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Legume options for summer-active pastures in a temperate rainfall environment of south-eastern Australia

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ABSTRACT

Context. High-quality, summer-active pastures could improve meat production in south-eastern Australia by facilitating livestock finishing over summer, with legumes critical for enhancing the nutritive value of pasture mixes. Available legumes vary in their ability to withstand moisture stress and grazing. **Aims.** We aimed to identify legumes suitable for a summer–autumn finishing system. **Methods.** We tested pure swards of 12 cultivars across eight legume species in replicated small-plot experiments at Goulburn and Bombala, New South Wales, assessing productivity, persistence and warm-season nutritive characteristics over 2–3 years. **Key results.** Lucerne (*Medicago sativa*) was clearly the most productive species during summer and outperformed the clovers (*Trifolium* spp.) in terms of persistence and productivity throughout most of the experimental period at both sites, except during autumn 2021 after high rainfall in March. Caucasian clover (*T. ambiguum*) was also highly persistent at both sites. Talish clover (*T. tumens*) and strawberry clover (*T. fragiferum*) were more persistent than white clover (*T. repens*) and red clover (*T. pratense*). White clover recovered strongly under high rainfall after drought, whereas red clover established rapidly but showed less capacity for post-drought recovery. Hybrid Caucasian × white clover was the least productive legume. Alternative clover species sometimes had slightly lower values of nutritive characteristics than white clover; red clover sometimes had distinctly lower values. **Conclusions.** Lucerne performed best but several clovers were also productive, persistent and of high nutritive value over the summer–autumn period. **Implications.** Talish, Caucasian and strawberry clovers warrant further investigation for inclusion in summer-active pastures in south-eastern Australia.

Keywords: clover, drought resilience, legume persistence, lucerne, perennial legume, southern tablelands, summer pasture, water-logging.

Introduction

Breeder/finisher systems in south-eastern Australia in which lambs are bred and finished on pasture or crop on the same farm can be profitable compared with other lamb production systems owing to the low cost of finishing and the income from wool (Warn *et al.* 2006; Productive Nutrition Pty Ltd 2011; Alcock 2016). However, the ability to finish lambs in pasture-fed systems is limited by a recurring deficit in high-quality forage in late spring and summer when digestibility and crude protein decline with pasture senescence.

The Southern Tablelands region of New South Wales (NSW) is typical of much of the south-eastern Australian high-rainfall zone in experiencing strong constraints on pasture growth in winter and frequent constraints on pasture quality and quantity in summer–autumn. Unlike more summer-dry regions of south-eastern Australia, the Southern Tablelands region experiences summer rainfall events capable of stimulating some growth by summer-active species in most years. Under typical management of lambing in late winter–early spring, the length of time between lambing and senescence of pasture is critical for lamb meat production on the Tablelands unless summer-active species such as lucerne (*Medicago sativa* L.) are available (Arnold *et al.* 1971; Donnelly *et al.* 1985). Some modification of the current sown pasture base of partially summer-dormant phalaris (*Phalaris aquatica* L.) and the cool-season annual subterranean clover (*Trifolium subterraneum* L.) toward more summer activity may be warranted for meat production systems. With wetter summer–autumn seasons and drier winter–spring seasons predicted for south-eastern NSW under future climate scenarios (NSW OEH 2014), the need to transition summer-active legumes into pastures may also increase.

Lucerne is widely recognised for its value in pasture-fed meat production over summer in south-eastern Australia (Morley *et al.* 1978; Reeve and Sharkey 1980; Kenny and Reed 1982; Donnelly *et al.* 1985) and, with forage brassica, is currently the main specialist summer finishing option on the Southern Tablelands. However, its use is severely limited by unfavourable soil conditions, with shallow depth, acidity, low fertility and poor drainage widespread (Donnelly *et al.* 1983; Hayes *et al.* 2019). The area unsuited to lucerne production is likely to be substantial given that most tablelands soils are acidic and of low to moderate fertility (Clements *et al.* 2003), with an estimated 10–14 Mha of agricultural land across New South Wales and Victoria having strongly to extremely acidic topsoils (pH <4.8; Commonwealth of Australia 2001).

Legumes are a vital component of south-eastern Australian pastures because of their dry matter (DM) production, high nutritive value and symbiotic nitrogen fixation, which underpins the nitrogen economy of productive pastures. Predominantly, these are cool-season annual legumes that dry off at the end of spring, although arrowleaf clover (*T. vesiculosum* Savi.) has later senescence and has been promoted to extend the season for finishing lambs for meat production (Thompson *et al.* 2010). Perennial summer-active pasture legumes that may act as alternatives in situations where lucerne is not adapted are limited by commercial availability to white clover (*T. repens* L.), red clover (*T. pratense* L.) and strawberry clover (*T. fragiferum* L.) (Hayes *et al.* 2019). White clover is the most commonly used perennial clover species on the NSW Tablelands but does not persist well under summer moisture stress. More drought-tolerant cultivars of white clover such as Grasslands Trophy and Grasslands Tribute are no longer available commercially (Hayes *et al.* 2019). Potential for red clover to achieve high liveweight gains by weaners in the Monaro region has been reported (Burge 1993). More prostrate, shortly stoloniferous cultivars of red clover are more persistent under grazing than earlier ‘crown’ types (Smith and Bishop 1998; Hyslop *et al.* 1999). Strawberry clover is recommended mainly for pastures prone to waterlogging and salinity, although it is also considered to be drought hardy (Clements *et al.* 2003).

Caucasian clover (*T. ambiguum* M.Bieb.) and talish clover (*T. tumens* Steven ex M.Bieb.) are deep-rooted perennial species suggested as possible options to improve drought tolerance and persistence of the legume component in tablelands pastures (Hayes *et al.* 2019); however, both currently experience seed supply problems in Australia. Caucasian clover displayed good persistence after 11 years under low fertiliser input at a higher rainfall locality in the Monaro region (Virgona and Dear 1996). Both Caucasian and talish clovers survived for 12 years, also under low fertiliser input conditions, at a much lower rainfall Monaro site but only on a south-facing slope and not as well as lucerne (Hackney *et al.* 2019). The authors also noted that perennial legumes may be better suited to the dry Monaro climate because they are less reliant for survival on autumn and spring rainfall than annuals, which must produce and regenerate from seed each year.

We evaluated a range of temperate pasture legumes for their potential to support meat production enterprises during summer–autumn in the Southern Tablelands/Monaro region of southern NSW. We tested the hypotheses that alternative legume options could equal or outperform lucerne in the focal period and region in terms of: (1) persistence, (2) productivity, and (3) nutritive characteristics. Viable legume alternatives to lucerne could improve the warm-season animal production potential of pastures in south-eastern Australia where soil conditions are not suitable for lucerne.

Materials and methods

Experimental design

The experiment consisted of 12 cultivars of seven perennial and one annual legume species grown in pure swards at two sites (near Goulburn and Bombala) in the Southern Tablelands/Monaro region of southern New South Wales. Cultivars and their features are shown in Table 1. Two or three cultivars of white clover, red clover and lucerne were included to examine variation within the species. Lucerne represented the standard summer forage species for the target region, white clover the standard perennial clover species, and subterranean clover (the annual) the most widely sown pasture legume. Lucerne is frequently used in monoculture, and therefore, we tested all legume options as monocultures to provide valid comparisons. Although the absence of a companion grass or herb would be expected to enhance persistence and productivity of the legumes during periods of moisture stress (e.g. Dear and Cocks 1997; Dear *et al.* 1998), it avoids complication of the results arising from the choice of companion plant.

The experimental design at both sites was a row–column with four replicates. Plot size was 6 m by 1.8 m with a 1-m buffer strip between the ends of plots kept clear by glyphosate application. There were 10 drill rows 18 cm apart across plots.

Sites

Sites near Goulburn and Bombala were chosen to represent environments where conditions were considered potentially suitable for growing pasture for finishing lambs over summer.

The Goulburn site was on the ‘Trentham’ property, Tirrannaville, ~20 km south of Goulburn (34.931°S, 149.676°E; elevation 670 m a.m.s.l.; annual average rainfall 670 mm). The Bombala site was on the ‘Burando’ property, Palarang,

Table 1. Species, cultivars, their characteristics, sowing rates and seedling densities in the experiments at Goulburn and Bombala, NSW.

Species	Cultivar	Characteristics	Sowing rate (kg/ha)	Seedling density (plants/m^2)	
				Goulburn	Bombala
White clover (*Trifolium repens*)	Haifa	Old standard cultivar for SE Australia, large-leaved type	2	36	59
	Nomad	Small-leaved type bred for improved persistence and drought tolerance (Agricom 2021)	2	43	156
	Trophy	Bred in Australia for improved tolerance of summer moisture stress (Ayres *et al.* 2007)	2	36	93
Red clover (*T. pratense*)	Astred	Stoloniferous, good persistence under grazing	5	104	126
	Rubitas	Stoloniferous, good persistence under grazing	5	93	156
Talish clover (*T. tumens*)	Permatas	Deep-rooted, new cultivar	4	44	79
Caucasian clover (*T. ambiguum*)	Kuratas	Deep-rooted, new cultivar bred in Tasmania for improved winter growth and seed production	6	64	106
Caucasian × white clover (*T. ambiguum x repens*)	Aberlasting	Crossed to improve drought tolerance of white clover	2	62	125
Strawberry clover (*T. fragiferum*)	Palestine	Old standard cultivar for SE Australia	4	18	97
Subterranean clover (*T. subterraneum*)	Leura	Late flowering for higher rainfall districts	10	52	72
Lucerne (*Medicago sativa*)	Sardi Grazer	Winter activity 6, bred for improved grazing tolerance	8	93	100
	Titan 9	Winter activity 9	8	91	188
l.s.d. (P = 0.05)				22	43

~15 km north-west of Bombala (36.833°S, 149.106°E; elevation 730 m a.m.s.l.; annual average rainfall 570 mm). The soil type at the Goulburn site was a Red Chromosol (Isbell 1996) derived from sedimentary parent material with a loam surface texture. The paddock was used for grazing oats in the year prior to sowing. Quartz stones were abundant in the upper soil profile. The soil at the Bombala site was classified as a Brown Dermosol on a basalt–sedimentary boundary with a loam to clay–loam surface texture. The paddock was used for grazing wheat in the year prior to sowing.

Soil chemical characteristics at the start of the experiment are shown in Table 2. We used hand augers to collect ~15 soil samples at depths of 0–0.1 and 0.1–0.2 m across each experimental site. Samples were bulked and dried at 40°C for 5 days, finely ground, and passed through a 2-mm sieve. Chemical analyses were conducted by the CSIRO Black Mountain Analytical Unit (Acton, ACT, Australia) for Goulburn samples and CSBP Soil and Plant Analysis Laboratories (Bibra Lake, WA, Australia) for Bombala samples. The Goulburn site had been limed in previous years and was potentially potassium-deficient based on critical values specified by Gourley *et al.* (2019).

Table 2. Soil chemical properties of the 0–0.1 and 0.1–0.2 m layers at the experimental sites.

Property	Goulburn		Bombala	
	0–0.1 m	0.1–0.2 m	0–0.1 m	0.1–0.2 m
pH (in $CaCl_2$)	5.8	4.6	4.5	4.6
Colwell P (mg/kg)	38	9	24	10
Colwell K (mg/kg)	112	64	240	241
KCl_{40} S (mg/kg)	22	15	20	13
P buffering index	50	51	62	72
Electrical conductivity (dS/m)	0.21	0.13	0.19	0.08
Organic C (%)	1.32	0.50	1.41	0.93
Exchangeable cations (cmol(+)/kg):				
Ca	6.27	2.41	3.65	3.15
K	0.20	0.02	0.75	0.52
Mg	0.73	0.51	0.93	0.91
Na	0.32	0.17	0.06	0.05
Al	0.01	0.20	0.29	0.26
Total cation exchange capacity (CEC)	7.52	3.30	5.68	4.89
Al (% of CEC)	0	6	5	5

Management

At Goulburn, seed was direct-drilled with a cone seeder on 17 April 2018. Croplift 15 (14.6% N, 12% P, 11.6% S; Incitec Pivot, Southbank, Vic., Australia) at 200 kg/ha and muriate of potash (50% K) at 125 kg/ha were broadcast before sowing, and a further 50 kg/ha of Croplift 15 was applied in the drill row at sowing. All species were inoculated with the recommended *Rhizobium* strain and lime-coated. Sowing rates are shown in Table 1. Very dry conditions in the months following sowing (13–59% of the long-term average rainfall per month between April and September; Fig. 1*a*) resulted in poor establishment, and the experiment was sprayed out and resown on 5 September 2018. Leura subterranean clover did not set seed after resowing and was reseeded by hand at 20 kg/ha on 9 May 2019. The resown experiment was mown to 0.05 m height on 2 November 2018, 4 December 2018 and 15 January 2019, to control self-sown oats and other weeds. Heavy growth of nightshade (*Solanum nigrum*) was removed by hand on 10 January 2019. Grass weeds were controlled by spraying with 330 mL/ha of Select Xtra (a.i. clethodim @ 360 g/L; Arysta LifeScience, Cary, NC, USA) with 1:100 Hasten adjuvant (Victorian Chemical Company, Coolaroo, Vic.) on 11 April 2019 and 31 August 2020. Broadleaf weeds were controlled by application of Broadstrike at 25 g/ha (a.i. flumetsulam @ 800 g/kg; Corteva Agriscience, Indianapolis, IN, USA)on 3 March 2020. Weeds were also controlled by hand-pulling and dabbing glyphosate as required.

At Bombala, seed was sown on 26 March 2019 with 150 kg/ha of Mo-single superphosphate (9% P, 11% S, 0.025% Mo) and 200 kg/ha of Calciprill (prilled lime; Omya, Oftringen, Switzerland). Weeds were controlled in the establishing experiment by hand-pulling and dabbing glyphosate on 18 June and 9 October 2019. Subsequent weed control was by hand-pulling.

Soil samples were taken at least annually to monitor P, K and S levels because cut herbage was removed from the plots. At Goulburn, Mo-single superphosphate was applied at 300 kg/ha on 3 April 2019 and single superphosphate was applied at 185 kg/ha on 30 November 2020. Colwell P was 40 km/kg in March 2019, 66 kg/kg in March 2020, and 31 mg/kg in October 2020. KCl_{40} S was 20 mg/kg in March 2020 but declined to 7 mg/kg in October 2020 after a wet winter and removal of large amounts of herbage. Muriate of potash was applied at 200 kg/ha on 3 April 2019, 180 kg/ha on 22 April 2020, and 150 kg/ha on 12 January 2021. Colwell K was 104 mg/kg in March 2019, 151 in March 2020, and 144 in October 2020.

At Bombala, single superphosphate was applied in March 2020 (250 kg/ha) and April 2021 (150 kg/ha). After starting at 24 mg/kg in January 2019, Colwell P was 21 mg/kg in February 2020 and 44 mg/kg in October 2020. KCl_{40} S was 14 mg/kg in March 2020 and 24 mg/kg in October 2020. Muriate of potash was applied at 110 kg/ha as a maintenance application in May 2020. After starting at 260 mg/kg, Colwell

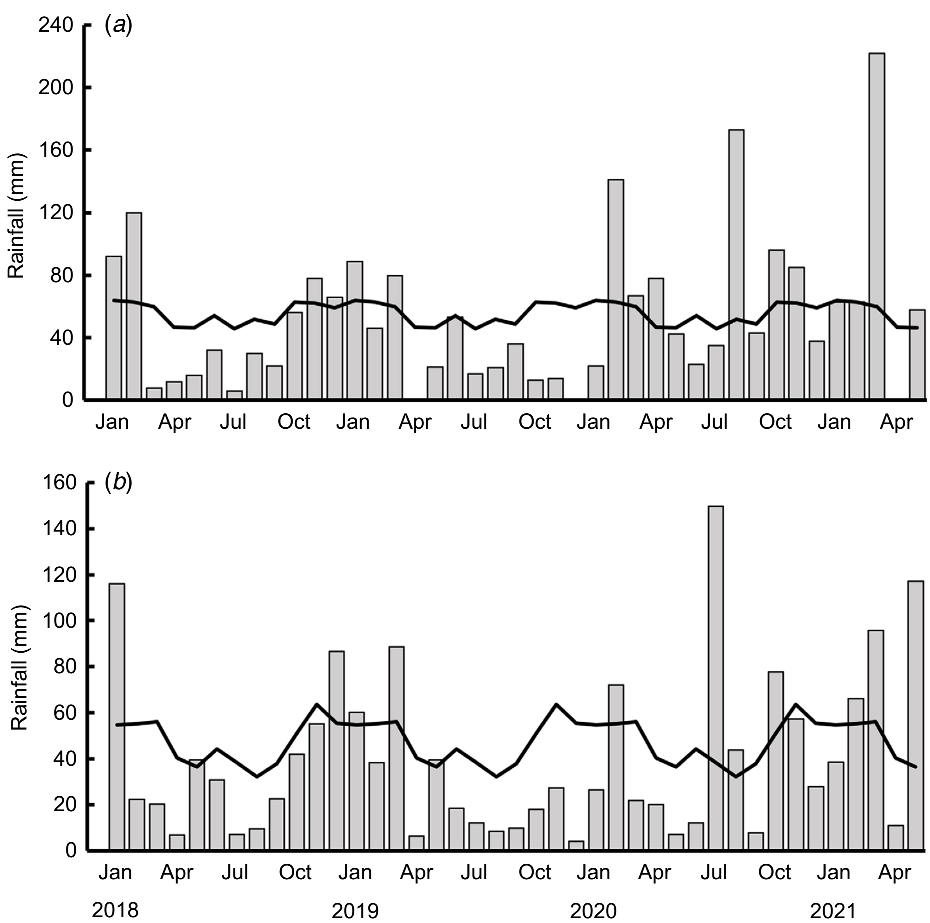

Fig. 1. Actual (bars) and long-term monthly (line) rainfall at (*a*) Goulburn site and (*b*) Bombala site.

K was 258 mg/kg in February 2020 and 330 mg/kg in October 2020.

Both experiments were managed by mowing to around 5 cm and removing herbage to simulate the careful grazing management, typically rotational grazing, expected for productive, high-input pastures. Experiments were grazed only once at each site. The Goulburn experiment was opened to grazing by sheep from the surrounding paddock for 4 days after the harvest in October 2019 when drought conditions were worsening. The Bombala site was accidently left open to grazing by a large mob of sheep from late January to 5 February 2020; however, this grazing event likely had a very small effect on the DM harvested on 12 March because most of the rainfall in this period occurred after grazing.

Data collection

Density of germinating seedlings was measured 4–5 weeks after sowing by counting the number of seedlings on both sides of a rod 0.5 m in length placed randomly six times between drill rows within a plot and converting to number of seedlings per m^2 using the row spacing of 0.18 m.

Persistence was assessed as change in frequency each year. Frequency was measured as the proportion of cells in a mesh grid in which the live base of the sown species was present. Grid dimensions were 1 m by 0.75 m divided into 50 cells (0.15 m by 0.10 m), with grids placed to measure 1-m lengths of five adjacent drill rows. Two grids were placed in fixed positions in each plot, with position determined by strings between pegs placed permanently at the sides of each row of plots. Total count for the two grids gave a percentage frequency. Frequency was measured at Goulburn on 4 December 2018, 12 September 2019, 27 February and 14 September 2020, and 8 April 2021, and at Bombala on 12 December 2019, 26 May 2020 and 3 May 2021.

Herbage mass of legume species was determined by calibrated visual estimation by two observers. Calibration curves were developed by pegging and cutting to ground level 0.25-m^2 quadrats of sown species, and representing scores on a 1–10 scale; weeds were avoided or removed from the harvested biomass. Up to four curves were derived depending on the structure of the species (e.g. (i) lucerne, (ii) Caucasian clover, (iii) red and talish clovers, and (iv) other clovers). Average R^2 for 40 calibrations across sites, times and species was 0.90. Herbage mass of sown legume species was scored in ten 0.25-m^2 quadrats per plot.

We quantified herbage mass in all seasons because a decision to use a perennial species depends partly on the pattern of production throughout the year. The Goulburn experimental site was first sampled on 8 March 2019; a high weed burden prevented earlier measurement. Subsequent measurements were made on 3 September and 11 November 2019; 10 March, 21 April, 31 August, 20 October and 27 November 2020; and 12 January, 22 February and 23 April 2021. Herbage growth at Bombala was very slow under drought conditions, only lucerne and red clover providing measurable amounts of herbage in December 2019, with totals <400 kg/ha. Therefore, the Bombala site was not fully sampled for the first time until 12 March 2020. Subsequent measurements were made on 20 May, 2 October and 2 December 2020, and 9 February and 19 April 2021. Plots at both sites were mown to 0.05 m height after each herbage mass assessment.

Herbage samples for measurement of nutritive characteristics were obtained only in the summer–autumn period. These were taken by hand-plucking from at least 10 random locations in each plot. Samples were kept in portable coolers with ice bricks until they were placed in a dehydrator, where they were dried for at least 48 h at 65°C and then ground through a Cyclotec mill (model CT293; FOSS, Denmark) fitted with a 1-mm screen for nutritive analyses.

All rainfall data at Goulburn were taken from the Bureau of Meteorology site on the 'Springfield' property, 3 km north of the experimental site. Actual rainfall data for Bombala were taken from the Bureau site on the 'Bukalong' property, 9 km north-east of the experimental site, and long-term average rainfall from the now-closed Bureau site at Cambalong, 6 km south.

Nutritive analyses

Ground herbage samples were analysed by near-infrared spectroscopy (NIRS) in the CSIRO Rural Research Laboratory (Floreat, WA), using procedures described by Norman *et al.* (2020). Briefly, ground samples were scanned using a Unity Spectrastar 2500X rotating top window system (Unity Scientific, Milford, MA, USA). The Southern Feedbase calibration was then used to predict neutral detergent fibre (NDF), acid detergent fibre (ADF), *in vitro* DM digestibility (DMD), organic matter (OM) and nitrogen (N). Predicted values were validated by wet chemistry analyses on ~10% of samples. Wet chemistry was also performed for a small number of samples that fell outside the calibration. DMD determination was made using a modified pepsin–cellulase technique (corrected using Australian Fodder Industry Association *in vivo* standards), NDF and ADF using an ANKOM 200/220 Fibre Analyser (ANKOM Technology, Fairport NY, USA), total N by combustion using a CN628 N Analyser (LECO, St. Joseph, MI, USA), and OM by ashing (Norman *et al.* 2020). Crude protein (CP) was calculated as N × 6.25 and metabolisable energy (ME) as 0.172DMD − 1.707 (Freer *et al.* 2007).

Statistical analyses

Analysis of sites combined was complicated because of starting a year later at Bombala than at Goulburn and the different timing of harvests, which depended on growth conditions at each site. Each site was therefore treated separately for statistical analyses.

The sequence of herbage mass measurements at each site (11 at Goulburn and six at Bombala) was analysed by the methods of De Faveri *et al.* (2015) for repeated harvests of perennial species in which genotype effects are modelled over times, accounting for temporal and spatial correlations. Analyses were based on linear mixed models estimated by residual maximum likelihood (REML) performed in ASReml-R (Butler *et al.* 2009).

The linear mixed models consisted of a fixed effect due to the mean of each harvest, random effects due to replicate and design (row, column) effects, random genotype effects over harvest times (following Smith *et al.* 2005 for selection in multi-environment trials), and random residual effects. The residual spatial and temporal covariance structure between repeated harvests was modelled through a 3-way separable spatio-temporal process (Smith *et al.* 2007; De Faveri *et al.* 2015). The residual temporal covariance components were modelled using antedependence structures to account for correlations between successive harvests. Spatial correlation matrices were tested for significance by using autoregressive models of order 1 in the row and column directions (ar1 × ar1; Gilmour *et al.* 1997). Spatial effects were found not to be strong in the column direction, so only row effects were modelled using ar1 at both sites as determined by the Akaike information criterion (AIC).

The random genotype effects were correlated across harvests, and best linear unbiased predictors (BLUPs) were predicted from the random model for each genotype at each harvest. The genetic co-variance matrix, consisting of genetic variances for each harvest and genetic correlations between harvests was modelled using factor analytic (FA) models (Smith *et al.* 2001*a*; De Faveri *et al.* 2015). The factor analytic model provides an efficient approximation to the full unstructured covariance structure but with fewer parameters required to be estimated (Kelly *et al.* 2007). An FA model of order 3 (FA3) was best at Goulburn, and an FA2 (2 factors) at Bombala as determined by the model with the lowest AIC.

Frequency data also were analysed by the methods of De Faveri *et al.* (2015) except that FA models were not required to model genetic effects owing to the smaller number of successive observations (five at Goulburn, three at Bombala), and full unstructured genetic variance–covariance matrices were fitted. Temporal residual covariance components were modelled using antedependence models of order 1 at both sites. As with herbage DM data, spatial effects were not strong for frequency in the column direction; therefore, only row effects were modelled as ar1.

Because measures for comparison among entries, such as least significant difference, are not appropriate for a random genotype effect, the probability of superiority of a BLUP over that of a pre-determined standard entry based on the correlation between true and predicted entry effects was calculated (see p. 137 of Smith *et al.* 2001*b*). In our analyses, the method was used to indicate superiority/inferiority compared with lucerne at the arbitrary 5% probability level. However, as a guide to variability of the data, twice the average standard error of a difference (av. s.e.d.) was also used as an approximate measure of least significant difference in tables and figures.

Seedling density at each site was analysed as a randomised block design after spatial analysis revealed that row and column effects were not significant.

Nutritive data were analysed for each summer–autumn season (year) separately and then for all years combined. Preliminary analyses at individual dates indicated that spatial adjustments were not warranted for Goulburn but that there was significant autoregressive correlation for rows at the Bombala site. Repeated-measures mixed-model analyses were used for the sequence of sample dates within each summer–autumn season, with sample date and cultivar as fixed effects and replicates within dates as random effects with an antedependence covariance structure of order 1. For the Bombala analysis, residual covariance components were modelled using antedependence of order 1 to account for correlations between successive harvests, and row spatial effects were modelled as ar1. Combined analyses across years were performed for the Goulburn data by mixed-model analysis with year and cultivar as fixed effects, and sample date within season and replicate within date and season as random effects. Because only one observation was made in the 2019–20 season at Bombala, an across years analysis was not performed.

Results

Seasonal conditions

Both sites were characterised by reasonable warm-season rainfall but greatly below-average cool-season rainfall in 2018 and 2019 (i.e. 89–108% of long-term average rainfall in summer 2018–19 and 40–61% in both winters; Fig. 1). The 2018–19 summer at Goulburn was one of the hottest on record, with a mean maximum temperature in January of 32.5°C, or 4.5°C above the long-term average (Bureau of Meteorology data; see Supplementary materials). Increasingly severe drought developed during 2019 at both sites, breaking in February 2020 at Goulburn and July 2020 at Bombala. From the start of July 2019 to mid-July 2020, rainfall received at the Bombala site totalled only 243 mm. Both sites received generally favourable rainfall after the drought broke to the end of the experiment, but the Bombala site had more months with well below-average rainfall.

Establishment and persistence

Establishment was slow at Goulburn, with seedling counts conducted at 77 days after sowing; by contrast, seedling counts were possible at Bombala at 29 days after sowing in the following year. Seedling densities were considerably higher at Bombala than at Goulburn (Table 1), reflecting the excellent germination conditions at Bombala.

Initial frequencies were higher for all species at Bombala than at Goulburn, with only Haifa white clover having frequency <60% at Bombala (Fig. 2). Red clover and lucerne had the highest initial frequencies at both sites. Following low seedling densities, initial frequencies were low (<40%) for strawberry, white and talish clovers at Goulburn (Fig. 2*a*).

At Goulburn, white, talish, Caucasian × white, and strawberry clovers increased considerably in the second year through stoloniferous spread, whereas red and Caucasian clovers spread less (Fig. 2*a*). Leura subterranean clover did not set seed in the first year after resowing in September and was reseeded by hand in autumn of the second year. Frequencies of white, Caucasian × white, red and subterranean clovers were very low (<10%) in late February 2020 at Goulburn, 2.5 weeks after the 2019–20 drought period ended (Fig. 2*a*). By contrast, frequencies of lucerne and Caucasian clover were unaffected by the drought, and talish and strawberry clovers declined much less. All species recovered by spring 2020 at Goulburn under high rainfall, but red clover recovered the least (frequency <40%). Most species declined at least partially over the final summer, most markedly Haifa and Nomad white clover and Caucasian × white clover.

At Bombala, lucerne and Caucasian, talish and strawberry clovers persisted well during the drought period from spring 2019 to winter 2020 (Fig. 2*b*). White, red and Caucasian × white clovers had declined considerably in frequency by May 2020. Subterranean clover again failed to set seed owing to drought in the first spring and was absent from the experiment thereafter. All perennial clover species expanded under drought-breaking rains in July 2020 to record high frequencies (i.e. >49%) in May 2021. Red clover recovered the least but, unlike its response at Goulburn, remained at reasonably high frequency post-drought (~50–60%, Fig. 2*b*).

Productivity

At both sites, lucerne was the most productive species during summer at each sampling time and in total (Figs 3 and 4). Only once was the summer productivity of another species not significantly lower than that of one of the lucerne cultivars (Haifa white clover vs Sardi Grazer lucerne at Goulburn in January 2021; Table 3). White and red clovers were more productive than talish, Caucasian and strawberry clovers in the 2018–19 summer at Goulburn, but the latter were more productive than all other clovers in the following summer immediately after the drought period (Table 3). Talish, Caucasian and strawberry clovers were also amongst the most productive clovers at Bombala under drought over the 2019–20 summer, along with Haifa and Trophy white and Astred red clovers (Table 4). At Goulburn, white clover was higher yielding, and talish and Caucasian clovers lower yielding, in the first half of the 2020–21 summer, with relatively small differences among clovers in the second half of the summer (Table 3). Meanwhile, perennial clover productivity in the 2020–21 summer at Bombala was highest for Astred red

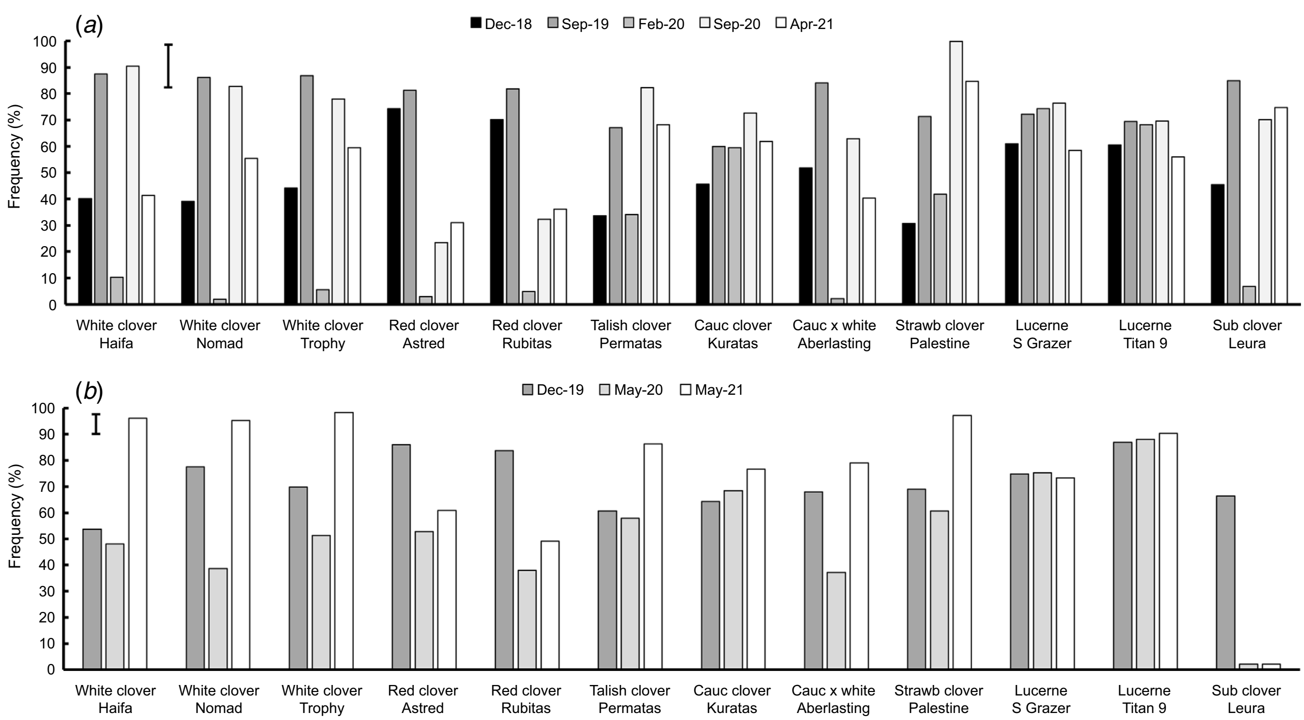

Fig. 2. Predicted frequency of live plant base at (*a*) Goulburn site and (*b*) Bombala site. Bars indicate 2 × average s.e.d.

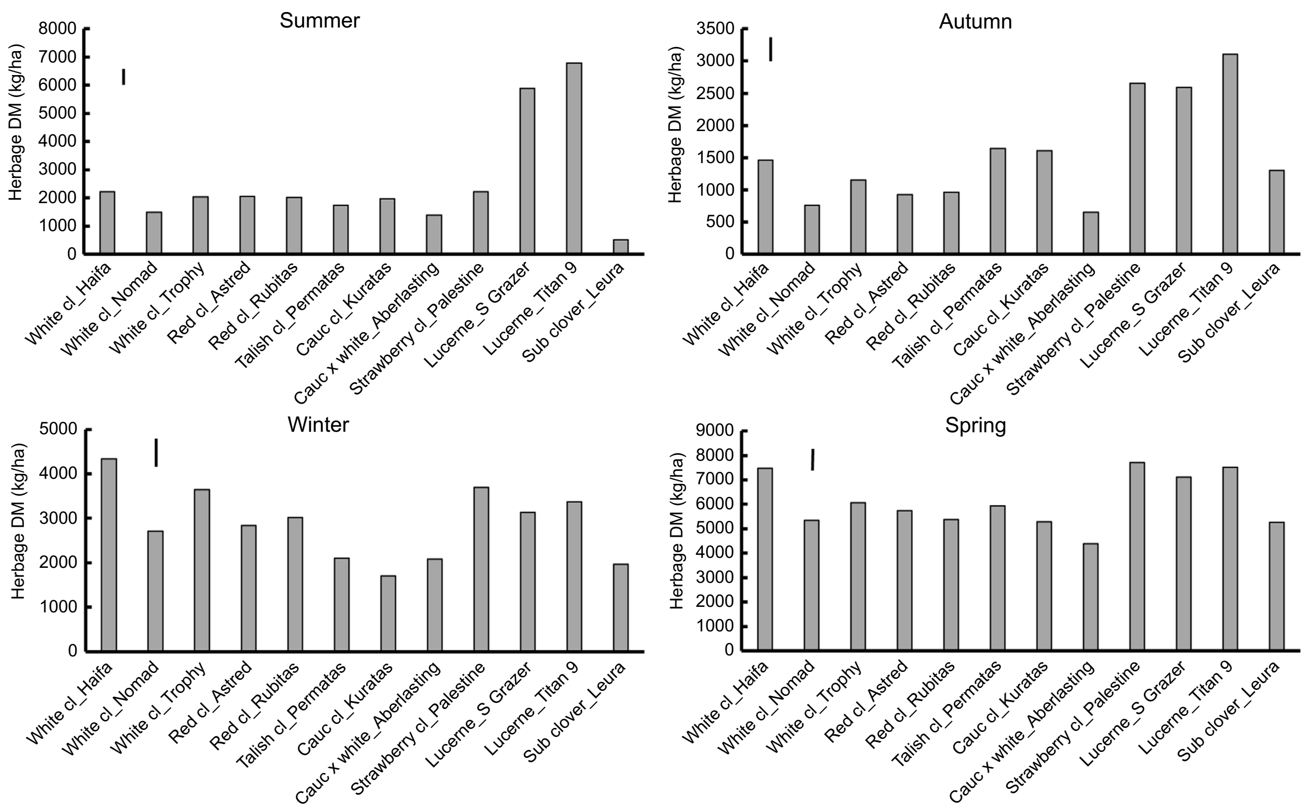

Fig. 3. Predicted total herbage production over 3 years for summer and autumn, and 2 years for winter and spring, at the Goulburn site. Bars indicate 2 × average s.e.d.

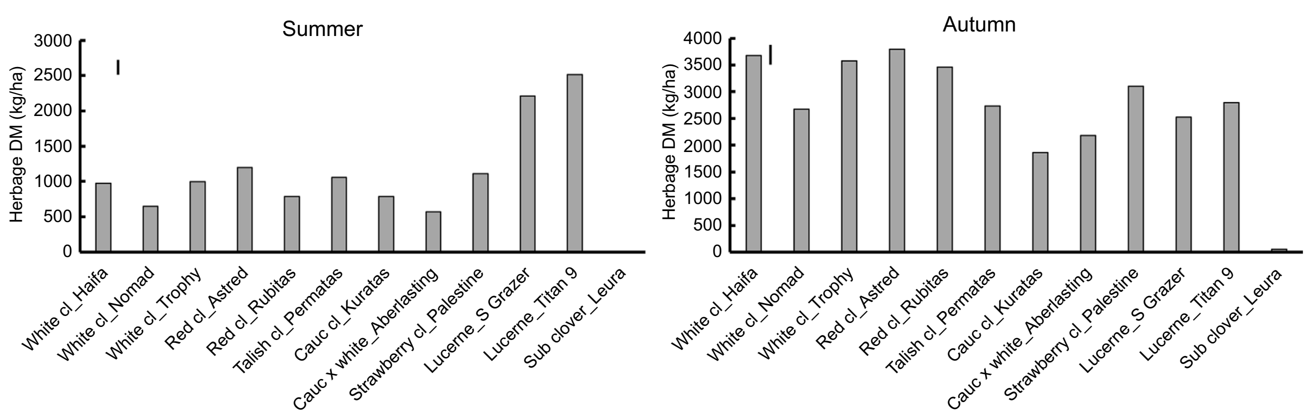

Fig. 4. Predicted total summer and autumn herbage DM production over 2 years at the Bombala site. Bars indicate 2 × average s.e.d.

and strawberry clovers and lowest for Caucasian × white clover (Table 4).

Lucerne continued to be the most productive species at both sites in autumn 2020 (Tables 3 and 4). Strawberry clover was the highest yielding clover at Goulburn during this post-drought autumn, followed by Caucasian, talish and Haifa white clovers. Under continued drought conditions at Bombala, strawberry clover was also amongst the group of highest yielding clovers, together with Astred red, talish, and Haifa and Trophy white clovers. In the moist autumn of 2021, all perennial clovers were at least as productive as lucerne at both sites, except Caucasian clover at Goulburn. Strawberry and Haifa and Trophy white clovers outyielded lucerne at both sites, whereas Caucasian clover yielded only ~50% of the most productive clover cultivars. Total autumn production at Goulburn was highest for lucerne and strawberry clover (Fig. 3); at Bombala, red clover and Haifa and Trophy white clover produced the most DM (Fig. 4).

In winter 2019 at Goulburn, lucerne was more productive than all clovers except Haifa and Trophy white clover (Table 3).

Table 3. Predicted seasonal herbage DM production (kg/ha) at Goulburn.

Species	Cultivar	Summer				Autumn		Winter		Spring		
		2018–19	2019–20	2020–21		2020	2021	2019	2020	2019	2020	
		08.03.19	10.03.20	12.01.21	22.02.21	21.04.20	23.04.21	03.09.19	31.08.20	11.11.19	20.10.20	27.11.20
White clover	Haifa	*814*	*86*	*928*	*395*	*784*	675	2216	**2114**	2225	1981	3271
	Nomad	*639*	*0*	*642*	*282*	*174*	587	*1512*	1200	*1409*	*1308*	*2624*
	Trophy	*835*	*0*	*848*	*361*	*329*	**819**	2116	**1532**	*1745*	1426	2886
Red clover	Astred	*756*	*151*	*733*	*407*	*316*	612	*1736*	1098	2057	*1388*	*2301*
	Rubitas	*754*	*107*	*743*	*420*	*363*	597	*1800*	1215	1756	*1402*	*2228*
Talish clover	Permatas	*330*	*408*	*480*	*523*	*854*	**792**	*884*	1220	*1238*	2392	*2301*
Caucasian clover	Kuratas	*442*	*553*	*471*	*509*	*924*	684	*834*	873	*988*	1944	*2357*
Caucasian × white clover	Aberlasting	*555*	*0*	*530*	*322*	*73*	582	*1200*	885	*1151*	*1226*	*2003*
Strawberry clover	Palestine	*325*	*653*	*665*	*580*	*1640*	**1013**	*1197*	**2504**	*1447*	**3498**	*2760*
Subterranean clover	Leura	*0*	*0*	*223*	*478*	*229*	**1075**	*258*	**1706**	*228*	**2910**	*2136*
Lucerne	Sardi Grazer	1271	2318	*1020*	1281	1983	607	2025	1109	1925	2156	3028
	Titan 9	1515	2905	**1166**	1189	2401	706	2356	1018	2166	2203	3141
	2 x av. s.e.d.	178	302	136	198	289	216	359	441	418	494	425

Values in bold are greater than that of one or both lucerne cultivars; values in italics are less than that of one or both lucerne cultivars (with probability >0.95). Negative values of DM production generated from the model are shown as a value of 0.

Table 4. Predicted seasonal herbage DM production (kg/ha) at Bombala.

Species	Cultivar	Summer		Autumn		Winter	Spring
		2019–20	2020–21	2020	2021	2020	2020
		12.03.20	09.02.21	20.05.20	19.04.21	02.10.20	02.12.20
White clover	Haifa	*202*	*768*	*333*	**3352**	*1201*	3040
	Nomad	*115*	*536*	*237*	**2437**	*837*	*2926*
	Trophy	*250*	*744*	*328*	**3249**	*1215*	3033
Red clover	Astred	*210*	*987*	*360*	**3442**	*1292*	**3627**
	Rubitas	*87*	*695*	*281*	**3180**	*962*	3439
Talish clover	Permatas	*258*	*798*	*314*	**2422**	*1173*	**4042**
Caucasian clover	Kuratas	*242*	*540*	*248*	*1615*	*950*	3024
Caucasian × white clover	Aberlasting	*85*	*488*	*200*	1987	*698*	*2290*
Strawberry clover	Palestine	*274*	*834*	*341*	**2765**	*1271*	3105
Subterranean clover	Leura	*4*	*4*	*24*	*26*	*77*	*194*
Lucerne	Sardi Grazer	966	1245	557	1973	2395	3106
	Titan 9	1069	1444	630	2167	2695	3467
	2 × av. s.e.d.	76	163	54	356	209	593

Values in bold are greater than that of one or both lucerne cultivars; values in italics are less than that of one or both lucerne cultivars (with probability >0.95).

However, in the following wet winter, strawberry clover was the most productive legume, followed by Haifa white, subterranean and then Trophy white clovers, all of which produced significantly more DM than lucerne. Caucasian and Caucasian × white clovers were the least productive species. Total winter production at Goulburn was highest for Haifa and Trophy white clover and strawberry clover, and lowest for Caucasian clover (Fig. 3). Herbage production at Bombala in winter 2020 was restricted to late winter–early spring after drought-breaking rain in mid-July, when lucerne DM was double that of the highest yielding clover species (Haifa and Trophy white, red, strawberry and talish clovers; Table 4).

Total spring production over 3 years at Goulburn was highest for Haifa white clover, strawberry clover and lucerne at ~7500 kg/ha, with the remaining species ~5500 kg/ha, except for Caucasian × white clover at 4400 kg/ha (Fig. 3). Haifa white clover was the most productive cultivar in spring 2019 and the second half of spring 2020 (Table 3). Strawberry clover was particularly productive in the first half of spring 2020 during the wet winter–early spring period, with subterranean and talish clovers also high in herbage DM. White clover and lucerne were the most productive species in the second half of spring 2020. Under good growth conditions at Bombala in spring 2020, talish and Astred red clovers were more productive than lucerne, whereas Caucasian × white and Nomad white clovers produced less DM than lucerne (Table 4).

Total production for the experiment at each site was highly correlated ($P < 0.01$, Fig. 5), with lucerne the highest in DM and Caucasian × white, Caucasian and Nomad white clovers the lowest. The higher ranking of red and talish clovers at Bombala than at Goulburn for total herbage DM production is evident in Fig. 5.

Nutritive characteristics

Metabolisable energy, CP and NDF contents of herbage sampled in summer and autumn at Goulburn and Bombala are shown in Tables 5 and 6. Effects of cultivar and sampling date × cultivar interaction were highly significant ($P < 0.001$) at both sites for all nutritive characteristics in each year, with the exception of sampling date × cultivar interaction for CP at Goulburn in the 2019–20 season. The F-value for the cultivar effect was usually at least twice that of the interaction.

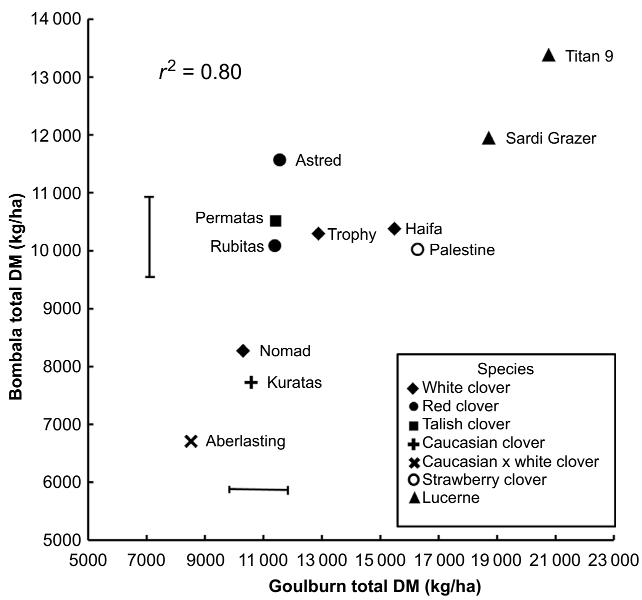

Fig. 5. Predicted total herbage DM production for the Goulburn and Bombala sites (subterranean clover is excluded because it did not establish at Bombala). Bars indicate 2 × average s.e.d.

Metabolisable energy content was high in all species at Goulburn in March and April 2020 following drought-breaking rainfall in early February (Table 5). Highest values (≥11 MJ/kg) were recorded in white, talish, Caucasian, and Caucasian × white clovers. Red clover was 0.4–0.6 MJ/kg lower in ME than these species, mainly in late summer and autumn, and lucerne ~1 MJ/kg lower, associated with higher NDF content (Table 5). Conditions at Bombala were much drier than those at Goulburn in March 2020, and ME levels were lower in the clovers but higher in lucerne and red clover (Table 6). ME content was markedly lower in early December 2020 at Bombala (Table 6) and in mid-January 2021 at Goulburn (Table 5), associated with a high degree of flowering in the clovers at both sites and a high bulk of herbage at Bombala. There was also a high degree of flowering at Goulburn in late November 2020, but herbage sampled was only 1 month old, and therefore relatively fresh, compared with 2 months old and drier at Bombala in early December. Strawberry clover was still completely vegetative in late November 2020 at Goulburn and had the highest ME content (Table 5). Conversely, lower ME contents of red and strawberry clovers in February 2021 at Bombala were associated with greater floral development than in other species (Table 6). ME contents in February and April at Goulburn and in April at Bombala were correlated ($r = 0.8$–0.9, $P < 0.01$) and of a generally similar magnitude, ~10.5 MJ/kg, except for red clover ME content, which was ~0.5–0.8 MJ/kg lower than that of the other species (Tables 5 and 6).

Crude protein content in DM was ~20% or more for all species and sampling dates, with the exceptions of mid-January 2021 at Goulburn when CP exceeded 20% of DM only in lucerne (Table 5) and early December 2020 at Bombala (Table 6) when floral development was high and ME content lower. Lucerne often had the highest CP content at individual sampling dates and was highest on average: 25% vs 21% of DM for the mean of all clovers at Goulburn, and 24% vs 20% of DM for mean of all clovers at Bombala. Red and Caucasian × white clovers tended to be slightly lower in CP content at Goulburn (Table 5) but this was less evident at Bombala (Table 6).

Neutral detergent fibre content in DM of legumes was mostly in the range 30–35% at both sites, except on two occasions, January 2021 at Goulburn and December 2020 at Bombala, with values in the range 35–40% of DM, associated with high levels of flowering in clovers. NDF content was lowest on average in April in all site–seasons, with values for some species <30% of DM. At Goulburn, lucerne and red, talish and strawberry clovers were higher on average in NDF content than white, Caucasian, and Caucasian × white clovers (Table 5). At Bombala, strawberry, red and talish clovers also tended to be higher in NDF and Caucasian clover

Table 5. Metabolisable energy, crude protein and neutral detergent fibre at Goulburn.

Species	Cultivar	Season 2019–20			Season 2020–21				
		Mar.	Apr.	Mean	Nov.	Jan.	Feb.	Apr.	Mean
		Metabolisable energy (MJ/kg DM)							
White clover	Haifa	**11.0**	**11.1**	**11.1**	10.1	*9.2*	**10.9**	**10.9**	10.2
	Nomad	**11.5**	**11.3**	**11.4**	10.1	*9.0*	**10.9**	10.7	10.2
	Trophy	**11.0**	**10.9**	**11.0**	10.3	*9.3*	**11.0**	**10.9**	10.4
Red clover	Astred	**10.8**	**10.7**	**10.7**	10.2	*9.5*	*9.8*	*10.0*	*9.9*
	Rubitas	**10.7**	**10.5**	**10.6**	10.1	*9.3*	*10.0*	*10.0*	*9.9*
Talish clover	Permatas	**11.1**	**11.0**	**11.1**	*9.7*	*9.3*	10.6	10.5	*10.0*
Caucasian clover	Kuratas	**11.2**	**10.9**	**11.0**	**10.8**	9.9	10.8	*10.4*	**10.5**
Caucasian × white clover	Aberlasting	**10.9**	**11.1**	**11.0**	10.2	*9.2*	10.7	10.7	10.2
Strawberry clover	Palestine	**10.8**	**10.9**	**10.9**	**11.0**	*9.3*	**10.9**	10.8	**10.5**
Subterranean clover	Leura				10.6		11.0	10.7	
Lucerne	Sardi Grazer	9.7	**10.5**	**10.1**	10.2	9.9	10.7	10.8	10.2
	Titan 9	9.8	*9.9*	*9.8*	10.4	10.1	10.5	10.5	10.4
	2 × av. s.e.d.	0.2		0.2	0.3				0.2
		Crude protein (% of DM)							
White clover	Haifa	23.7	*22.1*	*22.9*	*21.2*	*16.9*	*21.7*	*22.6*	*20.6*
	Nomad	24.2	*23.4*	*23.8*	*22.0*	*16.3*	22.1	*21.7*	*20.5*
	Trophy	*23.1*	*23.2*	*23.2*	*21.9*	*16.7*	*21.1*	*22.1*	*20.5*
Red clover	Astred	*20.0*	*20.8*	*20.4*	*20.8*	*18.0*	*18.2*	*20.6*	*19.4*
	Rubitas	*19.5*	*20.0*	*19.7*	*21.3*	*17.3*	*19.9*	*20.7*	*19.8*
Talish clover	Permatas	*22.8*	*24.9*	*23.8*	*20.1*	*18.4*	22.5	*22.7*	*20.9*
Caucasian clover	Kuratas	24.5	*23.7*	*24.1*	*21.4*	*17.9*	21.8	*20.0*	*20.3*
Caucasian × white clover	Aberlasting	*19.1*	*21.1*	*20.1*	*19.9*	*15.8*	*20.3*	*21.7*	*19.5*
Strawberry clover	Palestine	22.8	*24.2*	*23.5*	24.0	*15.6*	22.8	*22.2*	*21.1*
Subterranean clover	Leura				*21.2*		*21.0*	*21.9*	
Lucerne	Sardi Grazer	26.5	**30.1**	**28.3**	23.0	21.5	22.9	25.5	23.2
	Titan 9	26.4	*24.5*	*25.5*	23.8	21.9	23.4	25.4	23.6
	2 × av. s.e.d.	2.8		1.9	1.6				0.9
		Neutral detergent fibre (% of DM)							
White clover	Haifa	*32.7*	*29.5*	*31.1*	33.9	**40.0**	*32.1*	*27.8*	33.5
	Nomad	*25.5*	*29.1*	*27.3*	34.0	**40.3**	*31.8*	28.9	33.8
	Trophy	*34.7*	*29.7*	*32.2*	32.9	**39.0**	*31.1*	28.2	32.8
Red clover	Astred	*34.6*	32.2	33.4	36.4	37.7	37.3	**32.4**	**35.9**
	Rubitas	*33.8*	33.7	33.7	35.9	**38.5**	36.1	32.0	**35.6**
Talish clover	Permatas	*33.7*	31.6	*32.6*	37.8	**41.0**	34.5	29.9	**35.8**
Caucasian clover	Kuratas	*28.9*	*30.3*	*29.6*	*32.1*	37.9	33.2	30.5	33.4
Caucasian × white clover	Aberlasting	*30.6*	*28.4*	*29.5*	34.8	**39.7**	32.7	27.7	33.7
Strawberry clover	Palestine	35.3	34.3	34.8	*31.8*	**39.5**	33.9	29.5	33.7
Subterranean clover	Leura				*32.3*		*32.5*	29.9	
Lucerne	Sardi Grazer	39.6	*30.8*	35.2	35.9	36.5	35.1	30.5	34.5
	Titan 9	38.3	35.6	37.0	35.5	35.6	34.4	29.8	33.6
	2 × av. s.e.d.	4.4		3.8	2.4				1.3

Values in bold are greater than, and those in italics less than, one or both lucerne cultivars on the same sampling date, or mean of sampling dates within a season, by more than two average s.e.d.

Table 6. Metabolisable energy, crude protein and neutral detergent fibre at Bombala.

Species	Cultivar	Season 2019–20	Season 2020–21			
		Mar.	Dec.	Feb.	Apr.	Mean
		Metabolisable energy (MJ/kg DM)				
White clover	Haifa	10.8	*8.7*	*10.2*	10.6	*9.8*
	Nomad	*10.1*	*8.9*	*10.1*	10.4	*9.8*
	Trophy	10.6	*8.9*	*10.1*	10.7	*9.9*
Red clover	Astred	10.9	9.1	*9.5*	*9.9*	*9.5*
	Rubitas	10.8	9.2	*9.9*	10.0	*9.7*
Talish clover	Permatas	*10.2*	*8.7*	*10.3*	10.7	*9.9*
Caucasian clover	Kuratas	10.6	9.2	10.7	10.3	*10.0*
Caucasian × white clover	Aberlasting	*10.1*	9.1	*10.2*	10.5	*9.9*
Strawberry clover	Palestine	*10.0*	9.5	*9.6*	10.3	*9.8*
Subterranean clover	Leura					
Lucerne	Sardi Grazer	10.9	9.4	11.0	10.4	10.3
	Titan 9	10.6	9.4	10.9	10.4	10.3
	2 × av. s.e.d.	0.4	0.4			0.2
		Crude protein (% of DM)				
White clover	Haifa	*20.6*	*14.9*	*19.8*	*19.7*	*18.2*
	Nomad	*21.4*	*15.5*	21.7	20.3	*19.2*
	Trophy	*20.1*	*15.5*	*20.8*	*19.1*	*18.5*
Red clover	Astred	*20.4*	*15.0*	*19.3*	*18.7*	*17.6*
	Rubitas	*20.9*	*15.9*	*19.9*	*19.9*	*18.6*
Talish clover	Permatas	*21.1*	*15.1*	22.7	**23.4**	20.4
Caucasian clover	Kuratas	*22.8*	*14.9*	21.6	*17.2*	*17.9*
Caucasian × white clover	Aberlasting	*20.7*	*16.0*	*21.2*	*19.3*	*18.8*
Strawberry clover	Palestine	*19.6*	17.0	*18.9*	20.5	*18.8*
Subterranean clover	Leura					
Lucerne	Sardi Grazer	28.0	17.9	22.8	21.3	20.7
	Titan 9	26.3	17.9	23.3	21.9	21.0
	2 × av. s.e.d.	2.6	1.7			1.0
		Neutral detergent fibre (% of DM)				
White clover	Haifa	**30.6**	**41.2**	**32.6**	27.2	**33.7**
	Nomad	**35.5**	**39.3**	**33.3**	29.2	**33.9**
	Trophy	**32.1**	**38.8**	**32.4**	*26.8*	**32.7**
Red clover	Astred	**36.3**	35.9	**34.4**	31.7	**34.0**
	Rubitas	**36.4**	35.2	**32.7**	31.3	**33.1**
Talish clover	Permatas	**34.4**	**42.3**	**34.2**	*26.8*	**34.4**
Caucasian clover	Kuratas	**30.1**	35.2	**31.9**	30.2	**32.4**
Caucasian × white clover	Aberlasting	**35.6**	35.4	**32.7**	28.0	32.0
Strawberry clover	Palestine	**38.6**	34.1	**40.0**	30.4	**34.7**
Lucerne	Sardi Grazer	26.2	35.6	27.4	29.6	30.9
	Titan 9	26.9	35.9	28.3	29.5	31.2
Subterranean clover	Leura					
	2 × av. s.e.d.	2.7	2.4			1.3

Values in bold are greater than, and those in italics less than, one or both lucerne cultivars on the same sampling date, or mean of sampling dates within a season, by more than two average s.e.d.

lower; however, lucerne had the lowest NDF, in contrast to Goulburn (Table 6).

Discussion

This study assessed the potential of a range of perennial legumes to produce high-quality forage as an alternative to lucerne for animal production, exemplified by finishing lambs for meat production, during the summer–autumn period on the Southern Tablelands of NSW. We quantified persistence and productivity in all seasons and nutritive characteristics in summer–autumn across 12 cultivars in small-plot experiments at two sites over 2–3 years. Both sites experienced very dry through to very wet periods during the warm season, providing a range of environmental conditions for comparing the performance of clover options with the traditional lucerne option. Unlike the study of Hayes *et al.* (2023), which observed legume performance over a much larger number of sites and soil types, our study emphasised performance on more fertile soils suited to supporting high-production activities such as lamb finishing.

Persistence

Final frequencies of live plant base measured in autumn 2021 showed that all of the perennial clovers except red clover were at least as persistent as one or both of the lucerne cultivars once they had recovered from the 2019–20 drought period. The poor persistence of red clover, particularly at Goulburn, may be related to its weakly stoloniferous habit, limiting its ability to regenerate after the 2019–20 drought. Although both cultivars of red clover established well in our study, the frequency of live base decreased markedly during the drought period at both sites, similar to white, Caucasian × white and subterranean clovers. Caucasian × white clover was bred to improve grazing and drought tolerance of white clover by transferring the deep-rooted rhizomatous growth habit of Caucasian clover (Marshall *et al.* 2001; Lloyd *et al.* 2017), but there was no evidence at either site of improved drought tolerance relative to the three white clover cultivars tested. The frequencies of deep-rooted lucerne and Caucasian clover were unaffected by the drought; talish clover, also with relatively deep roots, and strawberry clover were less affected than red, white and subterranean clovers. The presence of live plants in stoloniferous species, and the seedbank in subterranean clover at Goulburn, were evidently sufficient for regeneration because all of these species, except red clover, recovered from drought. Two of the white clover cultivars, Trophy and Nomad, had breeding histories emphasising improved drought tolerance (Table 1) but neither showed any advantage in this regard over the older cultivar, Haifa, the 2019–20 drought period being too severe for any level of improvement to be displayed.

The decline in frequency of most species at Goulburn over the final summer may have been linked to the low rainfall (only 61 mm) between 25 November 2020 and 29 January 2021. The warm-season grass *Eleusine tristachya* (goosegrass) invaded swards heavily in the final summer and this may also have affected legume growth. Lucerne appeared to be affected by waterlogging during winter-–early spring 2020, whereas the clovers did not. This was not quantified but some wilting symptoms in lucerne were observed, indicative of crown or root rot, suggesting that factors other than drought and grazing pressure potentially reduce lucerne survival compared with clovers.

Productivity

Lucerne was the most consistently productive species throughout the study. Hayes *et al.* (2023) made a similar observation at a much wider range of sites on the NSW Tablelands with the caveat that lucerne frequently failed to persist where conditions were unfavourable as a result of soil infertility, acidity and probably depth. Sardi Grazer was usually less productive than Titan 9 (10–20% less at Goulburn except on two dates and 10–14% less at Bombala), as has been observed under mowing elsewhere (Nan *et al.* 2019). Lucerne was by far the most productive species during summer at both sites, producing at least 2.6 times the total summer DM of the clover species at Goulburn and at least 1.8 times the total summer DM of the most summer-productive clover cultivar, Astred red clover, at Bombala. Haifa and Trophy white clover produced similar amounts of DM to lucerne in the first half of the 2020–21 summer but only about one-third of lucerne DM in the second half of the summer. In the drought summer of 2019–20, the next most productive species after lucerne was strawberry clover at both sites, with 22–28% the DM of lucerne. These results suggest that productivity during this period was related to the ability to access moisture, with a study in Western Australia demonstrating that lucerne had a significantly longer taproot than strawberry clover (McDonald 2008). Lucerne also significantly outyielded the clovers in autumn 2020 during drought at Bombala and immediately post-drought at Goulburn. A similar result was found by Norman *et al.* (2021) in the hotter, more summer-dry environment of Adelaide where lucerne was much more productive than a wide range of perennial legumes in all seasons.

Only under high rainfall and the absence of hot weather in March 2021 did the clover species yield similarly to or outyield lucerne in autumn. All perennial clovers at Bombala exhibited excellent growth over autumn 2021, yielding up to 3.4 t/ha after 2.3 months of growth, compared with 2.0–2.2 t/ha for lucerne; Caucasian × white was the only perennial clover that remained significantly less productive than lucerne at this time. Much less growth occurred at Goulburn (0.7–1.0 t/ha after 2 months) but all clovers were at least as productive as lucerne (0.6–0.7 t/ha), including subterranean clover.

Lucerne productivity outside our target period compared favourably with that of the clover species tested when moisture availability was limited. Lucerne was more productive than the clovers in winter 2019 at Goulburn (with the exceptions of Haifa and Trophy white clovers) and winter 2020 at Bombala. Under the wet winter–early spring conditions at Goulburn in 2020, most clovers were at least as productive as lucerne, except for Nomad white, red and Caucasian × white clovers. Strawberry clover was the most productive species during this period. At Bombala, Nomad white and Caucasian × white clovers were the only perennial clovers yielding less than lucerne in spring 2020.

Nutritive characteristics

Cultivar and sampling date had significant effects on the nutritive value of herbage produced over the summer–autumn period at both sites. Although lucerne generally provided a higher concentration of CP than clovers, its relative ME value was variable between sampling periods. All clover cultivars achieved ME concentrations equal to or higher than one of the lucerne cultivars in at least one sampling period at both sites and at levels generally suitable for rapid growth of lambs (10.5–11.0 MJ/kg DM; Jolly and Wallace 2007). Nutritive value can decline substantially in mature lucerne under dry summer–autumn conditions (Nie *et al.* 2021), as evidenced by the dry 2019–20 summer period at Goulburn, where all perennial clovers were higher in ME than lucerne. Lower ME values in all species were generally linked to times when NDF values were higher, associated with flowering or advanced stem development. Presumably, selection of higher quality leaf material by grazing animals could result in a higher ME diet than the bulk samples harvested here. Consistently lower ME values for red clover in late summer–autumn than for other clovers were also associated with higher NDF and sometimes lower CP. Differences in late summer can be ascribed to differences in stem content, but differences in April at both sites when plants were mostly vegetative suggest differences in leaf nutritive characteristics. This is supported by the data of Norman *et al.* (2021), who found that Rubitas red clover was lower in digestibility than white clover when vegetative but similar when flowering and when mature.

Clover species

The major determinant of persistence and productivity in this experiment appears to have been moisture stress and thus the ability to access moisture at depth. Lucerne remains the most reliably productive legume for warm-season growth and should be used where it can grow successfully (i.e. avoiding acidic and shallow soils and areas prone to waterlogging; see Hayes *et al.* 2023). However, our study identified best-bet alternative legume options for high-production paddocks in the temperate zone of south-eastern Australia where soils are not suitable for lucerne or where a diversified legume component is desired in mixed pasture. Here, we discuss the potential role of each of the tested clovers in the target region.

Strawberry clover showed unexpectedly good drought survival as well as expected tolerance of wet conditions and was one of the most productive entries with high nutritive value. It is regarded as drought-tolerant on the NSW Tablelands (Clements *et al.* 2003), which may be related to the origin of cv. Palestine in the Dead Sea region of Israel (Oram 1990). A glasshouse study demonstrated superior drought tolerance of strawberry clover compared with white clover (Hofmann *et al.* 2007). Our study suggests that strawberry clover could have wider application in general-purpose pasture on the Southern Tablelands than it does at present. Its productivity was similar to white and red clovers in summer, higher than white and red clovers in autumn in 2 years at Goulburn, but ~15% lower in the favourable autumn of 2021 at Bombala. Strawberry clover was the highest yielding species in the very wet winter–early spring period in 2020, and winter and spring production was generally good. Strawberry clover showed poor productivity in a New Zealand study (Gerard *et al.* 2022), variable productivity but good persistence in Tasmania (Knox *et al.* 2006), and similar productivity to white and red clovers in Adelaide (Norman *et al.* 2021). Li *et al.* (2008) found that strawberry clover had similar productivity to lucerne at waterlogging-prone sites with heavier soils even though significant waterlogging did not occur during their study. Knox *et al.* (2006) suggested that strawberry clover is favoured by hard grazing to control the grass component of a pasture, and thus, a lack of competition from a perennial grass may have enhanced its performance in our study. Susceptibility to grass competition may make strawberry clover unsuited to pastures managed to accumulate high levels of biomass. Strawberry clover is also considered to be highly sensitive to acid soils (Duncan 1999; M. Norton, pers. comm.). The registration description of cv. Palestine states that it tolerates a wide range of soil acidity but that it has a high requirement for P and K (Oram 1990). More research is required on the productivity, soil tolerances and grazing management of strawberry clover under non-waterlogged dryland conditions.

Talish clover was similar in production to white and red clover in this study and was less affected by drought. Norman *et al.* (2021) found that talish clover had similar productivity to Caucasian clover over a year and was less productive than white clover. In our study, nutritive characteristics of talish clover were either similar to those of white clover, or sometimes its ME was lower (associated with higher NDF) but nevertheless high enough for rapid growth of lambs. Norman *et al.* (2021) found that vegetative herbage of talish clover was substantially lower in digestibility than that of white clover, associated with higher ADF content. In the milder environment of the Southern Tablelands, productivity and nutritive characteristics of talish clover appeared closer to those of white clover than found in the study of Norman *et al.* (2021). Talish clover is likely to be suited to at least some areas with acidic soils, because it exhibited relatively high tolerance of Al in solution culture although it was relatively sensitive to manganese (McVittie *et al.* 2012). Although Hayes *et al.* (2023) found talish clover to be no more persistent than white clover, we found it to be more drought-tolerant at Goulburn and productive at both sites, likely reflecting our focus on more fertile and less acidic soils suited to lamb finishing. Our evidence suggests that talish clover is well worth considering for the Southern Tablelands environment if seed becomes available.

Caucasian clover was highly persistent, confirming its superior ability to survive drought compared with other clovers (Hackney *et al.* 2019; Hayes *et al.* 2019). It was less productive than white clover in the short term but similar in nutritive characteristics. Its ability to retain live base during drought at Goulburn assisted productivity in the immediate post-drought period compared with more slowly regenerating species. Over a much wider range of sites and soil conditions, Hayes *et al.* (2023) concluded that Caucasian clover established adequately but was inconsistent in persistence and production. Given its superior persistence compared with white clover in the high-production paddocks in our study, it is possible that a marked yield advantage for Caucasian clover could develop over a longer period of observation. Virgona and Dear (1996) observed much higher survival and production by Monaro Caucasian clover 11 years after sowing than Haifa white clover at a 1000 m altitude site in the Monaro region. These observations, combined with slow establishment (Black *et al.* 2006), mean that Caucasian clover is probably suited only to long-term, general-purpose pastures on the Southern Tablelands/Monaro. There has been considerable interest in Caucasian clover for both hill country and lowland environments in New Zealand, where sowing Caucasian alone in spring followed by grass in autumn has been recommended to overcome slow establishment by the clover (Black *et al.* 2000).

White clover in particular, but also red clover, remain worth of including in mixes for high-production paddocks because of their ability to respond with high-quality feed in moist, cool periods. However, they cannot be relied upon for high levels of forage production during normal summer conditions on the Southern Tablelands and will decline severely during drought. Survival of white clover in NSW Tablelands environments relies on survival and growth of stolons, which is most dependent on warm-season rainfall, and on annual regeneration from seedlings, which is dependent on cool-season rainfall (Hutchinson *et al.* 1995). The capacity of white clover to spread vigorously by stolons was an important factor in recovery from low establishment density at Goulburn and then in the year after drought at both sites. Although seedlings were not counted in the immediate post-drought period at Goulburn, recruitment of seedlings was also a likely factor in recovery from very low frequency of live base because considerable flowering was observed in the previous spring. Hayes *et al.* (2023) concluded that white clover was probably the most broadly adapted of the perennial legumes to tablelands environments, although still lacking persistence at many sites, and that it tolerated acidic and infertile soils better than lucerne.

Red clover displayed much lower capacity than white clover for stoloniferous growth and did not recover significantly once it declined during drought. Red clover was also lower in ME content than white clover on several dates, and this was associated with higher NDF and slightly lower CP. The main advantage of red clover is its rapid establishment making it suited to shorter term pastures.

The response of Aberlasting Caucasian × white clover to the 2019–20 drought period was similar to that of white clover in this study. It showed low winter productivity like Caucasian clover and was the least productive perennial species in all seasons, similar to observations in New Zealand (Gerard *et al.* 2022).

Subterranean clover was included in this study because it is the standard legume sown in nearly all pasture mixes on the Tablelands of NSW. The cultivar used, Leura, is late-maturing with a low level of hardseedness. It proved unable to set seed during the dry first spring at Bombala and died out; this may have been avoided by using an earlier maturing cultivar. Leura was able to set seed despite dry conditions at Goulburn in spring 2019 and strongly regenerated the following year under high rainfall, to be highly productive in winter and early spring. Although subterranean clover will contribute little to green forage consumed in summer, it nevertheless grows strongly in other seasons, when it can build the soil N levels needed for growth by other species in summer. Excellent adaptation to the Southern Tablelands environment means that subterranean clover of appropriate maturity type should be included in mixes even for summer-active perennial pasture.

Conclusions

Lucerne remains the most reliably productive legume under favourable soil conditions in the temperate environment of the Southern Tablelands and therefore the most suitable legume species for growing and finishing lambs throughout summer–autumn period. However, our study identified several clover options with reasonable persistence and productivity throughout the year and with high nutritive value over summer–autumn. Further research should address soil tolerances and optimal grazing management of talish, Caucasian and strawberry clovers in particular. Inclusion of these species in high-value pastures in south-eastern Australia could significantly improve livestock production potential over the warm season where soil conditions are not suited to lucerne, both through provision of high-quality forage when seasonal conditions allow and through their critical role in N fixation throughout the year.

Supplementary material

Supplementary material is available online.

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Data availability. The data that support this study will be shared upon reasonable request to the corresponding author.

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