively), and *Acacia* species averaged 2.0% N (s.e. 0.14).

There was an interaction ($P < 0.001$) between genera and sampling time for the P content of the shrubs; *Chenopodium* and *Maireana* had lower P contents in December than in June, but the other genera showed no significant difference between seasons. Across sampling times, *Chenopodium* had the highest P content (2.8 g/kg, s.e. 0.27), and *Acacia* and *Kennedia* the lowest (0.7 and 1.0 g/kg DM, s.e. 0.16 and 0.18, respectively; Fig. 2). Sulfur (S) content differed between genera ($P < 0.001$) but not with sampling time. *Atriplex*, *Rhagodia*, and *Chenopodium* species had the highest S content (4.8, 4.0, and 3.9 g/kg DM; s.e. 0.28, 0.35, and 0.56, respectively; Fig. 2). *Maireana*, *Acacia*, and *Enchylaena* were mid-ranked (2.5, 2.3, and 2.2 g S/kg DM; s.e. 0.28, 0.33, and 0.79, respectively), and *Eremophila* and *Kennedia* had the lowest S content (1.6 and 1.5 g/kg DM, s.e. 0.40 and 0.37, respectively; Fig. 2).

**Table 2. *In vitro* organic matter digestibility (OMD), and concentrations of neutral detergent fibre (NDF), acid detergent fibre (ADF), and nitrogen (N) (% DM) for 39 species of Australian native shrubs**

| Botanical name | *In vitro* OMD | NDF | ADF | N |
|---|---|---|---|---|
| *Acacia ligulata* | 38.7 | 24.2 | 18.8 | 2.1 |
| *Acacia loderi* | 51.3 | 33.5 | 24.0 | 1.8 |
| *Acacia myrtifolia* | 57.5 | 26.4 | 19.2 | 1.6 |
| *Acacia neriifolia* | 46.1 | 31.2 | 23.8 | 2.8 |
| *Acacia pycnantha* | 45.1 | 32.3 | 22.7 | 1.7 |
| *Acacia saligna* | 26.6 | 33.2 | 25.8 | 2.3 |
| *Atriplex amnicola* | 55.8 | 29.2 | 16.7 | 2.9 |
| *Atriplex cinerea* | 55.3 | 25.2 | 16.1 | 2.6 |
| *Atriplex isatidea* | 50.7 | 29.6 | 18.8 | 1.9 |
| *Atriplex nummularia* | 51.2 | 28.2 | 14.2 | 2.9 |
| *Atriplex paludosa* | 49.8 | 29.5 | 18.0 | 2.4 |
| *Atriplex rhagodioides* | 53.3 | 31.5 | 15.7 | 3.2 |
| *Atriplex semibaccata* | 48.7 | 36.2 | 20.8 | 2.6 |
| *Atriplex vesicaria* | 46.1 | 34.2 | 18.3 | 2.7 |
| *Chenopodium gaudichaudianum* | 53.4 | 32.5 | 17.5 | 2.9 |
| *Chenopodium nitrariaceum* | 65.8 | 21.0 | 11.2 | 3.5 |
| *Enchylaena tomentosa* | 57.8 | 25.2 | 13.4 | 3.0 |
| *Eremophila bignoniiflora* | 66.7 | 21.6 | 13.3 | 1.7 |
| *Eremophila glabra* | 63.0 | 27.8 | 16.4 | 1.8 |
| *Eremophila longifolia* | 65.7 | 21.3 | 16.9 | 1.4 |
| *Eremophila maculata* | 69.0 | 26.0 | 11.9 | 2.4 |
| *Kennedia eximia* | 38.1 | 32.9 | 23.9 | 2.1 |
| *Kennedia macrophylla* | 30.6 | 34.9 | 23.6 | 1.8 |
| *Kennedia nigricans* | 36.0 | 32.1 | 23.8 | 2.3 |
| *Kennedia prorepens* | 40.4 | 33.7 | 24.2 | 2.0 |
| *Kennedia prostrata* | 44.9 | 28.9 | 19.0 | 2.2 |
| *Maireana astrotricha* | 45.6 | 39.2 | 22.8 | 3.3 |
| *Maireana brevifolia* | 44.7 | 36.9 | 17.8 | 3.5 |
| *Maireana convexa* | 51.6 | 36.8 | 20.4 | 3.5 |
| *Maireana georgei* | 52.0 | 30.1 | 15.5 | 3.7 |
| *Maireana planifolia* | 42.4 | 43.0 | 28.2 | 3.8 |
| *Maireana pyramidata* | 48.7 | 34.1 | 18.7 | 3.2 |
| *Maireana sedifolia* | 42.2 | 44.6 | 26.5 | 3.6 |
| *Maireana tomentosa* | 41.7 | 41.0 | 26.1 | 4.1 |
| *Rhagodia candolleana* | 59.2 | 24.6 | 11.9 | 2.6 |
| *Rhagodia crassifolia* | 65.0 | 19.1 | 10.3 | 3.2 |
| *Rhagodia parabolica* | 67.6 | 18.2 | 9.6 | 3.1 |
| *Rhagodia preissii* | 67.4 | 17.8 | 9.1 | 1.9 |
| *Rhagodia spinescens* | 55.9 | 29.0 | 14.4 | 3.5 |

### *Sodium and potassium*

Sodium (Na) and potassium (K) contents both differed between genera ($P < 0.001$; Fig. 3) but not between sampling times. Sodium content was highest in *Atriplex* and *Maireana* species (57.5 and 55.6 g/kg DM, s.e. 3.22 and 3.33, respectively), which was ~50% higher than that of *Rhagodia* and *Eremophila* (38.5 and 33.5 g/kg DM, s.e. 4.08 and 4.56, respectively) and four times that of *Chenopodium* (13.6 g/kg DM, s.e. 7.44). *Eremophila*, *Acacia*, and *Kennedia* had the lowest Na contents (2.1–6.8 g/kg DM, s.e. 3.89–4.56). The ranking of genera for K content was not the same as for Na. *Chenopodium* had about twice the K content (62.5 g/kg DM, s.e. 3.46) of *Rhagodia* and *Atriplex* (31.4 and 29.3 g/kg DM, s.e. 2.18 and 1.73, respectively). *Maireana*, *Enchylaena*, and *Eremophila* were mid-ranked for K content (23.8, 18.8, and 14.0 g/kg DM; s.e. 1.73, 4.89, and

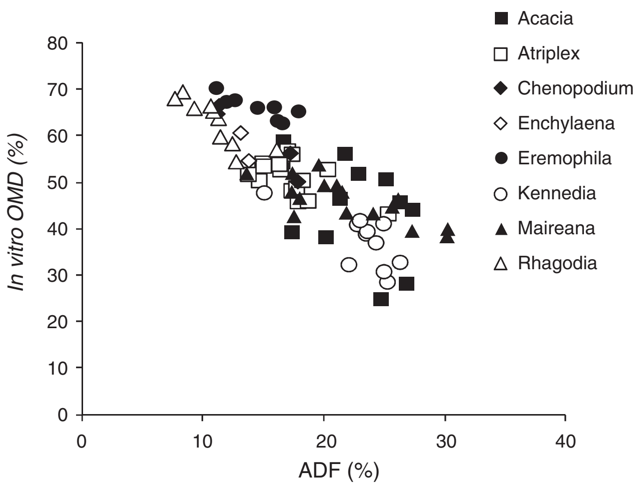


**Fig. 1.** Relationship between acid detergent fibre (ADF) and *in vitro* organic matter digestibility (OMD) for 39 Australian shrub species across eight genera, with plant material sampled in June 2007 and December 2008. With all data combined, the linear regression equation is $y = 1.60x + 80.61$ ($r^2 = 0.65$; $P < 0.001$).

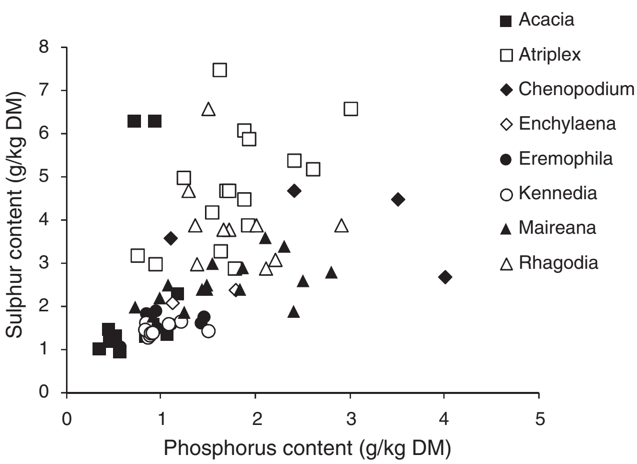


**Fig. 2.** Range of values for phosphorus (P) and sulfur (S) content of 39 Australian shrub species across eight genera, with plant material sampled in June 2007 and December 2008. Note: the *Acacia* samples with the highest S content were the June- and December-sampled *A. saligna*; the *Atriplex* samples with the highest S content were the June- and December-sampled *A. nummularia*; the *Chenopodium* samples with the high P content were *C. gaudichaudianum* and C. *nitrariaceum* sampled in December.

2.44, respectively), with *Acacia* and *Kennedia* having the lowest K content (10.4 and 8.4 g/kg DM, s.e. 2.08 and 2.30, respectively).

### *Other minerals*

All genera of shrubs contained more than the dietary requirement for ruminants (CSIRO 2007) for calcium (Ca, 5.1–11.8 *v.* 1–3 g/kg DM), magnesium (Mg, 2.6–11.4 *v.* 1–1.5 g/kg DM), copper (Cu, 2.2–9.8 *v.* 2–7 mg/kg DM), and iron (Fe, 84–413 *v.* 30 mg/kg DM) (Table 3). The concentrations of zinc (Zn) in all genera matched dietary requirements (20–30 *v.* 9.1–32.2 mg/kg DM; Table 3). The genera that possessed the

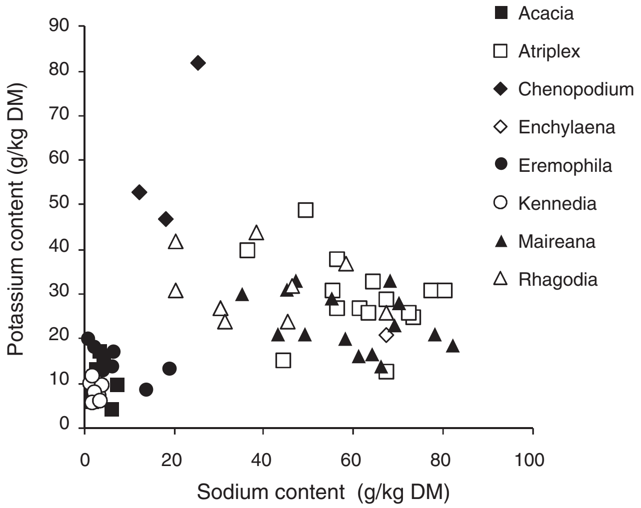


**Fig. 3.** Range of values for sodium (Na) and potassium (K) content of 39 Australian shrub species across eight genera, with plant material sampled in June 2007 and December 2008. Note: the *Chenopodium* sample with the high K content was *C. gaudichaudianum* sampled in December.

highest concentration of minerals were: Ca, *Atriplex*; Mg, *Rhagodia*; Cu, *Enchylaena*; Zn, *Atriplex*; and Fe, *Kennedia*.

### *Selection of forage shrubs for Expt 2*

The decision-tree of Emms *et al*. (2013) identified 18 species of merit, seven of which were considered suitable for the soil of the Quairading field site: *Acacia ligulata*, *Acacia neriifolia*, *Atriplex amnicola*, *Atriplex nummularia*, *Enchylaena tomentosa*, *Maireana brevifolia*, and *Rhagodia preissii*. The four species from this list with the highest *in vitro* OMD were selected for the field experiment: *A. amnicola*, *A. nummularia*, *R. preissii*, and *E. tomentosa*. *Eremophila glabra* was also included speculatively because of encouraging *in vitro* data on apparent anti-methanogenic properties (Durmic *et al*. 2010), but as it did not establish well at the site and contributed a negligible amount of biomass, no data on *E. glabra* are presented here.

## *Experiment 2. Field evaluation of the performance of livestock grazing shrubs and pasture*

### *Feed intake*

The mean intake of forage shrubs for sheep in the shrub system increased ($P < 0.001$) during the 8 weeks of grazing from 220 g/head.day over the first 4 weeks to 600 g/head.day during the final week, with the two *Atriplex* species making the largest contribution during the last 4 weeks of grazing (Fig. 4). The intake of *A. amnicola* and *E. tomentosa* did not vary significantly from week to week (average intake of 156 and 37 g/head.day, respectively). The intake of *A. nummularia* increased 4-fold ($P < 0.001$) in week 5, from 38 to 158 g/head.day and then doubled ($P < 0.001$) to 320 g/head.day during the final weeks of grazing. The intake of *R. preissii* showed a similar pattern of change to that of *A. nummularia*; it doubled from week 5 to week 6, but the average amount of *R. preissii* consumed was much lower, peaking at just 60 g/head.day in week 7. The proportion of edible leaf material consumed during the experimental period was: 70–90% of *A. amnicola* per week; 40% of *E. tomentosa* for the first 3 weeks, increasing to 90–100% by weeks 7 and 8; 20% of *A. nummularia* during the first 3 weeks, increasing to 80–100% during the last 3 weeks; 10% of *R. preissii* during the first 5 weeks, increasing to 50% by week 8 although with higher variability between the three groups than for the other species.

**Table 3. Content (mg/kg DM) of calcium, magnesium, copper, iron, and zinc for eight genera of Australian shrubs**

| Genus | Ca | Mg | Cu | Fe | Zn |
|---|---|---|---|---|---|
| *Acacia* | 10.2 | 3.0 | 2.3 | 81 | 9.2 |
| *Atriplex* | 11.8 | 8.2 | 8.7 | 234 | 32.2 |
| *Chenopodium* | 7.9 | 6.3 | 4.2 | 137 | 25.1 |
| *Enchylaena* | 5.1 | 1.8 | 9.8 | 255 | 17.6 |
| *Eremophila* | 7.3 | 2.8 | 5.6 | 155 | 14.4 |
| *Kennedia* | 8.5 | 3.5 | 4.3 | 424 | 12.6 |
| *Maireana* | 5.2 | 3.1 | 8.0 | 241 | 15.6 |
| *Rhagodia* | 8.8 | 11.5 | 6.9 | 208 | 25.8 |

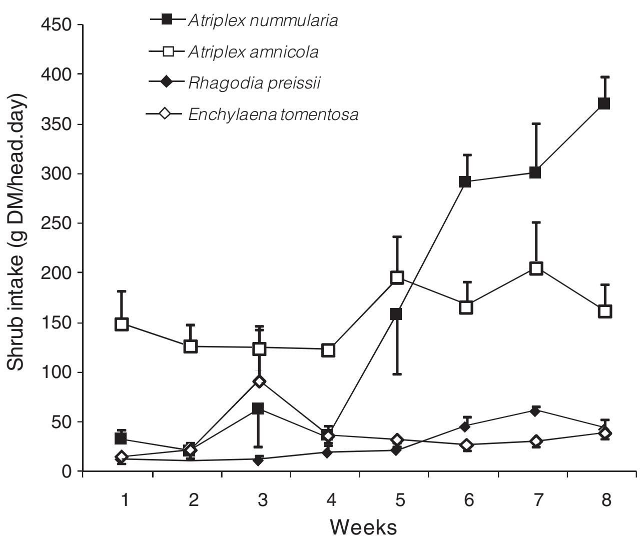


**Fig. 4.** Dry matter intake of the four shrub species on offer by sheep in the shrub treatment over the 8-week grazing period.

The mean intake of inter-row pasture by sheep in the shrub system was calculated as 1.4 kg DM/sheep.day (across weeks s.e. 0.14 kg DM/sheep.day). Observations when making the pasture quadrat cuts suggested that this might be an overestimate due to losses of plant material caused by trampling associated with the high grazing pressure. When this value was used, the intake of shrubs constituted an average of 24% of total DM intake during the 8 weeks of grazing, increasing from 16% in week 1 to 51% in week 8.

The intake of pasture and grain combined in the standard system averaged 0.6 kg DM/sheep.day (s.e. 0.02 kg DM/sheep.day). Assuming a metabolisable energy (ME) content of 7 MJ ME/kg DM for senesced pasture and 13.7 MJ ME/kg for grain (Cottle 1991), the energy intake of sheep in the control group was calculated to be 6 MJ/sheep.day, which is equivalent to weight maintenance for a 37-kg sheep.

### *Animal liveweight*

There was no significant change in the liveweight of sheep in the standard system treatment during the 8-week grazing period, nor was there any change in the liveweight of the sheep in the shrub system treatment for the first 4 weeks of grazing (Fig. 5). However, liveweight increased over the final 4 weeks of grazing for sheep in the shrub system, such that they finished the 8-week grazing period at an average weight of 39.0 kg, which was 2.8 kg heavier ($P < 0.05$) than the starting weight of both groups and the finishing weight of sheep in the standard system (36.2 kg). The rate of weight gain averaged 63 g/head.day for sheep in the shrub system, exceeding ($P < 0.01$) the weight maintenance of sheep in the standard system (average daily gain of 4 g/head.day). There was no significant change in condition score during the experiment, with all groups commencing the experiment with a condition score of 2.5 (s.e. 0.006) and finishing with a condition score of 2.7 (s.e. 0.028).

## Discussion

A key conclusion from the field study is that a forage system that includes Australian shrub species can be productive under commercial conditions, as predicted from whole-farm simulation modelling (O'Connell *et al*. 2006; Monjardino *et al*. 2010). We found that sheep gained nearly 3 kg of liveweight over a 2-month period when grazing a shrub system, at a time when feed quality and quantity would normally limit animal performance. Without any substantial rainfall or new pasture growth during the 2 months, the liveweight gain was achieved solely through the combination of shrubs and dry pasture, with the forage shrub contributing a significant portion of the daily intake during the latter half of the grazing period. Based on the amounts of grain provided to sheep grazing senesced, volunteer pasture (i.e. the standard system), the shrub system replaced 14 kg/head of supplementary grain and achieved a higher liveweight than standard practice. Adding perennial shrubs to the feed base of southern Australia is a particularly attractive proposition for parts of farming landscapes where cropping is not economically viable (Monjardino *et al*. 2010) because of the capacity of Australian native shrubs to tolerate difficult conditions, contribute digestible energy and nutrients to livestock during 'feed gaps', and provide a suitable microenvironment for productive pastures in the inter-row spaces.

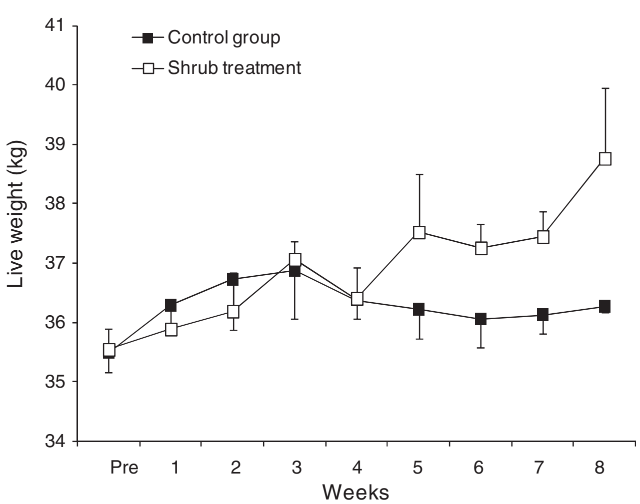


**Fig. 5.** Liveweight of sheep in the control group and shrub treatment before the experiment commenced (Pre) and over the 8-week grazing period.

Most species of Australian forage shrubs discussed here can be considered a 'standing supplement' of crude protein and minerals. With a moderate to high N content (most shrub species contained 2–3.5% N, or 12–23% crude protein), the shrubs offer scope for strategic use as a source of N to complement metabolisable energy provided by other feedstuffs. Under the grazing conditions of Expt 2, the sheep consumed an average of nearly 70 g crude protein/head.day from the forage shrubs. In the final week of grazing, when the intake of shrubs was highest, their consumption provided >100 g crude protein/head.day, approximately matching the protein requirements of young growing sheep (CSIRO 2007). However, to evaluate fully the contribution of Australian forage shrubs to the mineral nutrition of grazing livestock, further work is required to assess the bioavailability of minerals. Although several minerals were present in high concentrations in the shrub species tested (Na, K, S, Ca, and Mg), their coefficients of absorption have not been adequately described. The presence of mineral complexes or excessive losses of minerals in urine due to the diuretic effect of a high content of salt or other secondary compounds (Dearing *et al*. 2001; Estell 2010) may compromise the value of plants to provide minerals to livestock. When sheep consumed *A. nummularia* as the sole source of feed, Mayberry *et al*. (2010) found that sheep had a net loss of Mg, Ca, and P, which was attributed to reduced availability and absorption of the minerals, although the exact mechanisms were not identified.

When high concentrations of minerals are known to limit productivity, such as the intake-limiting, high-salt content of chenopod shrubs (Pistor *et al*. 1950; Masters *et al*. 2005), it is important that the shrubs are part of a mixed diet so that animals are able to avoid the over-consumption of particular nutrients or plant secondary compounds. Furthermore, forage shrubs can be used to complement the nutritional traits of other plants on offer. The timing of the provision of nutrients from forage shrubs complements the pattern of nutrient provision from winter-active pastures, and grazing of perennial shrubs before and during the break of season in autumn/early winter enables deferment of the grazing of annual pastures, thereby increasing pasture productivity and livestock carrying capacity at a whole-farm level (Monjardino *et al*. 2010). Another example of complementarity is that the high Na content of chenopod forage shrubs could be used to complement dual-purpose grazing crops, as early-season wheat plants are deficient in Na relative to the requirements of livestock. The provision of salt supplements has increased the growth rates of sheep grazing wheat in winter (Dove and McMullen 2009), a result that could perhaps be achieved by allowing sheep to graze winter wheat crops and saltbush simultaneously. In addition, the provision of a mixture of complementary plants is a feasible strategy to obtain value from the capacity of grazing livestock to adapt their grazing behaviour to optimise nutrient intake and minimise toxin intake (Burritt and Provenza 2000; Provenza *et al*. 2003; Villalba *et al*. 2004).

The *in vitro* OMD of the Australian native shrub species ranged from 69% to <30%. Overall, the genera with the highest OMD were *Rhagodia* and *Eremophila*, the genera with the lowest being the legume species, *Acacia* and *Kennedia*. The OMD of the other shrub species was ~57%, which, based on published relationships between OMD and metabolisable energy (CSIRO 2007), corresponds to ~8 MJ ME/kg DM, a value similar to that of moderate-quality grass hay and ~50% higher than that of a senesced annual pasture (Cottle 1991). The ratio of OMD to crude protein has been proposed as a functional approach for assessing the protein adequacy of forages. When the ratio exceeds 10 : 1 (Weston 1982) or 6 : 1 for lambs (Weston 1971), N is likely to be limiting for microbial protein synthesis. For the shrub species, the ratio was ~3 : 1, indicating that the intake of metabolisable energy will be limiting for animal production, rather than the supply of crude protein, if the shrubs are the sole source of feed. This reinforces the need to manage companion pastures or provide energy supplements to complement the nutritional attributes of the shrub species. In the grazing study reported here, we relied on the companion pasture to provide additional digestible energy, but supplementary grain feeding has also been shown to increase the liveweight gain of sheep grazing a saltbush-based pasture in autumn (Franklin–McEvoy *et al*. 2007; Norman *et al*. 2008).

The general lack of large differences in OMD between plant material from shrubs sampled in June (winter) *v.* December (summer) indicates relative consistency in nutritive value over time, which is in marked contrast to the wide range in nutritive value observed with pastures typical of much of southern Australia (Moore *et al*. 2009). The Australian shrub species can be classified as 'stress tolerators' (Norman *et al*. 2010*b*) with a growth habit that results in sustained productivity. A high degree of predictability of plant growth rate and nutritive value represents an opportunity to reduce risk associated with grazing systems in regions with a highly variable climate.

Although the *Eremophila* and *Rhagodia* species tended have the highest *in vitro* OMD, low *in vitro* fermentation of plants in these genera (compared with control plants; Durmic *et al*. 2010) suggests the presence of plant secondary compounds that do not interfere with enzymatic digestion by pepsin and cellulase but interact with the metabolism of rumen microbes. In the case of *R. preissii*, wide variation has been observed between individual plants growing at the same location in the concentration of oxalates and saponins, and wide variation in preferences by sheep for individual plants that were not accounted for by oxalate or saponin concentrations has been reported (Kotze *et al*. 2011). In the grazing study reported here, we found that sheep consumed <20% of the edible biomass provided by *R. preissii* during the first 5 weeks of grazing, but consumption increased to ~50% of edible biomass by week 8, albeit with high variation between the three groups of sheep in the shrub system. The increase in intake of *R. preissii* during the 8 weeks of grazing suggests that the animals showed an adaptive response, via either changes in the population of rumen microbial species or a behavioural adaptation to a novel feed. Further work on shrubs such as *Rhagodia* or *Eremophila* is warranted to investigate the presence of plant compounds that may affect rumen microbial activity or feed preferences, for example, the identification of plant accessions with naturally higher feeding values (Masters and Norman 2010) and the identification of suitable management options to overcome low feed intake of a novel plant (Estell 2010; Hai *et al*. 2013).

The two genera of legume species tested in the present study, *Acacia* and *Kennedia*, had the lowest *in* vitro OMD and a high ADF content. As high indigestible fibre content restricts voluntary feed intake, only small amounts of plants such as *Acacia* or *Kennedia* species would be consumed by grazing sheep if available. However, even a low intake of such species may provide benefits through the provision of condensed tannins (Bouazza *et al*. 2012), which may, at appropriate doses, increase the post-ruminal supply of N (Ben Salem *et al*. 2005) or have an anthelmintic effect (Iqbal *et al*. 2002). Australian data from the same research program as the work presented here found that six of the seven *Acacia* species tested and four of the six *Kennedia* species tested significantly inhibited the development of parasite larvae (Kotze *et al*. 2009).

The sheep in the field experiment reported here were managed in a way that provided them with a fresh plot of shrubs and inter-row pasture each week. This approach was taken to maximise the learning opportunities of the sheep by regularly providing them with the full mixture of plants. The increase in shrub consumption over the first 4–5 weeks of grazing showed that the animals had strong preferences when the forage shrubs were first offered but that this pattern changed as they adapted to a greater range of shrub species and consumed greater amounts of all species. Management of animals to encourage a broad diet selection is desirable because it should increase the likelihood that animals will select a nutritionally balanced diet (Provenza *et al*. 2003). The alternative is that a limited number of preferred plants would be eaten first and less preferred species would be eaten only once choice is eliminated. Nutrient imbalances in particular species, such as the shrubs of this study, may limit animal production when animals are reliant on a limited number of plant species. Furthermore, managing animals to broaden their diet selection should also help improve natural resource management, e.g. avoiding the over-grazing of inter-row pastures to better maintain ground cover and reduce the risk of soil erosion.

Additional benefits beyond the provision of nutrients to livestock could be expected with the inclusion of perennial shrubs in the feed base. For example, the presence of shrubs may improve the productivity of adjacent pasture in several ways, including (i) lowering saline ground water level to below the root-zone of annual pasture species (Bennett *et al*. 2012), thereby promoting a productive pasture sward; (ii) increasing soil carbon content (Zhao *et al*. 2007; Huang *et al*. 2012); and (iii) reducing wind speed, which lowers evaporative moisture loss from the soil that, in turn, can lead to a higher rate of pasture growth during dry periods (Lynch *et al*. 1980). When we monitored wind speed in a shrub paddock in the current study and compared it with wind speed in an adjacent open area (the control paddock), we found that the shrubs reduced wind speed by 15–50%, depending on the wind speed at the time (data not presented). This is consistent with a review of the role of shelter in protecting soils, plants, and livestock (Bird *et al*. 1992). Other extra-nutritional benefits include the potential to reduce gastrointestinal parasite burdens (Kotze *et al*. 2009), the provision of a reservoir for beneficial invertebrates (Danne *et al*. 2010; Bianchi *et al*. 2013), and improvements in biodiversity (e.g. Seddon *et al*. 2009; Collard *et al*. 2011; Lancaster *et al*. 2012). Ongoing research is aimed at quantifying methane production from sheep grazing shrub-based forage systems and monitoring organic carbon in soils where shrubs are planted. All of these characteristics, in combination with direct effects of shrubs on livestock nutrition, should be considered in a systems approach to value fully the role of forage shrubs in the feed base.

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