Final report

Perennial pasture & forage combinations to extend summer feed for southern NSW

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Abstract

The quality and quantity of pasture on the NSW Southern Tablelands declines in late spring/early summer, limiting the ability to finish lambs over the summer-autumn period. We tested a range of species with potential to fill this feed gap. Summer-active grasses, herbs and legumes were assessed for productivity, persistence, and nutritive quality in replicated small-plot trials on farms for two to three years. Lucerne was the most reliably productive species during summer (except on acidic soil), while chicory provided reliable high-quality feed from late spring into autumn. A lamb finishing experiment produced higher rates of liveweight gain over two summer-autumn periods on herb-based pasture (chicory, plantain and legume) than grass-based pastures (phalaris, brome-cocksfoot and tall fescue, with legumes), lucerne and forage brassica. Phalaris, cocksfoot, chicory, forage brassica and lucerne production were modelled over 60 years in APSIM and feed availability across management scenarios were evaluated. The summer activity of lucerne and chicory produced the most complementary growth patterns and the largest reductions in the frequency and size of feed deficits. Converting a portion of high-fertility grazed land to high-quality summer-active forages such as lucerne and chicory could reduce the risk of feed deficits and allow for finishing of lambs on-farm.

Executive summary

Background

There is strong interest in meat production in southern NSW but the ability to finish lambs on pasture is limited by the decline in herbage quality and growth in late spring through early summer. This project investigated perennial pasture and forage species that could increase the proportion of lambs finished over the summer-autumn period by producers in Southern Tablelands environments. Reducing the risk of a warm-season feed gap could significantly improve profitability for the target producers. The project focussed on herbage production, quality and persistence, and rates of lamb growth on a range of pasture and forage combinations. The results can be used to inform decisions about the species to include in the feed mix that will best support livestock production over the summer-autumn period in southern NSW.

Objectives

The objectives achieved in this project were to:

- Identify pasture options emphasising perennials that are productive, persistent and of high nutritive quality during the summer-autumn period in southern NSW and similar environments.
- Quantify lamb production on a range of pasture and crop forages in the summer-autumn period.
- Predict the likely impact of increasing the supply of high-quality, summer-active forages on meat production and enterprise performance.

Methodology

- On-farm replicated plot trials to evaluate pasture options over 2-3 years at two core sites and two supplementary sites on the Southern Tablelands, assessing production, persistence, and nutritive quality.
- Animal production experiment to evaluate the finishing component of lamb enterprises over the summer-autumn growth/fattening period (2 years).
- Modelling component to explore value for meat production of incorporating more summer-active pasture into feedbase on Southern Tablelands farms.

Results/key findings

- Chicory proved to be an excellent warm-season specialist in Southern Tablelands environments, reliably producing herbage of high quality and quantity through this period and showing the ability to recover well from drought. Summer-active cocksfoot, perennial ryegrass, prairie grass and plantain also performed well over the target period. Lucerne was the best performing legume trialled and should remain an important component of the summer-autumn feed mix but was not as resilient as chicory to acid soil conditions and waterlogging. Red, white and subterranean clovers also have a role to play in summer-specialist mixed pastures.

- Herb-based pasture (chicory, plantain and legumes) produced the highest rates of lamb liveweight gain in both years of the summer-autumn grazing experiment (cf. phalaris-legume, tall fescue-legume, brome-cocksfoot-legume, lucerne and brassica).
- Modelling of alternative forage systems suggested that converting 20% of grazed land to high-quality summer-active forages could support a conversion to a fat lamb enterprise while reducing or lowering the risk of forage deficits. Significant gains in livestock enterprise productivity & profitability could be supported where the marginal cost of implementing these forages is less than $200/ha/yr.

Benefits to industry

Dedicating a portion of fertile grazing land to chicory-based pasture (and/or lucerne where soil conditions allow) to support warm-season lamb production is likely to significantly improve the profitability of livestock enterprises on the Southern Tablelands. The potential benefits of incorporating high-quality summer-active perennial species in the feedbase flow from a reduced risk of feed deficits over the summer-autumn period, avoiding the need for supplementary feeding or early sale of lambs, and improved livestock production through higher rates of liveweight gain. The benefits of this system change could extend to areas of Victoria and Tasmania with similar seasonal distribution of rainfall and may also be applicable to cattle operations across the region.

Future research and recommendations

- Parameterization of more summer-active species and cultivars in agricultural modelling applications (e.g. APSIM) would enable more reliable predictions of performance across environments and seasons.
- A multi-year on-farm demonstration of chicory-based pasture under well-managed grazing could help to encourage adoption by producers that are currently sceptical about persistence.
- Validation of results in Victoria and in cattle operations would increase the potential impact of the research results.

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1. Background

1.1 The issue

The 1990's and 2000's saw a large shift in the Australian sheep industry away from wool production towards lamb meat production due to a change in relative prices of wool and lamb meat (Warn et al. 2006; Rowe 2010; Pattinson et al. 2015). Traditional wool production regions such as the Tablelands of NSW experienced an increase in dual-purpose Merino enterprises combining wool and meat production, with a proportion of ewes joined to terminal sire breeds (Pattinson et al. 2015). Breeder/finisher systems in which lambs are bred and finished on pasture or crop on the same farm can be profitable compared with other systems due to low cost of finishing and the income from wool (Warn et al. 2006; MLA Final Report 2011). However, the ability to finish lambs may be restricted by availability of feed which can result in selling unfinished lambs earlier as stores at a lower price. In particular, the ability to finish lambs in pasture-fed systems is limited in southern Australia by a recurring deficit in high quality forage as digestibility and crude protein decline with pasture senescence during late spring and summer.

While profitability in sheep production systems can be achieved in a number of ways (Robertson and Friend 2020), grazing and modelling studies indicate that, in general, most profitable use of the typical pasture growth curves for the High Rainfall Zone of south-eastern Australia is made by lambing in late winter-early spring since this maximises ewe stocking rates, which are mainly limited by low pasture growth rates in autumn-winter, and minimises supplementary feeding (Arnold et al. 1971; Reeve and Sharkey 1980; Warn et al. 2006). This applies particularly in cold areas such as the Tablelands of NSW where pasture growth is strongly limited in winter. However, this constrains the ability to achieve target weight and condition of lambs before the normal decline in pasture quality with the onset of summer. Previous research has shown that the length of time between lambing and senescence of pasture is critical for lamb meat production on the Tablelands (Arnold et al. 1971; Donnelly et al. 1985). The trend towards higher carcass weight lambs (Pattinson et al. 2015) requiring longer to finish exacerbates this situation.

The Southern Tablelands region is typical of the southern half of the NSW Tablelands in experiencing strong constraints on pasture growth in winter and frequent constraints on pasture quality and quantity in summer-autumn. A traditional wool-growing region, it also has experienced strong movement towards lamb meat production in recent decades (Spoljaric 2019). The Monaro Farming Systems group, for example, reported that meat production increased from 20% to 50% of farm enterprise in its membership in a 6-year period up to 2015 (R. Taylor, pers. comm.). Average rainfall typically in the 500-700 mm range is uniformly distributed but highly variable between and within years. Some areas such as the Monaro and those nearer the coast have a more summer rainfall- dominant distribution although annual totals may be low on the Monaro (Clements et al. 2003). Pastures usually dry off to varying extents over summer and most areas are considered marginal for prime lamb production unless summer-active species such as lucerne (*Medicago sativa* L.) are available (Donnelly et al. 1985).

Lucerne and forage brassica currently are the main specialist summer finishing options on the Southern Tablelands. 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; Kenney and Reed 1982 et al., Donnelly et al. 1985) although its value still depends on frequency and amount of summer rainfall (Robertson et al. 2020). However, lucerne is severely limited in area on the Southern Tablelands by unfavourable soil conditions (Donnelly et al. 1983). Soil constraints due to shallow depth, acidity, low fertility and poor drainage are widespread. The role of dual-purpose crops in filling seasonal feed gaps, mainly in winter, on the Southern Tablelands has also been explored in recent years (McGrath et al. 2021).

1.2 A role for more summer-active pasture?

Unlike more summer-dry environments in much of southern Australia, irregular but often substantial rainfall events capable of stimulating some pasture growth occur in most years on the Southern Tablelands. Experience in this region has shown that long-term persistence of sown pastures is best if they are based on phalaris (*Phalaris aquatica* L.), a deep-rooted and partially summer-dormant species, and annual subterranean clover (*Trifolium subterraneum* L.) mixed with volunteer annual grasses which provide limited response to summer rainfall. Some high-quality species with a more summer-active growth rhythm such as perennial ryegrass are considered to lack the persistence through drought required for economic return *under traditional wool production systems* (Axelsen and Morley 1968), except in relatively small areas with above 800 mm average rainfall (Clements et al. 2003). However, some modification of the current sown pasture base in southern NSW towards more summer activity may be warranted for meat production systems.

The project asked whether there is a role in meat production systems, targeted at suitable paddocks, for increased adoption of perennial pasture species with a more summer-active growth rhythm than phalaris, which could produce a higher quantity and quality of herbage in summer-autumn, be adequately persistent under Southern Tablelands conditions, and show better adaptation than lucerne to soil constraints such as acidity. Perennials were a particular focus because they offer the potential for lower long-term cost if persistent enough, more permanent ground cover and higher carbon accumulation compared with annual crops. Successful demonstration of targeted use of summer-active perennials in pastures to increase high quality summer feed in the summer-dry climate of south-western Victoria (Clark et al. 2013; Ward et al. 2013) provided encouragement that a similar approach would be successful on the Southern Tablelands where summer rainfall is more likely. Extension of this role in future is possible with predictions for south-eastern NSW of a change in rainfall distribution towards drier winter-spring seasons and wetter summer-autumn seasons (NSW Government 2020).

Success in identifying suitable options would provide growers in southern NSW an additional opportunity to finish a higher proportion of lambs than is presently possible utilising existing pasture and limited areas of lucerne and summer crops. Dual-purpose Merino breeder/finisher enterprises which are more opportunistic rather than specialist meat producers were a particular target since specialist meat producers are more likely to have reliable systems for finishing in place already. Modelling of Monaro systems concluded that finishing lambs rather than selling as stores was clearly profitable with little effect on ewe numbers or increase in economic risk (Alcock 2016). Availability of higher nutritive quality pastures over summer could also influence other areas of farm management such as survival and growth of Merino weaners, improvement of ewe condition for joining and cattle operations.

1.3 Species examined

A range of commercially available temperate options that are often used in higher rainfall, cooler environments (e.g., New Zealand, southern Victoria) or in more summer-dominant rainfall environments (e.g., Northern Tablelands) were considered worth re-evaluating for meat production systems on the Southern Tablelands. Perennial non-legume species included summer-active cocksfoot (*Dactylis glomerata* subsp. *glomerata* L.), summer-active tall fescue (*Festuca arundinacea* Schreb.), perennial bromes (*Bromus* spp.), chicory (*Cichorium intybus* L.), plantain (*Plantago lanceolata* L.) and perennial veldt grass (*Ehrharta calycina* Sm.). Cocksfoot cultivars with a range of summer dormancy levels are already widely used on more acidic, less fertile soils of the Tablelands. Summer-active tall fescue is a more drought- and heat-tolerant species than perennial ryegrass and is considered to have a potential role in areas of south-eastern Australian with >600 mm rainfall, particularly on heavier soils (Raeside *et al.* 2012a). It has shown promise in sheep production systems on appropriate soil types even in the summer-dry environment of south-western Victoria (Raeside *et al.* 2012b; Clark *et al.* 2013). Chicory is a deep-rooted species with potential for south-eastern Australia, combining high summer growth and nutritive quality (Li *et al.* 2010). Chicory was effective in supporting lamb growth over summer on the Central Tablelands of NSW (Holst *et al.* 2006). Perennial bromes are considered to have potential in medium-high rainfall areas in south-eastern Australia (Hackney *et al.* 2007). Coloured brome (*B. coloratus* Steud.) was almost as productive during summer as perennial ryegrass under irrigation in northern Tasmania (Smith *et al.* 2015) and was more persistent under dry conditions (Hall and Hurst 2012). Evaluation of tropical grasses for the Tablelands is still at an early stage but results from the cold environment of Orange on the Central Tablelands show that some tropical grass species can survive there and produce well over summer (W. Badgery, pers. comm.).

Legumes are a vital component of southern Australian pastures for their ability to fix nitrogen and for their high nutritive value. Predominantly, these are cool-season annual legumes that dry off at the end of spring although one of these, arrowleaf clover (*Trifolium vesiculosum* Savi.), has later senescence and has been promoted for extending the season for finishing lambs for meat production (Thompson et al. 2010). The range of perennial legumes commercially available for south-eastern Australia is limited to lucerne, white clover (*T. repens* L.), red clover (*T. pratense* L.) and strawberry clover (*T. fragiferum* L.); all are summer-active in their growth rhythm (Hayes et al. 2019). White clover is the most commonly used perennial clover species on the NSW Tablelands but does not persist well under moisture stress. More drought-tolerant cultivars of white clover such as Grasslands Trophy and Grasslands Tribute have been bred (Hayes et al. 2019) but are not available commercially possibly because of the dominance of the white clover market by New Zealand cultivars. Red clover has shown the potential for high liveweight gains by weaners in the Monaro region (Burge 1993). Modern 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). Deeper-rooted species such as caucasian clover *(Trifolium ambiguum* M.Bieb.), and talish clover (*Trifolium ambiguum* M.Bieb.), are likely to survive much better than white clover under drought but also are restricted in availability of seed. 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). Hackney et al. (2019) 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.

Many of the non-legume and legume species examined in this project were evaluated for persistence and productivity by Hackney et al. (2006, 2019) on a low fertility granite soil in a 500 mm rainfall area of the Monaro, representative of the harsher conditions likely to be experienced on the Tablelands and where meat production remains difficult. Evaluation in higher rainfall areas with more productive soils and higher fertiliser input, better suited to meat production activities, may be more appropriate for some of these species. Most of the species were also evaluated under irrigation for one summer and dryland conditions for a second summer in the lower rainfall, summer-dry climates of Adelaide and Perth (Vercoe 2015; Norman et al. 2021).

One component of the project evaluated a range of more familiar and novel pasture options, which at present could be under-utilised on the Southern Tablelands, for productivity and nutritive value as well as an early view of persistence. These species will be expected to produce a higher quantity and quality of herbage in the summer-autumn period than phalaris and persist better than lucerne under typical tablelands soils conditions. An animal component measured lamb production on a range of forages including an annual crop option in the summer-autumn period. We tested three grass-based pastures: phalaris, tall fescue and brome-cocksfoot, a chicory-plantain mix, pure lucerne, and forage brassica (*Brassica rapa* x *oleracea* L.). The grass- and herb-based pastures were sown in combination with white clover, red clover, subterranean clover and lucerne. The modelling component considered phalaris, cocksfoot, chicory, lucerne and forage brassica under a range of farm management scenarios.

2. Objectives

2.1 Objective 1

Identify pasture options emphasising perennials with the ability to contribute high quality feed for meat production enterprises such as fat lamb finishing in the summer-autumn period in southern NSW and similar environments.

This objective was met by evaluating a range of potentially suitable species in replicated small-plot trials at four sites on the Southern Tablelands/Monaro regions. A northern core trial site was located in the Goulburn area and a southern site in the Bombala area. A non-legume experiment evaluating 20 cultivars across 14 species and a legume trial evaluating 12 cultivars across 8 species were conducted at each core trial site. Data on production, persistence and nutritive quality were collected over the planned 3 years at the Goulburn core trial site and over 2 years at the Bombala core trial site due to a delay in sowing to achieve more suitable conditions. Phalaris and lucerne were considered the standard species against which other species were compared. Chicory, plantain, cocksfoot and tall fescue were identified as species of interest.

Two supplementary sites were established north of Gunning for 3 years and at Dry Plain (north-west of Cooma) for 2 years to extend project coverage of the Southern Tablelands/Monaro region. The Gunning site examined mixtures involving factorial combinations of three non-legume and legume species with a range of summer activities on a deep acid soil. Phalaris–sub clover was the most successful mixture through drought despite the deep acid soil. Tall fescue persisted poorly through severe drought but recovered partially under subsequent high rainfall. Chicory was shown to be a summer-active, high-quality replacement for lucerne on acid soils. A subset of non-legume species from the core trials all survived well at the cooler, high elevation Dry Plain site, including perennial ryegrass. Data from a pilot species evaluation experiment at Canberra started before the project is also included in this report.

Objective 2

Data on production, persistence, and nutritive quality in a range of summer-active pasture options at several sites on the Southern Tablelands, to be made available in a document written for a producer audience and by presentation to farmer meetings.

To encourage grower interest, all on-farm species evaluation sites were located on the properties of members of the Monaro Farming Systems [MFS] or Tablelands Farming Systems [TFS] groups. Richard Culvenor presented the premise, design and preliminary results of this project at meetings of both farmer groups and the Southern Australian Livestock Research Council in the early stages of the project. Showcasing sites over the summer-autumn period proved very difficult due to conflicts with harvesting times for producers, and most of the engagement over this period was limited to the hosts of our trials. The Gunning site was attended by TFS members in late spring 2019, and we engaged with several producers and consultants through regular meetings of the LPP Southern Advisory Committee (including a visit to the Canberra grazing study in November 2020). The grazing study and pilot species evaluation trial in Canberra were also presented to attendees of the CSIRO Experiment Station Field Days in November of 2018 and 2019. In December 2020, Richard Culvenor presented our project results to-date at the Tasmanian LPP Online Workshop that was well-attended by producers. We are currently preparing a publication targeted at farmers on the Southern Tablelands that outlines our project and the key results. We intend to disseminate this publication via MLA's website and advertise its availability through MFS and TFS. There has also been significant interest from seed companies selling chicory, and they may provide an avenue for further disseminating the results of this project. A summary of formal engagement activities is given in **Table 2.1** with estimates of producer and consultant attendance numbers.

Table 2.1. Engagement with producers and consultants throughout project.

Date	Event	Presenter	Attendance
Sep 2018	Monaro Farming Systems Spring Field Day, Nimmitabel NSW (Stutz conducted informal discussions with farmers about existing feeding practices in fat lamb enterprises)	Culvenor	40
Nov 2018	CSIRO Experiment Station Field Day, Hall ACT	Culvenor & Stutz	28
Dec 2018	Graminus Consulting Farm Walk, Gunning NSW	Culvenor	20
May 2019	Southern Australian Livestock Research Council (SALRC) Meeting, Acton ACT	Culvenor	20
	LPP Southern Advisory Committee Meeting, Cowra NSW	Culvenor	6
Oct 2019	LPP Southern Advisory Committee Meeting, Mandurama NSW	Culvenor	8
Nov 2019	Southern Tablelands Farming Systems Field Day, Gunning NSW	Culvenor	25
	CSIRO Experiment Station Field Day, Hall ACT	Culvenor & Stutz	35
Feb 2020	HRZ Legume Workshop	Culvenor	22
Nov 2020	LPP Southern Advisory Committee Meeting, Acton ACT (hosted) + tour of grazing trial, Hall ACT	Culvenor & Stutz	3
Dec 2020	Tasmanian LPP Workshop	Culvenor	25

Objective 3

Data on lamb production on a range of pasture and crop forages in the summer-autumn period on the Southern Tablelands.

This objective was met through a grazing experiment conducted over two summer-autumn seasons in Canberra to compare the lamb production value of six summer forage options for the Southern Tablelands. The experiment compared a conventional pasture option (phalaris-legume) to alternative summer-active grass-based (brome-cocksfoot-legume, tall fescue-legume) and herb-based (chicory-plantain-legume) pastures and the two standard summer forage options of pure lucerne and brassica. Forage treatments were compared for lamb liveweight gains and associated pasture growth and nutritive quality. Lamb liveweight gains were highest on the herb treatment in both years while total liveweight gain per hectare was highest on forage brassica in year 1 and brome-cocksfoot-legume in year 2.

Objective 4

Simulations utilising historical rainfall records to model likely impact of increased supply of higher nutritive quality feed in summer on meat production and enterprise performance.

While experimental work conducted in this project has examined the potential of a range of different forage options to provide high quality forage during summer, the potential for prospective forage options to fill feed gaps over a wider range of seasons requires a longer-term analysis. Further, there are questions about the extent of the farm that could or should be allocated to these alternative forages in order to supply sufficient summer forage, balanced against providing feed at other times of year. System simulation modelling can help add insights into these two questions and help to quantify the relative changes in the capacity to balance feed supply and demand and mitigate the risk of feed deficits for a range of different forage options and farm configurations.

The production of phalaris, cocksfoot, forage brassica, chicory and lucerne were simulated in APSIM for sites in Goulburn and Bombala. A whole-farm feed-energy balance calculator was then used to evaluate the timing, frequency and magnitude of feed gaps amongst a range of potential scenarios combining different forage and livestock enterprise configurations. The modelling showed that converting 20% of grazed land to high-quality summer-active forages could support a fat lamb enterprise while reducing or lowering the risk of forage deficits. The summer activity of lucerne and chicory produced the most complementary growth patterns and the biggest reductions in the frequency and size of feed deficits.

Objective 5

Post-doc animal production scientist trained through shared employment on this project and project on “Improving the use of forage brassicas in mixed farming systems”.

Dr Rebecca Stutz was appointed as a postdoctoral fellow in July 2018 following advertisement nationally and internationally. She worked across both projects over the 3-year appointment and progressed to a Research Scientist position in July 2021. This has renewed Canberra-based capability for animal production research at CSIRO.

3. Methodology

3.1 On-farm species evaluation component

3.1.1 Experimental sites

Four experimental sites were established in the Southern Tablelands/Monaro region of NSW to evaluate productivity, nutritive quality and persistence of a range of non-legume and legume species as an indication of their likely ability to contribute high quality feed for lamb meat production in the summer-autumn period (Fig. 1). Two “core” sites were chosen to represent environments where rainfall and soil conditions were considered suitable for growing pasture for finishing lambs over summer. The full set of species and cultivars of a range of non-legumes (grasses and herbs) in one experiment and legumes in a separate experiment were tested in at these sites. In addition, two "supplementary" sites were chosen to extend the coverage of the target region. One was located on a deep acid soil and the second at a higher altitude locality than the core sites. Only a subset of species was sown at these sites. Also included in this report is a pilot species evaluation experiment begun 2 years prior to the commencement of the project but continued as part of the project until autumn 2020.

Core sites were located at:

(i) Goulburn (Tirrannaville): on the "Trentham" property, approx. 20 km south of Goulburn on the Braidwood Road (34.931°S, 149.676°E, 670 m altitude, LTA rainfall 670 mm). Situated towards the coastal side of the target region favouring more summer rainfall. Red chromosol soil type derived from sedimentary material with a loam surface texture. Paddock utilised for grazing oats in year prior to sowing.

(ii) Bombala (Palarang): on the "Burando" property, approx. 15 km. NW of Bombala (36.833°S, 149.106°E, 730 m altitude, LTA rainfall 550-570 mm). Average rainfall low for summer-active species but not as low as site used by Hackney et al. (2019). Productive soil classified as a brown dermosol on a basalt-sedimentary boundary with a loam to clay-loam surface texture. Paddock utilised for grazing wheat in year prior to sowing.

Supplementary sites were located at:

(i) Gunning (Merrill): on the "Merrill" property, approx. 18 km north of Gunning on the Crookwell Road (34.644°S, 149.330°E, 800 m altitude, LTA rainfall approx. 680-700 mm). Higher altitude than region immediately to the south; deep acid soil. Red kurosol soil type with a loam surface texture. Pasture paddock previously used for grazing.

(ii) Dry Plain: on the "Glenfinnan" property, approx. 24 km. NW of Cooma area (36.119°E, 148.902°S, 1150 m altitude, LTA rainfall approx. 650 mm). High altitude, cooler location. Pasture paddock previously used for grazing. Yellow chromosol soil type with a loam surface texture.

The pilot study sown in 2016 was conducted at the CSIRO Ginninderra Experiment Station (GES), Canberra (35.201°S, 149.081°E, 600 m altitude, LTA average rainfall 689 mm) on a north-facing slope. Soil type was a yellow chromosol grading to a red chromosol in the upper slope.

Soil chemical characteristics in 0-10 and 10-20 cm layers at the start of the experiment are shown in Table 1. Analyses were conducted by the CSIRO Black Mountain Analytical Unit (Goulburn, Gunning) or CSBP Soil and Plant Analysis Laboratories (Bombala, Dry Plain) both of which are ASPAC certified. The Goulburn site had been limed in previous years and was considered potassium deficient. Strong acidity and high exchangeable Al levels are evident at the Gunning site.

All evaluation experiments were successfully completed with the collection of 2-4 years of data depending on site. While lucerne gave the most reliable summer production, chicory was also identified as a species of particular interest for summer production, high nutritive quality, drought survival and acid soil tolerance.

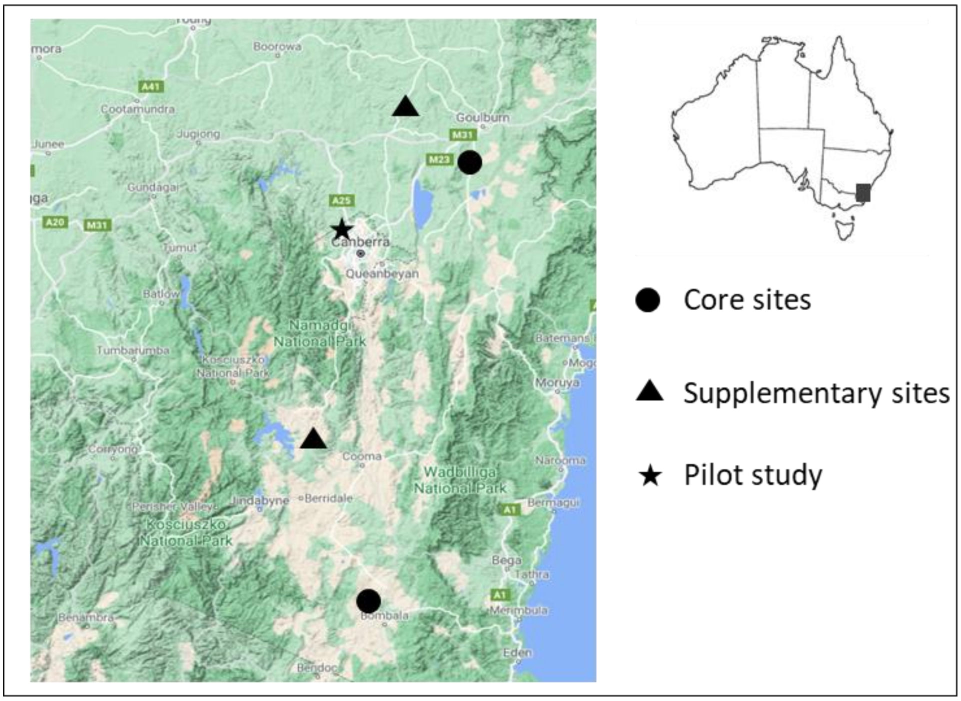


Figure 3.1. Location of species evaluation sites.

Table 3.1. Soil chemical properties at the experimental sites.

Property	Units	Goulburn		Bombala		Gunning		Dry Plain	GES
	Depth (cm)	0-10	10-20	0-10	10-20	0-10	10-20	0-10	0-10
pH ($CaCl_2$)	pH units	5.8	4.6	4.5	4.6	4.0	4.1	4.6	5.4
Colwell P	mg/kg	38	9	24	10	18	2	57	66
Colwell K	mg/kg	112	64	240	241	358	310	102	208
KCl_{40} S	mg/kg	22	15	20	13	12	7	11	7
PBI		50	51	62	72	135	167	46	44
EC	dS/m	0.21	0.13	0.19	0.08	0.23	0.09	0.06	0.06
OC	%	1.32	0.50	1.41	0.93	n/d	n/d	3.0	0.87
Exch. Ca	cmol(+)/kg	6.27	2.41	3.65	3.15	2.44	1.58	4.75	3.75
Exch. K	cmol(+)/kg	0.20	0.02	0.75	0.52	0.68	0.61	0.38	0.39
Exch. Mg	cmol(+)/kg	0.73	0.51	0.93	0.91	0.96	0.78	1.42	0.48
Exch. Na	cmol(+)/kg	0.32	0.17	0.06	0.05	0.04	0.02	0.04	0.06
Exch. Al	cmol(+)/kg	0.01	0.20	0.29	0.26	2.20	3.13	0.31	0.02
Total CEC	cmol(+)/kg	7.52	3.30	5.68	4.89	6.32	6.12	6.34	4.70
Al % of CEC	%	0	6	5	5	35	51	4	<1

3.1.2 Core site trials – Non-legumes

Species

The non-legume experiments at Goulburn and Bombala contained 20 cultivars of 14 perennial grass and herb species (**Table 3.2**). A range of perennial ryegrass cultivars based on seed company recommendations was included despite the preconception that perennial ryegrass was not sufficiently drought-tolerant in the target environment. More than one cultivar of the important summer-active species, tall fescue and cocksfoot, were also included. Winter-active (Mediterranean) tall fescue is adapted to the Southern Tablelands environment but was not included because of the emphasis on summer activity. One tropical grass, digit grass, was included on the recommendation of Carol Harris and Suzanne Boschma, NSW Department of Primary Industries.

Table 3.2. Species and cultivars in the core non-legume experiments

Species	Common name	Cultivar	Notes
Festuca arundinacea	Tall fescue	Quantum II Max P	Summer-active type, industry standard cultivar
		Hummer Max P	Summer-active type, relatively new cultivar
		Finesse Q	Summer-active type, relatively new cultivar
Dactylis glomerata ssp. *glomerata*	Cocksfoot	Porto	Summer-active type, standard cultivar for SE Australia
		Savvy	Summer-active type, reputed to be more summer-active than Porto
Lolium perenne	Perennial ryegrass	Base AR37	Late-season tetraploid ryegrass
		Excess AR37	Mid-season diploid ryegrass
		Kidman	Early-season diploid ryegrass
Bromus wildenowii	Prairie grass	Atom	
B. stamineus	Grazing brome	Gala	
B. valdivianus	Pasture brome	Bareno	
B. coloratus	Coloured brome	Exceltas	Recently released from Tasmania
Secale montanum	Mountain rye	Family 10	Cold-tolerant species suited to ST/Monaro, experimental CSIRO line (Oram 1996)
Ehrharta calycina	Perennial veldt grass	Mission	Promising species for SE Australia (Hayes et al. 2015)
Digitaria eriantha	Digit grass	Premier digit	Tropical grass, reasonable cold tolerance
Cichorium intybus	Chicory	Puna	Original cultivar, most persistent type, little winter production
		Commander	Winter activity higher than Puna
Plantago lanceolata	Plantain	Tonic	
Phalaris aquatica	Phalaris	Holdfast	Standard species for sown pastures on Southern Tablelands/Monaro
Medicago sativa	Lucerne	Sardi Grazer	Standard summer forage species for Southern Tablelands/Monaro; grazing-tolerant cultivar

Site management

Experimental design at both sites was a row-column design with 4 replicates. Plot size was 6 m × 1.8 m with a 1-m buffer strip between the ends of plots kept clear by glyphosate application. Sowing rates are shown in **Table 4.1**.

The Goulburn trial was direct-drilled with a coneseeder on 17 April 2018 except for perennial veldt grass, which was sown by hand on 9 May 2018 due to late arrival of seed, and digit grass which was sown by hand in October. There were 10 drill rows 18 cm apart across plots. Croplift 15 (14.6% N, 12% P, 11.6% S) at 200 kg/ha and muriate of potash (50% K) at 125 kg/ha were broadcast before sowing with a further 50 kg/ha of Croplift 15 sown in the drill row. Chicory and lucerne plots were considered to lack density in patches by late winter. Extra seed was sown into these patches on 5 September 2018 to achieve more even plots. The trial was mown on 2 November 2018 to control self-sown oats. Weeds were controlled throughout the experiment mainly by hand-pulling and chipping and occasionally by dabbing glyphosate. Very dry conditions were experienced in the 5 months after sowing.

The Bombala trial was planned for sowing in early spring 2018 but this was delayed until the following year because of dry conditions. The trial site was lightly cultivated on 6 February 2019 to remove furrows and seed sown into moist soil at the same sowing rates and with the same coneseeder used at Goulburn on 26 March 2019. Calciprill (prilled lime) at 200 kg/ha, to alleviate localised soil acidity for germinating seedlings, and Croplift 15 at 150 kg/ha were applied in the furrow with the seed. Good follow-up rain (38 mm) was received 3 days after sowing. An attempt to sow digit grass by hand was made in October and early December 2019 but both attempts failed under drought conditions.

Soil fertility was maintained by fertiliser application at reasonably high levels appropriate to a better paddock targeted for a high-value lamb finishing system. This contrasts with the lower soil fertility often adopted under fine wool enterprises and on soils with inherently low fertility where native grasses predominate. Nitrogen was applied as urea from the first summer onwards since species were sown without a companion legume and the experiment was managed by a cut and removal method which prevented nutrient return to plots, following protocols for perennial grass trials in the Pasture Variety Testing Network (Kemp 2011).

At Goulburn, single superphosphate (9% P, 11% S) was applied in April 2019 (300 kg/ha) and December 2020 (65) kg/ha) which maintained Colwell P at 38 mg/kg in February 2018, 45 mg/kg in February 2019 and 38 mg/kg in October 2020. Muriate of potash was applied in April 2019 (200 kg/ha), April 2020 (180 kg/ha) and January 20201 (150 kg/ha). Even with these applications, potassium remained marginal at all sampling dates (Colwell K 111 mg/kg in February 2019, 121 mg/kg in February 2020, 133 mg/kg in October 2020). KCl_{40} S was 9 mg/kg in October 2020, which was considered adequate, after starting at high levels in 2018 (22 mg/kg). Urea (46% N) was applied to replace nitrogen removed at each harvest, typically 2 t/ha of herbage assuming 3% N (Kemp 2011). Applications were made on 12-Dec-18, 7-Feb-19, 3-Jun-19, 15-Jan-20, 29-Mar-20, 11-Sep-20, 21-Oct-20, 3-Dec-20, 13-Jan-21, 24-Feb-21 at an average rate of 138 kg/ha or 62 kg N/ha.

At Bombala, maintenance 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 24 mg/kg in February 2020 and 44 mg/kg in October 2020. Muriate of potash was applied at 100 kg/ha as a maintenance a0pplication in May 2020. After starting at 260 mg/kg, Colwell K was 240 mg/kg in February 2020 and 310 mg/kg in October 2020. KCl_{40} S was high at 16 mg/kg in October 2020 after starting at 20 mg/ka before sowing. Urea was applied on 27-Nov-19, 13-Mar-20, 19-Aug-20, 12-Oct-20, 4-Dec-20, 27-Jan-21, 11-Feb-21 and 22-Apr-21 at an average rate of 118 kg/ha or 54 kg N/ha.

Herbage growth was controlled by mowing and removal (see next section). Trials were grazed only once at each site. The trial at Goulburn was opened to grazing by sheep from the surrounding paddock for 4 days after the harvest in October 2019 as drought conditions were worsening. The Bombala site was accidently left open to grazing by sheep from late January to 5 February 2020.

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 6 times between drill rows within a plot and converting to seedlings/m^2 using the row spacing of 0.18 m.

Persistence was estimated by measuring change in frequency each year. Frequency was measured as the proportion of cells in a mesh grid in which live base of the sown species was present. Grid dimension was 1 m × 0.75 m divided into 75 0.15 m × 0.10 m cells placed so as to measure five 1 m lengths of adjacent drill rows. Two grids in fixed positions were measured in each plot with position determined by strings between pegs placed permanently at the sides of each row of plots. Frequency at Goulburn was measured on 13-Nov-2018, 12-Sep-2019, 11-Sep-2020 and 16-Apr-2021, and at Bombala on 12-Dec-2019, 26-May-2020 and 3-May-2021.

Herbage mass was measured using a Wintersteiger Cibus 5 forage harvester fitted with load cells to measure weight of herbage as it was cut. Cutting width was 1.25 m, which left the outside rows, and cutting height was 5 cm. Subsamples were collected from the delivery chute to measure moisture content and for subsequent grinding and nutritive quality analysis. Subsamples were weighed after each set of 5 plots at Goulburn and 8 plots at Bombala and stored in eskies with ice bricks to keep samples cool until they were placed in a dehydrator. After each assessment, herbage remaining in outside rows was removed as much as possible with the forage harvester and then with a ride-on mower. Herbage samples were dried for at least 48 h at 65 ℃ and ground through a Cyclotec mill fitted with a 1 mm screen for nutritive quality analysis. On occasions when weeds were considered likely to contribute to harvested herbage mass, scores of % sown species by two observers were used to correct for presence of other species; samples for nutritive quality were taken by hand from weedy plots. This occurred on four dates at Goulburn (22-Apr-20, 11-Sep-20, 22-Feb-21, 8-Apr-21) and once at Bombala (2-Dec-20). The forage harvester was not used for the autumn assessment at Bombala on 20 May 2020 because of insufficient biomass. In this case, green herbage was scored by two observers on a 10-point scale and calibrated by cutting 23 x 0.25 m^2 quadrats to ground level.

Where reproductive stems were present at a harvest, the proportion of each plot with stems was scored as a percentage since stem material was likely to affect nutritive quality. Scores were consistently made at Goulburn but not always at Bombala. These scores were only an approximate indication of stem presence since they were a visual estimate only and did not fully take account of density of stems or stage of maturity.

There were 14 harvests at Goulburn and 7 at Bombala. There was also a harvest made of seedling growth at Bombala on 9 October 2019 because of high herbage mass on some species, notably perennial ryegrass. Herbage DM was measured throughout the year to obtain a complete description of species growth, not just in the summer-autumn period. However, nutritive quality analyses were restricted to the summer-autumn period. Timing of harvests was a compromise because of the range of species with potentially differing requirements. Trials were typically harvested when there was about 2-2.5 t/ha herbage DM present on the highest yielding plots, or it was judged that a grower would wish to graze the pasture given the seasonal conditions. However, herbage DM on highest-yielding plots varied from as low 0.5 t/ha under drought at Bombala to 4-5 t/ha after 7 weeks growth also at Bombala at the end of spring in the high rainfall year 2020. When rainfall was favourable in the spring-autumn period at Goulburn, average regrowth interval for 8 harvests was 41 days or 6 weeks. It is acknowledged that this interval was too long for optimum nutritive quality in some species in some seasons, e.g., every 2-3 weeks in spring and 3-4 weeks in summer-autumn maintains higher quality in tall fescue in an irrigated subtropical environment (Callow et al. 2003) and frequent close grazing in spring to control reproductive growth is recommended in dryland temperate environments (Raeside et al. 2012). Digit grass and chicory were harvested only 17 days after drought-breaking rains in early February 2020 at Goulburn because of very rapid growth and a desire to maintain nutritive quality. They were harvested again 14 days later with the other species. More frequent harvests were otherwise considered impractical because of distance to field sites and because they may have damaged species requiring longer cutting intervals. Lucerne, for example, may have had insufficient spells between cuts at Goulburn since flowering proportion was often well below the recommended 10% minimum (McDonald et al. 2003).

Leaf number has become a recommended determinant of grazing readiness based on the principle that allowing growth until just before senescence of the oldest leaf maximises soluble carbohydrate levels, green DM yield and persistence (Fulkerson and Donaghy 2001). Thus the 3-leaf stage has been recommended for perennial ryegrass (Fulkerson and Slack 1995) and tall fescue (Raeside et al. 2012; Lawson et al. 2017), the 3.5-4-leaf stage in prairie grass (Fulkerson et al. 2000) and other bromes (Turner 2007) and the 4-5 leaf stage in cocksfoot (Rawnsley et al. 2002). Leaf stage was loosely monitored mainly at Goulburn. Perennial ryegrass was typically at the 2.5-3 leaf stage at 6 harvests in the spring-autumn period at Goulburn, cocksfoot in the 3-4 leaf stage and phalaris around the 4-leaf stage on 4 occasions, and tall fescue 2.5-3 leaf stage at a single February observation.

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

Nutritive quality 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 dry matter digestibility (DMD), organic matter (OM) and nitrogen (N). Predicted values were validated by wet chemistry analyses on approximately 10 % of samples; wet chemistry was also performed for a small number of samples that fell outside the calibration. DMD was determined using a modified pepsin-cellulase technique (corrected using AFIA in vivo standards), neutral detergent fibre (NDF) and acid detergent fibre (ADF) using an ANKOM 200/220 Fibre Analyser (Ankom® Tech. Co., Fairport NY, USA), total nitrogen (N) by combustion using a Leco CN628 N Analyser (Leco, St. Joseph MI, USA), and organic matter (OM) by ashing (Norman et al. 2020). Crude protein (CP) was calculated as N × 6.25 and metabolisable energy (ME) as 0.172 DMD - 1.707 (Freer et al. 2007).

Statistical analysis

Analysis of sites combined was complicated by 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 the main statistical analysis. Commonality between sites was examined by a combined multi-environment (MET) analysis as described below.

The sequence of herbage mass measurements at each site (14 at Goulburn and 6 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 (and sites for multiple sites) accounting for temporal and spatial correlations. For analysis at a single site, each harvest time can be considered as a separate trial in an MET. 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 or site by harvest combination, random effects due to replicate and design (row, column) effects, random genotype effects (following Smith et al. 2005 for selection in METs) and random residual effects. The residual spatial and temporal covariance structure between repeated harvests was modelled using 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 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 these experiments so that only row effects were modelled using ar1 at Goulburn and only column effects at Bombala. For the combined analysis of harvests at both sites, only row effects were modelled using ar1. Time of harvest in the combined analysis was taken from the date of sowing at Goulburn for both sites after initial examination of herbage mass data showed that the effect of actual date of harvest (seasonal/environmental effect) was stronger than the effect of time from sowing. The harvest of seedling growth at Bombala was not included in the sequence analysed using FA models.

The random genotype effects were correlated across harvests (and sites in the combined sites analysis) and the best linear unbiased predictors (BLUPs) were predicted from the random model for each genotype at each harvest. The genetic covariance matrix, consisting of genetic variances for each harvest and genetic correlations between harvests (and at each site in the combined analysis) was modelled using factor analytic (FA) models (Smith et al. 2001; 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 FA6 model (6 factors) was best at Goulburn and an FA3 (3 factors) at Bombala as determined by the model with the lowest Akaike Information Criterion (AIC). An FA7 model was used for the combined analysis of harvests at both sites. To aid interpretation of the results from the FA models, the clustering technique of Cullis et al. 2010) based on the dissimilarity matrix was employed as in De Faveri et al. (2015). The resulting dendrogram is shown only for the combined sites analysis to examine the extent to which sites gave common results. Matrices of genetic correlations between harvests were also derived but are not presented here.

Because measures for comparison among entries such as LSD 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 page 137 of Smith et al. 2001). The method can also be used to indicate which entries were inferior to the standard. In our analyses, the method was used to indicate superiority over phalaris in tables of herbage DM and in statements made in the text. However, as a guide to variability of the data, twice the s.e.d. was also used as an approximate measure of least significant difference in tables and figures.

The methods of De Faveri et al. (2015) were also employed for analysis of frequency data except that factor analytic models were not required to model genetic effects due to the smaller number of successive observations (4 at Goulburn, 3 at Bombala) and full unstructured genetic variance-covariance matrices were fitted. Temporal residual covariance components were modelled using antedependence at both sites. Like herbage DM data, spatial effects were not strong for frequency in the column direction so that only row effects were modelled using ar1 at both sites.

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 quality data were analysed for each summer-autumn season (year) separately and then for all seasons combined. Repeated measures mixed model analyses in GenStat 19 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 residual covariance structure of order 1. Preliminary analyses of individual dates had indicated that spatial adjustments were not warranted, and so spatial effects were ignored in the analyses. The combined analyses across seasons (years) were performed by mixed model analysis with season and cultivar as fixed effects and sample date within season and replicate within date and season as random effects.

3.1.3 Core site trials - Legumes

Species

The legume experiments at Goulburn and Bombala contained 12 cultivars of 8 perennial legume species (**Table 3.3**). More than one cultivar of white clover, red clover and lucerne were included to examine variation. Lucerne represents the standard summer forage species for the target region, white clover the standard perennial clover species and the annual subterranean clover the most widely sown pasture legume. All legume species were inoculated with the recommended *Rhizobium* strain and lime coated.

Table 3.3. Species and cultivars in the core legume experiments.

Species	Common name	Cultivar	Notes
Trifolium repens	White clover	Trophy	Bred in Australia for improved tolerance of summer moisture stress
		Haifa	Old standard cultivar for SE Australia, large-leaved type
		Nomad	Small leaved type bred for improved persistence and drought tolerance
T. ambiguum x repens	Caucasian × white clover cross	Aberlasting	Cross between caucasian and white clover to improve drought tolerance of white clover
T. ambiguum	Caucasian clover	Kuratas	Deep-rooted clover. New cultivar bred in Tasmania for improved winter growth and seed production
T. tumens	Talish clover	Permatas	Deep-rooted clover, new cultivar.
T. pratense	Red clover	Astred	Stoloniferous red clover with good persistence under grazing
		Rubitas	Stoloniferous red clover with good persistence under grazing
T. fragiferum	Strawberry clover	Palestine	Old standard cultivar for SE Australia

T. subterraneum	Subterranean clover	Leura	Late flowering sub clover for higher rainfall districts
Medicago sativa	Lucerne	Sardi Grazer	Winter activity 6 lucerne bred for improved grazing tolerance
		Titan 9	Winter activity 9 lucerne

Site management

Experimental design at both sites was a row-column design with 4 replicates. Plot size was 6 m × 1.8 m with a 1-metre buffer strip between the ends of plots kept clear by glyphosate application. There were 10 drill rows 18 cm apart across plots.

The Goulburn trial was direct-drilled with a coneseeder on 17 April 2018. Croplift 15 (14.6% N, 12% P, 11.6% S) at 200 kg/ha and muriate of potash (50% K) at 125 kg/ha were broadcast before sowing with a further 50 kg/ha of Croplift 15 sown in the drill row. Sowing rates are shown in Table Y. Very dry conditions in the months following sowing resulted in poor establishment and the trial was sprayed out and resown on 5 September 2018. The new trial was mown to 5 cm height on 2 November and 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 pulling on 10 January 2019. Grass weeds were controlled by spraying with 330 mL/ha Select Xtra (360 g/L clethodim) with 1:100 Hasten adjuvant on 11 April 2019 and 31 August 2020. Broadleaf weeds were controlled by application of Broadstrike (800 g/kg flumetsulam) at 25 g/ha on 3 March 2020. Weeds were also controlled by hand-pulling and dabbing glyphosate as required.

The Bombala trial was sown on 26 March 2019 with 150 kg/ha Mo-single superphosphate (9% P, 11% S, 0.025 %) and 200 kg/ha Calciprill (prilled lime). Weeds were controlled in the establishing trial by hand weeding 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 herbage was removed from the plots. At Goulburn, Mo-single superphosphate was applied at 300 kg/ha on 3 April 2019 and 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 K was 258 mg/kg in February 2020 and 330 mg/kg in October 2020.

Herbage growth was controlled by mowing and removal. Trials were grazed only once at each site. The trial at Goulburn was opened to grazing by sheep from the surrounding paddock for 4 days after the harvest in October 2019 as drought conditions were worsening. The Bombala site was accidently left open to grazing by sheep from late January to 5 February 2020.

Data collection

Density of germinating seedlings and frequency of live base of sown species were measured as for the non-legume trials. Frequency at Goulburn was measured on 4-Dec-2018, 12-Sep-2019, 27-Feb-20, 14-Sep-2020 and 8-Apr-2021, and at Bombala on 12-Dec-2019, 26-May-2020 and 3-May-2021.

Herbage mass in legume trials was not sampled by forage harvester because a considerable proportion of the clover herbage was frequently below the cutting height of 5 cm. Instead, herbage biomass of the sown legume species was measured by calibrated visual estimation by two observers. Calibration curves were developed by pegging and cutting to ground level 0.25 m^2 quadrats representing scores on a 1-10 scale. Up to 4 curves were derived depending on the structure of the legume stand, 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 species was scored in ten 0.25 m^2 quadrats per plot. The Goulburn legume trial was first sampled in March 2019 because a high weed burden prevented earlier measurement. Subsequently, it was measured just before the non-legume trial was harvested. Measurement dates at Goulburn were 8-Mar-19, 3-Sep-19, 11-Nov-19, 10-Mar-20, 21-Apr-20, 31-Aug-20, 20-Oct-20, 27-Nov-20, 12-Jan-21, 22-Feb-21 and 23-Apr-21. The legume trial at Bombala was not fully sampled until March 2020 due to lack of growth under drought conditions. Measurement dates at Bombala were 12-Dec-19, 12-Mar-20, 20-May-20, 2-Oct-20, 2-Dec-20, 9-Feb-21 and 19-Apr-21. Legume trials at both sites were mown to 5 cm after harvest of the adjacent non-legume trial.

As for the non-legume experiments, herbage samples for measurement of nutritive quality 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 cool in eskies 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 fitted with a 1 mm screen for nutritive quality analysis by NIRS as described for the non-legume experiments.

Statistical analyses

The sequences of herbage mass measurements at each site were analysed as for the non-legume experiments using the methods of De Faveri et al. (2015). Genetic effects across harvest times were fitted as random effects and BLUPs were predicted from the random model. The genetic variance covariance matrix was modelled using factor analytic models. A factor analytic model of order 3 (FA3) was best at Goulburn and an FA2 (2 factors) at Bombala, with temporal residual correlations modelled using antedependence of order 1. Spatial correlations were not strong in the column direction and were modelled as ar1 only for rows at both sites as determined by the Akaike Information Criterion (AIC).

Frequency data also were analysed by the methods of De Faveri et al. (2015) except that factor analytic models were not used to model genetic effects due to the low number of successive observations (5 at Goulburn, 3 at Bombala). Temporal residual covariance components were modelled using antedependence of order 1 at both sites. Similar to herbage DM data, spatial effects were not strong for frequency so that only row effects were modelled as ar1 at both sites. The final model at both sites employed an unstructured variance-covariance matrix.

Nutritive quality data were analysed for each summer-autumn season (years) separately and then for all seasons combined. Preliminary analyses at individual dates indicated that spatial adjustments were not warranted in the Goulburn legume experiment but that there was significant autoregressive correlation for rows in the Bombala legume experiment. 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 residual 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 using ar1. The combined analyses across years were performed for the Goulburn legume experiment by mixed model analysis with season 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.

3.1.4 Supplementary site trials – Gunning mixtures experiment

This experiment explored how two perennial grass species and a perennial herb with a range in summer growth potential combined with three legume species also with a range of summer growth potential in an acidic soil profile. The site was located at 800 m altitude approx. 18 km north of Gunning on the "Merrill" property in the northern part of the Southern Tablelands (Fig. 1). Long-term average rainfall at the site is around 680-700 mm. Soil data at the start of the experiment is shown in Table 1. The soil was acidic to depth with high exchangeable Al (mean 42% of CEC to 1 m depth, range 26% in 1-10 cm layer to 53% in 20-30 cm layer; data from R. Hayes, NSW DPI) and $CaCl_2$ pH in the surface 10 cm was 4.0 before sowing.

Lime at a rate of 3.5 t/ha was incorporated into the topsoil two weeks before sowing. $CaCl_2$ pH in the surface 10 cm was 4.6 two years later.

Experimental design

Three non-legume species, phalaris, tall fescue and chicory, were sown in factorial combination with 3 legume species, subterranean clover, white clover and lucerne, as well as grown alone, to give a total of 15 treatments in a randomised block design with 3 replicates. Species and cultivars are shown in Table 3.4. Phalaris, tall fescue and chicory were sown at a rate of 4, 8 and 5 kg/ha, respectively, of uncoated seed and sub clover, white clover and lucerne were sown at a rate of 10, 2 and 8 kg/ha, respectively, of uncoated seed. Legume seed was inoculated with the recommended *Rhizobium* strain and lime coated.

Table 3.4. Species in the Gunning mixtures experiment.

Common name & cultivar	Summer activity	Comments
Non-legume		
Phalaris cv. Landmaster	Partially summer-dormant perennial grass	Standard species for permanent improved pasture in region; cultivar with improved acid soil tolerance (Culvenor et al. 2011)
Tall fescue cv. Quantum II MaxP	Summer-active perennial grass	High quality grass potentially suitable for meat production systems. Acid soil tolerance of cultivar unknown but other summer-active cultivars highly Al-tolerant (Song et al. 2017)
Chicory cv. Puna	Summer-active perennial herb	High quality summer forage species; reputation for acid soil tolerance
Legume		
Subterranean clover cv. Leura	Cool-season annual	Standard legume for region; acid soil tolerant
White clover cv. Haifa	Summer-active perennial	High-quality summer-active legume; marginal persistence under drought

Lucerne cv. Aurora	Summer-active perennial	Standard summer forage species; high persistence under drought in suitable soil; sensitive to soil acidity

Site management

The experiment was sown into cultivated soil on 25th May 2018, two weeks after incorporation of lime. Sowing date was later than preferred due to low autumn rainfall. Plot size was 6 m x 2 m with 12 drill rows 16.5 cm apart across the plots. Mo-single superphosphate (9% P, 11 % S, 0.025 % Mo) at a rate of 210 kg/ha was applied at sowing. Plots not sown to grasses were sprayed with 250 mL/ha Select Xtra (360 g/L clethodim) with 1:100 Hasten adjuvant on 9 October 2018 to control grass weeds, mainly ryegrass. The whole experiment was sprayed on the same date with Broadstrike (800 g/kg flumetsulam) at 25 g/ha to control broadleaf weeds. Ryegrass and broadleaf weeds were subsequently hand-pulled on 23 October.

Soil fertility was maintained by the application of single superphosphate at a rate of 185 kg/ha on 23 May 2019, 110 kg/ha on 20 March 2020 and a further 250 kg/ha on 8 December 2020 after soil tests indicated P level was still only moderate at 18 mg/kg Colwell P. Urea at a rate to supply 50 kg N/ha was applied to plots containing non-legumes growing alone on 15 January 2020 and 27 August 2020.

Due to low legume presence and density of legume seedlings in April 2019, an attempt was made to re-seed legume into bare areas at triple the original sowing rate on 23 May 2019. The experiment was then grazed in late May and mid-August, and mown in early July and late September, to reduce competition from the established non-legume species. The experiment was also grazed and mown in July 2020 and mown again in late September due to difficulties in controlling prolific growth. Herbage measurements were not taken during these two period periods. The experiment was also mown to 4-5 cm cutting height after each herbage assessment. Most of the finely chopped herbage was left on the plots except in spring 2020 when herbage mass was very high.

Data collection

Seedlings of sown species were counted 3 months after sowing and seedlings of sown legume species were counted in February 2020 and 2021. Seedlings of sown + volunteer legumes were counted in April 2019 and February 2020. Each time, seedlings were counted in the diagonals of a 1 m x 1 m mesh divided into 100 cells of 0.1 m x 0.1 m, placed twice randomly in each plot, a total of 0.4 m^2 per plot.

Frequency was measured in October 2018, September 2019, August 2020 and late March 2021 as the proportion of cells in a mesh grid in which live base of the sown species was present. Grid dimension was 1 m × 0.75 m divided into 75 0.15 m × 0.10 m cells. Two grids in fixed positions were measured in each plot.

Botanical composition was visually assessed using the Botanal dry weight rank method (t'Mannetje and Haydock, 1963; Tothill et al. 1992) and sward biomass assessed by calibrated visual estimation by two observers on 12 occasions: 6 Dec in 2018; 28 Mar, 22 May, 15 Nov in 2019; 20 Mar, 14 May, 1 July, 29 Oct, 10 Dec in 2020; 15 Jan, 10 Mar and 7 May in 2021. Composition and herbage mass were assessed in ten 0.25 m^2 quadrats per plot. Calibration curves were developed by pegging and cutting to ground level 0.25 m^2 quadrats representing scores on a 1-10 scale.

Statistical analyses

The experimental design allowed analysis of data as a non-legume species × legume species factorial once plots of either of the other species types grown alone was omitted. For example, once plots containing legume species grown alone were omitted, a factorial analysis of variance of non-legume data with non-legume and legume main effects and a non-legume × legume interaction was performed which allowed testing of the effect of companion legume species on non-legumes. A similar analysis was performed on legume species data once non-legume-alone plots were omitted. Where there was no need to test for effect of companion legume, e.g. total sward biomass, data was analysed as a simple randomised blocks design with 15 treatments. All analyses were performed in Genstat 19 (VSN International, Hemel Hempstead, UK).

Series of observations on sward herbage mass and composition were made in each spring-summer-autumn period for each year of the study. Data from each period were analysed separately. A period of prolific growth in the very wet winter and first half of spring in 2020 was also analysed separately from warm-season period data. For each period, sampling date, non-legume species and legume species were considered fixed effects and rep within each time as a random effect with covariance components modelled using antedependence of order 1 to account for correlations between successive harvests. Fixed effects were analysed as a factorial as explained above. Standard error of the difference multiplied by 2 was used as an approximate indication of significant difference.

3.1.5 Supplementary site trials – Dry Plain species evaluation experiment

Experimental design

A subset of 10 non-legume species grown at the core sites was evaluated in a cool, high-altitude site at Dry Plain about 30 km NW of Cooma in the northern Monaro region. The site was located on the "Glenfinnan" property at an altitude of 1150 m and long-term average rainfall around 680 mm. Species and sowing rates were: phalaris cv. Holdfast, 4 kg/ha; tall fescue cv. Hummer Max P, 15 kg/ha; perennial ryegrass cv. Kidman, 20 kg/ha, cocksfoot cv. Savvy, 5 kg/ha; prairie grass cv. Atom, 30 kg/ha; grazing brome cv. Gala, 25 kg/ha; coloured brome cv. Exceltas, 25 kg/ha; perennial veldt grass cv. Mission, 3 kg/ha; chicory cv. Puna, 5 kg/ha; plantain cv. Tonic, 8 kg/ha.

Site management

The experiment was sown on 26th March 2019 with 120 kg/ha of Starter 15 (15% N, 12 % P, 12 % S). Plot dimensions were 7.5 m × 2m with a row spacing of 16.5 cm. Weeds were controlled by chipping on 3 October 2019 and then by mowing and removal of cut material on 3 December 2019 because of heavy growth of annual grasses (vulpia, barley grass). Broadleaf weeds (mainly thistles) were subsequently controlled by chipping.

Herbage growth was controlled by mowing to 5 cm after each sampling. When herbage mass very high in November 2020, cattle were first allowed to graze the experiment and then remaining herbage mown and removed from the plots.

Soil fertility was maintained by the application of single superphosphate (9% P, 11% S) at 125 kg/ha on 9 April 2020 and 5 March 2021. Colwell P was 57 mg/kg in 2020 and 75 mg/kg in 2021. KCl_{40} S was 11 mg/kg in 2020 and 15 mg/kg in 2021. Muriate of potash was applied at 105 kg/ha on 5 March 2021. Colwell K was 102 mg/kg in 2020 and 201 mg/kg in 2021. Because the experiment was sown without a companion legume, urea to supply 50 kg N/ha was applied on 9 April 2020, 100 kg N/ha on 22 January 2021, and 50 kg N/ha on 5 March 2021.

Data collection

Seedling density was measured on 24 May 2019 by counting seedlings on both sides of a 50 cm rod placed 6 times in each plot. Basal frequency was measured on 3 Oct 2019, 25 Jun 2020 and 13 May 2021 by counting presence of live base in 50 cells (15 cm x 10 cm) in each of 2 fixed quadrats (1 m x 0.75 m) per plot. Herbage mass was measured on 28 Feb, 24 Apr, 9 Oct and 16 Nov in 2020, and 22 Jan and 5 Mar in 2021 by cutting the sown species in two 50 cm x 50 cm quadrats per plot to ground level with electric shears.

Statistical analyses

Seedling density data were analysed as a randomised block design and the least significant difference at P=0.05 calculated. The sequence of herbage DM and frequency data were analysed by mixed models with sampling date and species as fixed effects and replicate as a random effect with covariance components modelled using antedependence of order 1 to account for correlations between successive harvests. Spatial effects were not strong and were ignored for frequency. For herbage DM, spatial effects due to rows but not columns were modelled as ar1. Standard error of the difference multiplied by 2 was used as an approximate indication of significant differences.

3.1.6 Canberra pilot species evaluation experiment

Experimental design

There were 14 cultivars in 10 species arranged in a randomised blocks design with 6 replicates. Species, cultivars and sowing rates were: summer-active tall fescue cvv. Quantum II Max P and Hummer Max P, 15 kg/ha; summer-active cocksfoot cvv. Savvy and Porto, 5 kg/ha; phalaris cvv. Holdfast, Lawson and Confederate, 4 kg/ha; grazing brome cv. Gala, pasture brome cv. Bareno and coloured brome cv. Exceltas, 25 kg/ha; chicory cv. Puna, 5 kg/ha; plantain cv. Tonic, 8 kg/ha; lucerne cv. Stamina 5, 10 kg/ha; red clover cv. Astred, 5 kg/ha. Lawson and Confederate phalaris were included because of claims in company advertising that they were more responsive to summer rainfall than other cultivars.

Site management

The experiment was sown on 20 October 2016 with 100 kg/ha Croplift 15 (15%N, 12%P, 12%S). Plot size was 7.6 m × 1.8 m with 10 drill rows. A 1-metre buffer strip between the ends of plots was kept clear by glyphosate application. Some plots emerged poorly because of soil crusting and 28 plots were resown on 29 March 2017 including most plots of chicory, plantain, red clover and lucerne after 200 kg/ha of single superphosphate (9%P, 11%S) and 100 kg/ha of urea (46%N) were broadcast prior to irrigation. Irrigation totalling 88 mm was applied during a period of low rainfall from mid-December 2016 to late March 2017 to assist establishment. Later fertiliser applications were Croplift 15 at 200 kg/ha in May 2018 and 205 kg/ha in April 2019, muriate of potash at 225 kg/ha in April 2019, and urea at 100 kg/ha in October 2017, October and November 2018 and February 2019, and 120 kg/ha in April 2020. Urea application was low in 2019 because of drought conditions. Soil Colwell P was always in excess of 50 mg/kg.

Weeds were controlled in 2017 and 2018 and certain broadleaf weeds (fleabane, fat hen, pigweed) in later years by hand-pulling and chipping and occasionally by dabbing glyphosate. However, weed content became high in some plots in 2019 and 2020 after sown species had declined. Main weeds in summer were windmill grass (*Chloris truncata*), *Panicum* spp. and crumbweed (*Chenopodium pumilio*). Main weeds in winter were *Bromus* spp. spreading from brome plots and jersey cudweed (*Gnaphalium luteo-album*).

Herbage growth was mown at a cutting height of 4-5 cm after each sampling occasion. Phalaris plots were mown twice and the whole trial once at 6-7 cm cutting height in November 2017 to suppress pollen production in phalaris entries due to proximity to a breeder's seed production block. Because of this and then a dry summer it was decided to commence herbage DM measurements in autumn 2018.

Data collection

Seedling density was measured on 17 November 2016 by counting seedlings on both sides of a 50 cm rod placed 6 times in each plot. Frequency was measured as the proportion of cells with at least some live base of sown species in two mesh grids at fixed locations in each plot. Grids were 1 m × 0.75 m containing 50 cells 0.15 m × 0.10 m with the 0.15 m approximating the drill row spacing. Frequency was first measured in August 2017 to allow resown plots to establish. Subsequently it was measured in June 2018, May 2019 and June 2020.

Seasonal herbage dry matter growth of sown species was estimated visually at 10 positions in each plot on a 0-10 scale except for three occasions when herbage was tall enough in all species to use a forage harvester with a 1.25 cutting width and 5 cm cutting height (spring 2018, summer 2018/19 and autumn 2019). Autumn growth was sampled on 7 Jun 2018, 30 May 2019 and 25 May 2020, winter growth on 13 Sep 2019 and 10 Sep 2019, spring growth on 18 Dec 2018 and 22 Nov 2019, and summer growth on 22 Feb 2019 and 17 Mar 2020. Visual estimates were calibrated by cutting 50 cm × 50 cm quadrats to ground level with electric shears covering the range of scores in groups of species with similar morphology at a particular harvest, e.g. phalaris, cocksfoot-tall fescue, bromes, lucerne-red clover, chicory, plantain. Plots were mown to 5 cm height after visual estimates. On two occasions (summer and autumn 2019) when the forage harvester was used, botanical composition was estimated using the Botanal dry weight rank method (t'Mannetje and Haydock, 1963; Tothill et al. 1992) in ten quadrats per plot to provide a correction for weed content. Calibration samples and samples for moisture content when the forage harvester was used were dried at 70°C.

Statistical analyses

Data for frequency of live plant base were tested for antedependence using the ANTORDER procedure in Genstat 19 and found to be of order 1. A repeated measures ANOVA assuming antedependence of order 1 was conducted using the AREPMEASURES procedure in Genstat 19. Herbage mass data were analysed by mixed model analysis using REML with year, season and cultivar as fixed effects in factorial combination and replicate and plot within harvest time as random effects using an antedependence correlation model between harvest times. Herbage DM data were square root transformed to stabilise the variance. An approximate least significant difference value was calculated as twice the average standard error of a difference. Additional analyses of total summer DM and total annual DM for the experiment were found not to require transformation and were analysed as a one-way ANOVA.

3.2 Grazing study component

3.2.1 Experimental design

The objective of the grazing trial in Canberra was to compare the lamb production value of six summer forage options for the Southern Tablelands over two summer-autumn seasons (2019/20 and 2020/21). The design compared a conventional pasture option (phalaris) to alternative summer-active grass-based (brome-cocksfoot, tall fescue) and herb-based (chicory-plantain) pastures and cropping options of pure lucerne and brassica. The comparison between lucerne and forage brassica was considered important to confirm simulation results obtained by Doug Alcock, Graz Prophet Consulting, Cooma, which suggested that brassica was superior to lucerne.

The trial was located at Ginninderra Experiment Station, Hall ACT (35.187°S, 149.052°E, 600 m altitude, LTA rainfall 700 mm). The site comprised three replicate 0.36-ha plots of each forage treatment in a randomized complete block design (**Fig. 3.2**). Treatments were compared in terms of plant productivity and nutritive quality, and the associated lamb liveweight gains.

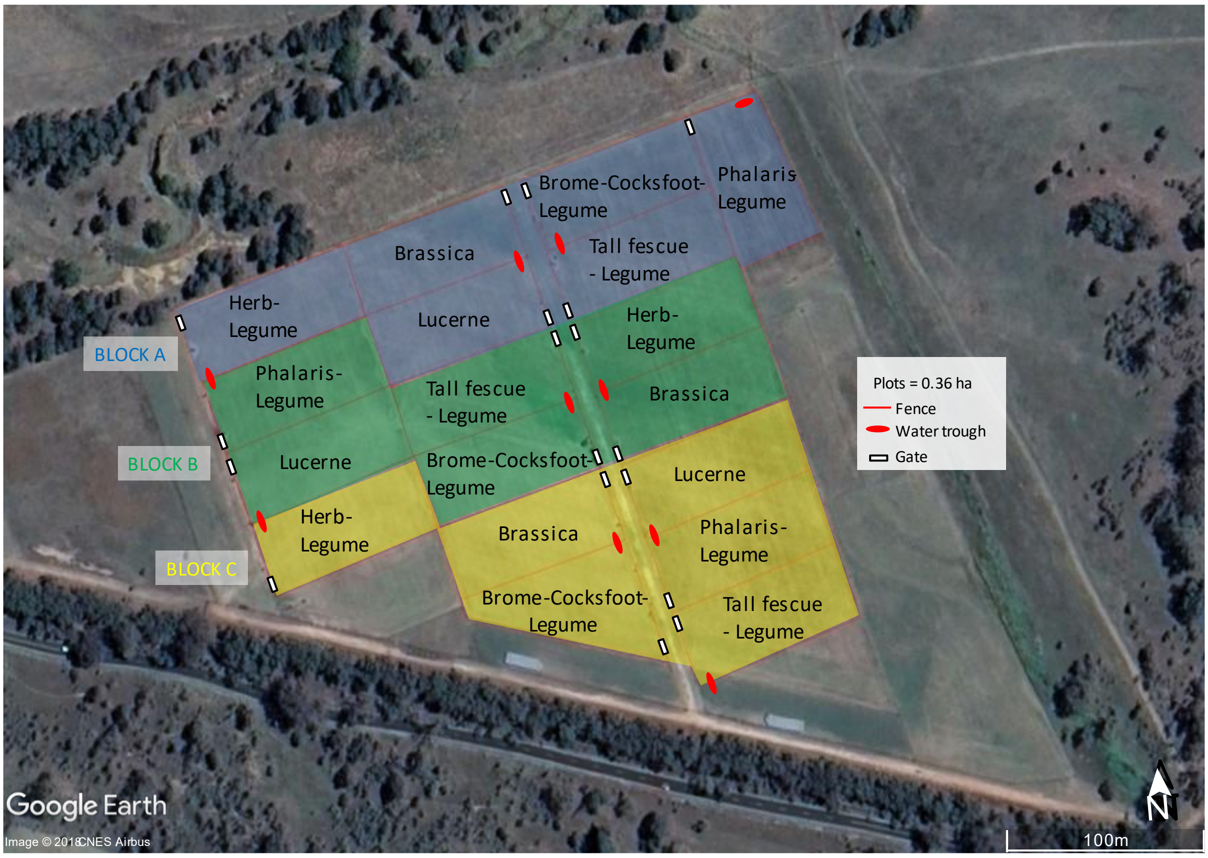


Fig. 3.2. Layout of treatments in the Canberra grazing trial; plots are 0.36 ha each.

3.2.2 Site management

The paddock already had a kangaroo-proof fence around the perimeter from previous projects on dual-purpose crops. The site was sown to wheat in 2017 and was fallowed during 2018. Lime at 4 t/ha (pH_{CaCl2} 4.3 prior to lime) and 250 kg/ha of Mo-single superphosphate were applied in September 2018, and the paddock cultivated and rolled. The initial intended sowing time was spring 2018 but this was delayed due the dry conditions and forecasted dry summer. All forage treatments except the brassica were sown at the end of April 2019 with 100 kg/ha of starter fertilizer (14.2% N, 12.9% P, 10.7% S) and received good rain in the days following sowing (**Fig. 3.3**). A complete list of cultivars and sowing rates is shown in **Table 3.5**.

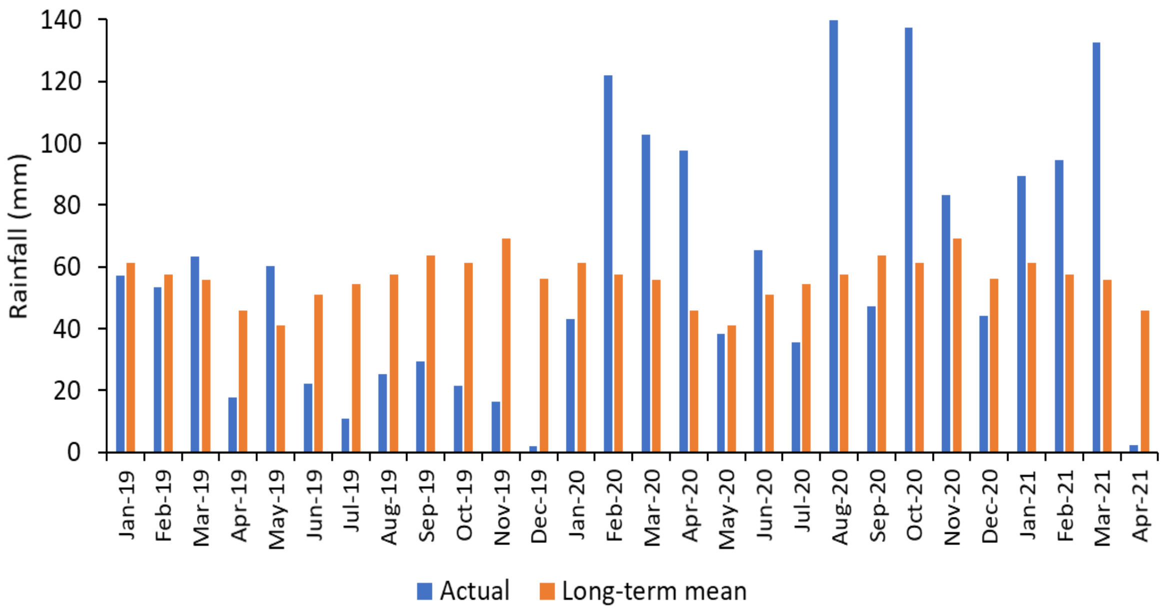


Fig. 3.3. Actual and long-term mean rainfall (mm) at the BOM Melba site (~2.5 km from grazing experiment).

Chlorpyrifos (350 g a.i./ha) was applied within two weeks of sowing to control invertebrate pests. In early July, the lucerne and herb plots, and bare brassica plots, were also treated with the grass-selective herbicide haloxyfop (52 g a.i./ha) to control ryegrass. The brassica plots were treated with glyphosate (540 g a.i./ha) one week prior to sowing with 100 kg/ha fertilizer (14.6%N, 12.0% P, 11.6% S) in mid-August 2019. Lucerne, herb-legume and brassica plots were treated with the grass-selective herbicide clethodim (119 g a.i/ha) in late September to control ryegrass. In early October, the whole site was mulch mown to approximately 10 cm to control weeds. In mid-November, the brassica and lucerne plots were sprayed with the insecticide gamma-cyhalothrin (4.5 g a.i./ha) to control grubs; brassica plots were subsequently crash-grazed by a mob of 196 Merino ewes to remove severely insect-damaged leaf material and encourage new growth. Where needed, ryegrass heads and wild radish were mown off. Brassica plots were sprayed against grubs and caterpillars in December and February using gamma-cyhalothrin (4.5 g a.i./ha).

Except the brassica, the productivity and condition of the forage plots was poor through the very dry and hot months of December, January and early February. Two significant rainfall events occurred from 7th-10th February (88 mm) and 15th-17th February (33 mm), resulting in fresh growth in the second half of February. The grazing trial commenced on 3rd March 2020, with a staggered start over consecutive days for Blocks A, B and C.

Legumes did not persist well in the herb plots, possibly due to shading by the plantain and chicory plants, so we broadcast seeds of our legume mix at 22 kg/ha over the destocked herb plots on 14th May 2020. One herb plot had a very high wireweed component that impeded the growth of the herbs; here we broadcast a 1:1 mix of chicory and plantain seed at 12.5 kg/ha. Brassica plots were sprayed with glyphosate and dicamba in mid-June, then slashed and tilled to prepare the paddock for resowing in September.

Table 3.5. Cultivars and sowing rates in Stockade grazing trial

Forage treatment	Species	Cultivar	Sowing rate (kg/ha)
Phalaris-Legume	Phalaris	Holdfast	4
	White clover	Nomad	1
	Red clover	Astred	3
	Lucerne	Sardi Grazer	10
	Subterranean clover	Leura	3.5
Tall fescue-Legume	Tall fescue	Hummer Max P	15
	White clover	Nomad	1
	Red clover	Astred	3
	Lucerne	Sardi Grazer	10
	Subterranean clover	Leura	3.5
Brome-Cocksfoot-Legume	Prairie grass	Atom	5
	Grazing brome	Gala	5
	Coloured brome	Exceltas	5
	Pasture brome	Bareno	5
	Cocksfoot (summer-active)	Savvy	2
	White clover	Nomad	1
	Red clover	Astred	3
	Lucerne	Sardi Grazer	10
	Subterranean clover	Leura	3.5
Herb-Legume	Chicory	Puna	5
	Plantain	Tonic	5
	White clover	Nomad	1
	Red clover	Astred	3
	Lucerne	Sardi Grazer	10
	Subterranean clover	Leura	3.5
Lucerne	Lucerne	Sardi Grazer	12
Brassica	Forage rape	Winfred	5

All treatments except the brassica were carried over from the first summer trial (2019/20). We applied single superphosphate at 115 kg/ha to these plots in August 2020. Brassica plots were treated with glyphosate (1.1 kg a.i./ha) and resown in September 2020 with 100 kg/ha fertilizer (14.6% N, 12.0% P, 11.6% S). Urea was applied to brassica plots post-grazing in mid-December at a conservative rate of 70 kg/ha (46% N) to reduce the risk of animal health issues over summer.

3.2.3 Livestock management

The use of animals in this experiment was approved by the CSIRO 'Wildlife, Livestock and Laboratory Animal' Animal Ethics Committee (application number 2018-32). Merino-Suffolk first-cross lambs were bred on-station and born in the winter prior to each grazing trial. We selected lambs for the trials that were closest to the mean weight for the cohort and assigned sheep to plots to achieve an even distribution of weights. Each plot comprised six core animals used to assess daily weight gain (DWG), and additional animals when the quantity and quality of the available biomass permitted. Additional animals were used in an attempt to maintain forage condition (i.e. prevent lodging and heading) and to estimate the total liveweight production potential; however, during some periods following substantial rain, the number of additional animals available was insufficient to keep pace with plant growth. One day before being introduced to plots, lambs were vaccinated against Cheesy Gland and clostridial diseases (Glanvac 6, Zoetis, Australia), sprayed with a blowfly preventative (CLiCKZiN; Elanco Animal Health, New Zealand; a.i. dicyclanil), and drenched for round worms, nasal bots and itch mites (Hat-Trick, Ancare, Australia; a.i. abamectin, levamisole and oxfendazole). All animals had access to water troughs and shade shelters throughout the trials (**Fig. 3.4**).

Figure 3.4. Shelters and water troughs in plots.

Year 1 of the grazing trial was preceded by a drier-than-average spring (**Fig. 3.3**), resulting in poor quantity and quality of forage over summer (**Fig. 3.5**). Grazing was delayed until 3rd March 2020, and each plot was initially stocked with only the 6 core lambs (~17 head/ha). Forage plots grew vigorously through March in response to several rainfall events and warm weather; it was therefore decided that stocking rates should be increased, allowing for equal amounts of DM per animal. An additional 90 lambs were fasted, weighed and sorted onto plots on 7th April (Week 5). The trial was completed on 28th April after 8 weeks of grazing; however, lambs were retained on plots to maintain forage condition. To protect plants from overgrazing, two of the herb plots and all of the lucerne plots were destocked on 7th May, the remaining biomass sampled, and lambs fasted for final weighing the next day. The last herb plot was destocked on 12th May, together with the brassica plots. The destocked lambs were grazed in the laneways and buffer strips until 22nd May, when they were allocated as additional grazers to the pasture plots, with stocking rates proportional to available DM. All 198 sheep were removed from plots, fasted and weighed for a final time on 2nd June. All treatments except the brassica were rotationally grazed by mobs of Merino ewes over winter and spring 2020 (**Table 3.6**). Brassicas were grazed once in mid-December 2020.

Figure 3.5. Condition of grazing trial site on 2nd January 2020.

Table 3.6. Total and green biomass available in early-August 2020 when rotational winter grazing by mobs Merino ewes commenced. Values are means ± standard errors over three replicates in each treatment.

Treatment	Biomass 3-Aug-2020		Grazing 11-Aug to 19-Dec-2020		
	Total DW (kg/ha)	Green DW (kg/ha)	Stocking rate (no./ha)	Grazing days/ha	Mob size (no./ha)
Phalaris-Legume	3487 ± 177	2332 ± 294	44 ± 3	5702 ± 443	517 ± 32
Tall fescue-Legume	3397 ± 267	2538 ± 262	49 ± 2	6381 ± 313	510 ± 2
Brome-Cocksfoot-Legume	3268 ± 172	2830 ± 198	43 ± 2	5533 ± 248	542 ± 30
Herb-Legume	2793 ± 440	1795 ± 351	38 ± 2	4883 ± 233	564 ± 24
Lucerne	2994 ± 455	2438 ± 364	39 ± 4	5054 ± 488	503 ± 22
Brassica	0	0	72 ± 8*	2237 ± 248	478 ± 31

*Brassica grazing from 17-Nov to 18-Dec-2020.

Year 2 was preceded by a wetter-than-average spring (**Fig. 3.3**). The grazing trial commenced on 5th January 2021 with 12 lambs/plot (~33 head/ha). All plots were destocked 4 weeks after the trial commenced and restocked with 9 lambs/plot (25 head/ha) at 6 weeks (mid-February). There were periods of hot and dry weather throughout the summer that required partial destocking of plots in response to forage quantity and quality; during these periods, lambs were grazed on phalaris-cocksfoot pastures nearby. Herbage growth was stimulated by a high rainfall period from 29th January to 6th February (127 mm) and maintained by another period from 21st to 24th March (96 mm).

3.2.4 Data collection

Forage sampling and weighing of fasted sheep occurred every fortnight until the end of April, a common sale date for lambs from this cohort. Lambs were fasted from approximately 17:00 and weighed and condition scored between 07:00 and 09:00 the next day before being introduced to the experimental plots. Prior to introducing/re-introducing lambs, we sampled the available forage by cutting 12 quadrat samples (0.48 m x 0.48 m) in a zig-zag pattern across each plot. The samples were immediately placed in eskies with ice bricks, weighed, sub-sampled and dehydrated at 70°C for 72 h. One sub-sample was used to calculate the fresh-dry weight conversion factor, while the other was separated into forage components before drying to determine the composition. The samples were then ground in a Cyclotec mill with 1.0 mm sieve for analyses of nutritive quality via NIRS in the CSIRO Rural Research Laboratory (Floreat WA). We also attempted to estimate herbage growth rates using three large sheep exclosures per plot (heavy mesh construction of approx. 1.2 m H x 1.2 m W x 1.2 m L). Exclosures were placed randomly across the plot and a quadrat (0.48 m x 0.48 m) cut adjacent to each exclosure that was visually estimated to be similar to the centre of the exclosure. The following fortnight, we cut a quadrat in the centre of the exclosure to establish growth, moved the exclosure, and cut a new quadrat adjacent to it. We found this method produced growth estimates with high variances and thus moved to monthly growth rate measurements with two quadrats per exclosure in Year 2. While this reduced the variability around mean herbage growth rates, better estimates might be achieved by using more numerous but smaller exclosures, or by including ungrazed plots of each treatment in the study design, allowing quadrats to be cut randomly at each sampling interval as for our forage sampling procedure (this was not practically feasible in our experiment).

3.2.5 Statistical analysis

We conducted all statistical analyses using the lme4 package (Bates et al. 2015) in program R v.4.1.2 (R Core Team 2021). We used linear mixed effects models to test the main effect of forage treatment (6 levels) on plant and animal responses. We included block as a random effect for plant responses (e.g. ME density) and plot nested within block as a random effect for animal responses (e.g. rate of LWG). For repeated measures data (e.g. herbage production), we included the interaction with sampling week as a main effect, and plot nested within week as a random effect.

3.3 Modelling component

3.3.1 System feed gap modelling approach

We used a simple whole-farm feed-energy balance calculator to evaluate the timing, frequency and magnitude of feed gaps amongst a range of potential scenarios combining different forage and livestock enterprise configurations (see Bell et al. 2018 for more detail). The calculator matches long-term predictions of forage growth and metabolizable energy supply from different forage sources against the annual cycle of energy demand for different livestock enterprises. Monthly livestock demands were calculated based on widely used calculations of animal energy requirements for each class of stock accounting for annual growth, lactation and pregnancy cycles for the livestock system and forage quality (Freer et al., 1997). The tool does not predict the consequence of animal performance but rather uses calculations of the demand required to meet the needs of animals for reproduction and growth at rates specified.

Forage supply is drawn from a database of pre-run long-term monthly production and quality of available forage sources derived from other simulation models and calculates the whole-farm energy supply based on their different proportional contributions. Protein and other nutrients were not included to keep the approach simple and focus on the main nutritional limitation of livestock system productivity in the target regions.

Feed gaps were quantified using two complementary statistics. The likelihood of short-term feed gaps was assessed using the frequency of months when growth of fresh feed was less than livestock demand, which indicates periods when fresh high-quality forage is insufficient and livestock would be utilising forage carried forward from previous months, often with lower nutritive value. The likelihood that insufficient forage, including that carried over from previous months, to meet livestock demand indicates periods when supplementary feeding or reductions in stock numbers would be necessary to avoid losses in livestock condition and/or risks of land degradation due to high forage utilisation and low ground cover.

3.3.2 Livestock enterprise and farm set up

Scenarios of introducing alternative forage options into the livestock systems on the Southern Tablelands was investigated for 2 locations, Bombala and Goulburn. At each site a livestock enterprise was specified that involved a self-replacing Merino ewe flock (culled at age 7) that was joined to Poll-Dorset rams from mid-February to mid-April, lambing occurred from early Aug to early Sept, lambs were weaned and 15% of ewes were culled in mid-Nov each year. We assumed a weaning percentage of 115% on the total mated ewe flock. Two livestock enterprise scenarios were then compared. The first involved the standard system where lambs were sold as stores at approximately 28 kg LW in December each year, compared to a lamb finishing system where the cohort of lambs were kept until mid-April each year to meet a market specification of 55 kg LW.

At each location a representative farm enterprise was set up with the stocking rate adjusted to achieve a mean pasture utilisation of approximately 40% in the standard store lamb livestock system. This equated to 3.8 breeding ewes per ha at the Goulburn site and 3.4 breeding ewes per ha at Bombala. The base farm utilised a cocksfoot summer-dormant pasture with 20% of the area being higher productivity land and the other 80% lower fertility land (producing 40% lower production each month).

A series of scenarios were compared for each site and livestock system whereby either half (10%) or all (20%) of the higher productivity land was replaced with either lucerne, forage brassicas sown in autumn or spring or chicory, or combinations of these (10% each). Hence, ten alternative forage systems were simulated compared to the baseline for each site and livestock system.

3.3.3 Forage production simulations

Forage production was simulated in APSIM version 7.10 (Holzworth et al. 2014) for cocksfoot, forage brassica, chicory, lucerne, and phalaris at sites in Goulburn and Bombala. Cocksfoot (cv. Currie), lucerne (cv. Aurora) and phalaris (cv. Australian) were simulated as pasture plants sourced from the model AgPasture as part of integrated mixed model AusFarm (Li et al., 2010; Herrmann et al., 2015). Forage brassica (cv. Winfred) and chicory (cv. Puna) are crop models within APSIM (Holzworth et al., 2014; Chichota et al., 2020; Watt et al., 2022). The management and soil details were sourced from data collected in the field from the species evaluation and grazing components of this project. Both soils were Kandosols and similar soils were sourced from APSoil database and then adapted such that the crop biomasses were consistent with the field data recorded. Climate data were sourced from the SILO database for each location.

The forages were cut once they reached a threshold of 2000 kg ha^{-1} to approximate rotational grazing. The models were tested against experimental data collected in the project to ensure similar production levels were achieved. This is shown in Fig. 3.6 for chicory, lucerne and phalaris, which shows that while some deviation in predicted biomass production was observed, annual and seasonal production were sensible for lucerne and phalaris; the chicory model performed less well.

After the baseline simulations were set up, they were run for 60 years from 1961 to 2021. The simulations were initiated in 1952 to allow for an equilibration period before the data input period. The pasture grasses were grown and cut continuously until 2021. Forage brassica was simulated twice, once as an autumn crop and once as a spring crop. The spring simulation for forage brassica was sown on October 4 and killed on June 4 each year, resetting the soil water, nitrogen, and organic matter each year on July 1. The autumn simulation for forage brassica was sown on March 4 and killed on December 4 each year, resetting soil water, nitrogen, and organic matter on January 1. The system was reset every 5 years for chicory. For all simulations, dry matter accumulation and average dry matter digestibility were output at the end of every month.

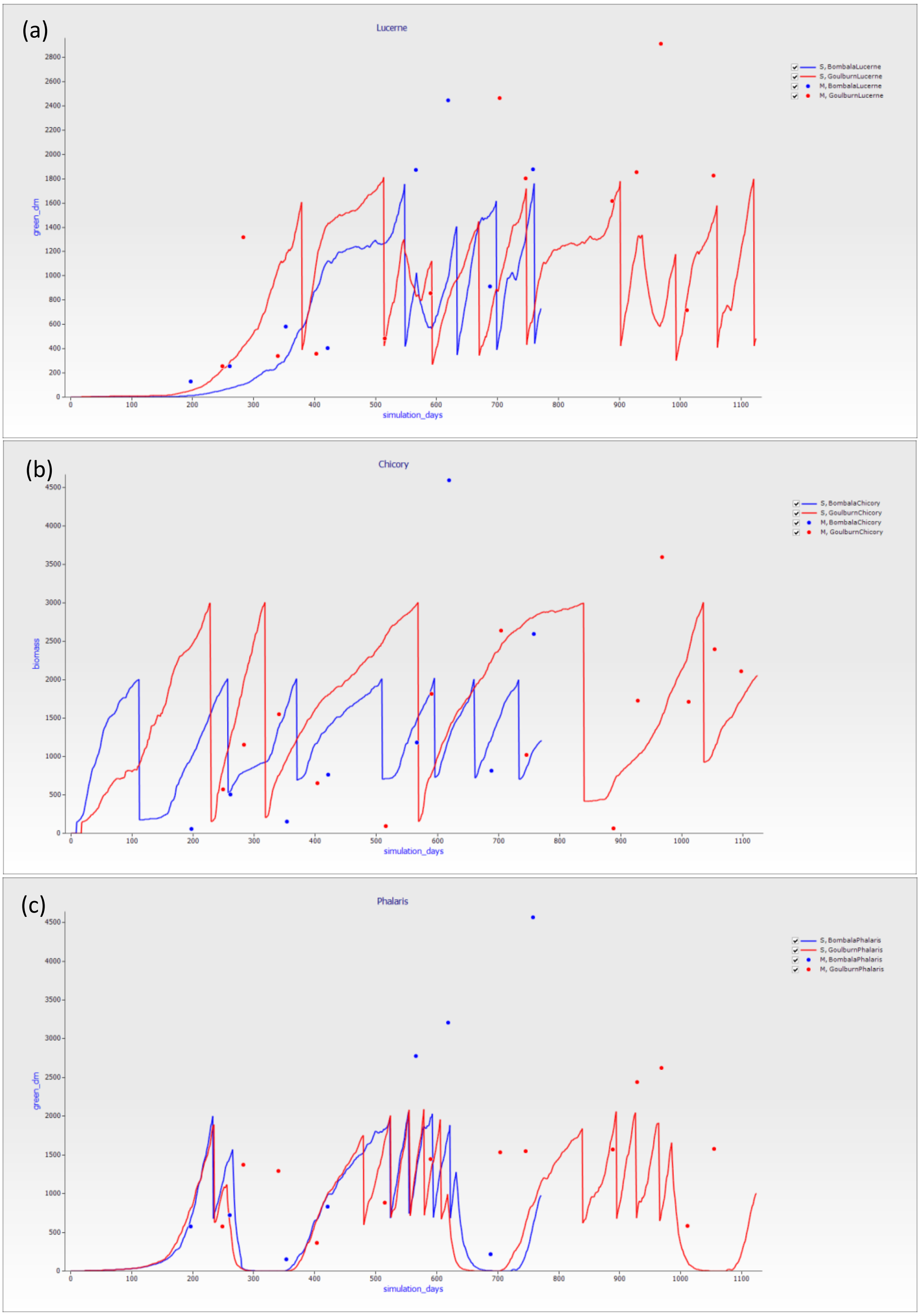


Figure 3.6. Comparison of measured biomass (dots) compared to model simulations (lines) of (a) lucerne, (b) chicory, and (c) phalaris, from experimental sites conducted during 2018/2019 and 2019/2020.

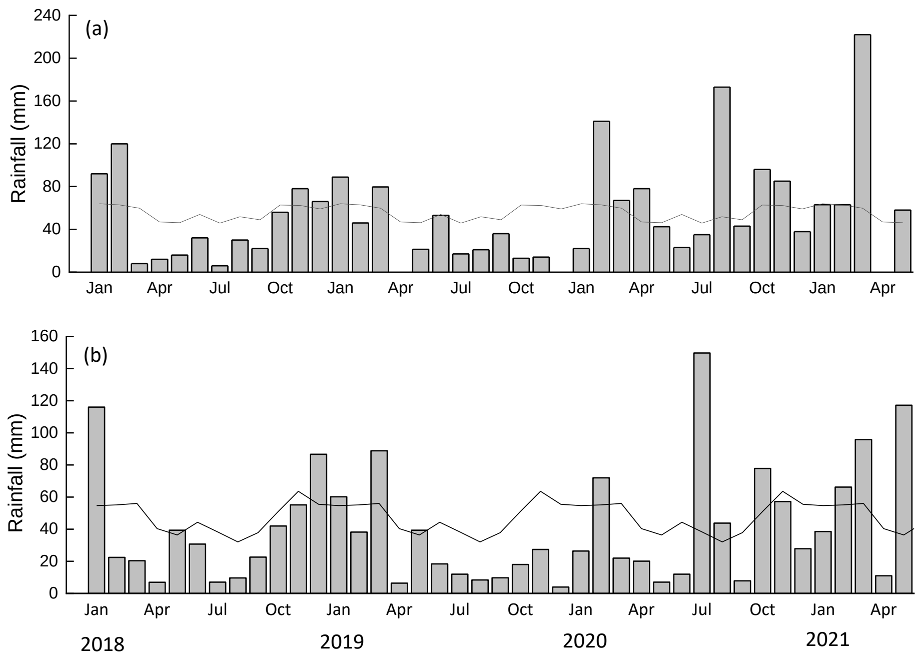
4. Results

4.1 Core site trials – Non-legumes

4.1.1 Rainfall

Both sites were characterised by reasonable warm-season rainfall but much below average cool-season rainfall in 2018 and 2019 (Fig. 4.1). The low cool-season rainfall in 2018 resulted in slow establishment at Goulburn and the delay of sowing to the following year at Bombala after late selection of the site. 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 only 243 mm were received at the Bombala site. 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 than the Goulburn site.

Figure. 4.1. Actual (bars) and long-term monthly (line) rainfall at the (a) Goulburn site, and (b) Bombala site.



4.1.2 Seedling density

Seedling densities were consistent between sites (*r*=0.92, *P*<0.01), largely reflecting differences among species in the number of seeds sown, with perennial ryegrass and tall fescue much higher than the other species (Table 4.1). Values were mostly satisfactory to establish dense plots, the exceptions at Goulburn being Commander chicory and Sardi Grazer lucerne when first sown. Both cultivars were improved by re-seeding bare patches. Mountain rye and coloured brome did not emerge as well at Bombala as at Goulburn (Table 4.1). Coloured brome plots achieved reasonable cover, but mountain rye plots were very sparse. Although not counted at Goulburn, perennial veldt grass established satisfactorily at both sites.

Table 4.1. Species, cultivar, sowing rate and seedling density in the Goulburn and Bombala core site non-legume experiments

Species	Cultivar	Sowing rate (kg/ha)	Seedling density (plants/m²)	
			Goulburn	Bombala
Summer-active tall fescue	Quantum II Max P	15	252	249
	Hummer max P	15	312	228
	Finesse Q	15	354	276
Summer-active cocksfoot	Savvy	5	146	112
	Porto	5	113	84
Perennial ryegrass	Base AR37	20	397	297
	Excess AR37	20	511	368
	Kidman	20	530	498
Prairie grass	Atom	30	150	125
Grazing brome	Gala	25	196	157
Pasture brome	Bareno	25	222	194
Coloured brome	Exceltas	25	240	40
Mountain rye	Family 10	10	91	23
Perennial veldt grass	Mission	3	n/d	44
Digit grass	Premier	2	n/d	n/d
Chicory	Puna	5	115 (78)†	67
	Commander	5	132 (54) †	86
Plantain	Tonic	8	156	113
Phalaris	Holdfast	4	120	105
Lucerne	Sardi Grazer	8	204 (45) †	97
Lsd (*P*=0.05)			62	48

*n/d Perennial veldt grass and digit grass were sown by hand on different dates to other entries and seedling density was not measured.
†Value in brackets shows density before oversowing sparse patches on 9 September and recounting on 13 November

4.1.3 Frequency

Frequency data over 4 years at Goulburn and 3 years at Bombala are shown in Fig. 4.2. Perennial ryegrass and tall fescue had the highest initial frequencies at both sites. Chicory and plantain established at lower initial frequencies than most perennial grasses. Coloured brome, mountain rye and perennial veldt grass established at much lower frequency at Bombala than at Goulburn. Porto cocksfoot also established less well at Bombala than at Goulburn. Digit grass established at relatively low initial frequency at Goulburn but increased in frequency each year thereafter to be very persistent despite the cold environment.

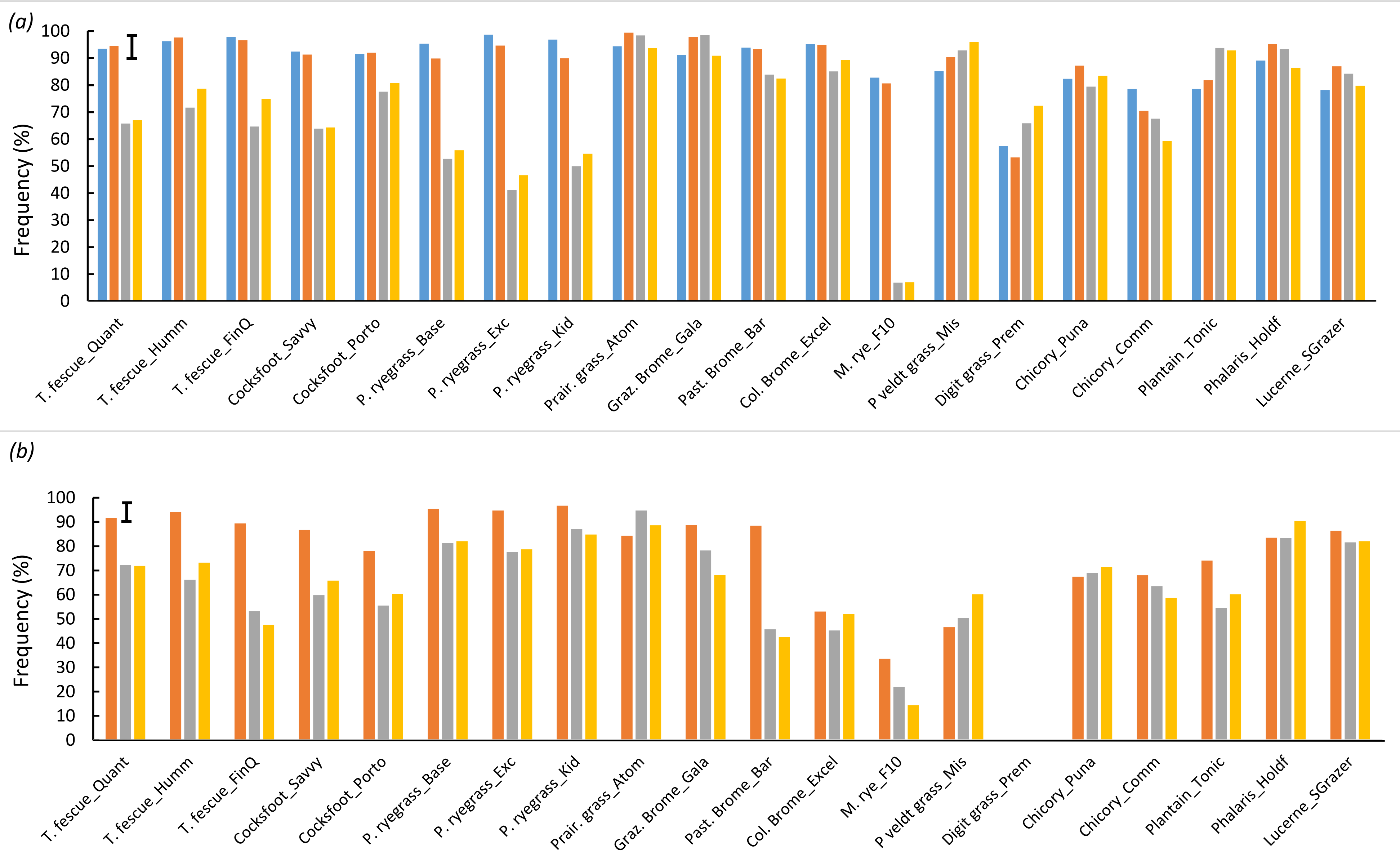
The two "standard" species, phalaris and lucerne, were persistent at both sites as were perennial veldt grass, Puna chicory and prairie grass. Commander chicory declined in frequency by 25 % at Goulburn and 14 % at Bombala over the duration of the experiment but remained at a frequency of 59 % at the final measurement at both sites.

Tall fescue, cocksfoot and perennial ryegrass all declined during the 2019-20 drought period at both sites. Tall fescue cultivars declined in frequency by an average of 30 % between 2019 and 2020 but partially recovered under higher rainfall in 2021. Finesse Q tall fescue was less persistent than Quantum II MaxP and Hummer MaxP at Bombala but not at Goulburn. Cocksfoot also declined in frequency by around 30 % at Bombala. At Goulburn, Porto was more persistent than Savvy (15 % decline for Porto vs. 30 % for Savvy). Perennial ryegrass declined in frequency by an average of 47 % across cultivars, the most of any commercial species. Excess AR37 was the most affected cultivar. Perennial ryegrass survived much better at Bombala, declining by only 14 % on average with Excess AR37 again the most affected by a small margin.

Several species were persistent at Goulburn because of high levels of seedling recruitment rather than longevity of established plants. These included prairie grass, grazing brome, pasture brome, coloured brome and plantain. Levels of seedling recruitment were observed to be much lower at Bombala, probably due to the drier summers and possibly due to timing of late spring/early summer removal of heads by mowing. Under these conditions, prairie grass persisted well but pasture brome in particular declined in the drought period from 2019 to 2020. Grazing brome and plantain also declined but both still had reasonable frequency in the third year.

The experimental breeding line of mountain rye persisted poorly at both sites. It was unclear whether the large decline at Goulburn between 2019 and 2020 was because of drought or because the stand was mown at a critical phase of growth. This species requires an opportunity to set and disperse seed regularly which our cutting regime prevented. If managed optimally, mountain rye would likely have displayed better persistence.

Figure. 4.2. Predicted frequency of 20 cultivars over 4 years (2018, 2019, 2020, 2021) in the core site non-legume experiments at (a) Goulburn and (b) Bombala. Bars indicate average s.e.d. × 2 for the same cultivar.



4.1.4 Herbage production

Goulburn

Seasonal herbage production at Goulburn is shown in Table 4.2 and for individual harvests where multiple harvests were made within a season in Table 4.3. Total herbage production at Goulburn is shown in Fig. 4.3.

Summer. The first summer (2018/19) was relatively moist although hot at Goulburn and most temperate grass cultivars and chicory produced more herbage DM than phalaris (Table 4.2). Prairie grass, chicory, mountain rye and tall fescue cultivars were top ranked in that order, yielding from 1.0-1.9 t/ha, or around 50% more herbage than phalaris. The advantage of most species over phalaris occurred mainly in the late spring-early summer period (12/12/2018 harvest in Table 4.3). Phalaris yielded similarly to most species in mid-January 2019 (Table 4.3). Chicory in particular, and digit grass, prairie grass and tall fescue yielded higher than phalaris in the second half of the summer (13/3/2019 in Table 4.3) which was a drier period with high temperatures when many species became visibly stressed.

The second summer period from mid-November 2019 to early February 2020 was one of severe drought. Summer 2019/20 in Table 4.2 therefore shows the growth response to drought-breaking rains from 9 February to 11 March 2020. Digit grass, chicory and lucerne were outstanding in their response, yielding around 2.5 t DM/ha in 30 days, a growth rate of over 80 kg/ha/d. Of the other species, phalaris and plantain formed an intermediate group around 1.5 t/ha which was significantly higher (P<0.05) than the remaining species. Perennial ryegrass, coloured brome, pasture brome and mountain rye were slow to respond to these rains, mountain rye declining severely post-drought.

The third summer (2020/21) had average rainfall but was much cooler than the first summer. Like the first summer, many species yielded higher than phalaris (Table 4.2) with this yield advantage occurring most consistently in the first half of summer (13/01/2021 harvest in Table 4.3). Digit grass was clearly the most productive species with chicory and cocksfoot also high yielding (Table 4.2). Coloured brome was most productive of the perennial bromes and was similar to tall fescue (Table 4.2). Under adequate rainfall, some species also outyielded phalaris in the second half of the third summer (24/02/2021 in Table 4.3). Digit grass was clearly the highest yielding species in this period followed by cocksfoot and chicory.

In summary, total summer yields at Goulburn were highest for chicory, followed by digit grass, cocksfoot, prairie grass, lucerne and tall fescue (Fig. 4.3). Chicory, digit grass and lucerne were consistently high whether in moister summers or coming out of drought. Tall fescue and cocksfoot were less stable due to their slower response after the dry 2019/21 summer. Relative to the first summer, cocksfoot came through the drought better than tall fescue and perennial ryegrass (Table 4.2). Prairie grass was also less stable for summer yield being high in the first summer and low in the final summer. Perennial ryegrass (due to lower drought survival), the perennial bromes and perennial veldt grass were similar to or lower yielding than phalaris which was stable at around 2 t/ha irrespective of conditions (Fig. 4.3). In species with multiple cultivars, Hummer tall fescue was most productive tall fescue in summer, Base AR37 the most productive ryegrass, and only small differences were observed between cocksfoot and chicory cultivars (Fig. 4.3).

Autumn. Prairie grass was the highest-yielding species in all autumn seasons at Goulburn (Table 4.2) and in total for the experiment yielded 35% more in autumn than the next highest cultivar (Base AR37 perennial ryegrass) and 60% more than phalaris (Fig. 4.3). Cultivars of perennial ryegrass and tall fescue yielded higher than phalaris in autumn 2019 and these and several other species (plantain, chicory, cocksfoot, grazing and coloured bromes, perennial veldt grass and digit grass) also yielded higher in autumn 2021 (Table 4.2). Post-drought (autumn 2020), many temperate grasses recovered slowly but both cocksfoot cultivars and Base AR37 perennial ryegrass recovered sufficiently by 22 April to be not significantly (P>0.05) lower yielding than phalaris, which was similar in yield to lucerne (22/04/2020 in Table 4.2). Plantain, chicory and tall fescue increased in autumn yield relative to other species from the first to the third years whereas perennial ryegrass did not. Pasture brome was consistently ranked low for autumn yield (Table 4.2). In terms of total autumn production for the experiment, Base AR37 perennial ryegrass, Hummer tall fescue and plantain ranked second to fourth behind prairie grass. However, differences were generally small amongst most species and cultivars (Fig. 4.3).

Winter. Phalaris was clearly the most productive species in winter 2019 at Goulburn and was equalled only by lucerne in winter 2020 immediately post-drought (Table 4.2). In total over the experiment, phalaris produced nearly 30 % more herbage in winter than the next highest species, lucerne and perennial veldt grass and double that of tall fescue and cocksfoot (Fig. 4.3). Higher in winter yield among the remaining cultivars were Kidman perennial ryegrass, grazing brome and prairie grass (Table 4.2, Fig. 4.3). Chicory and digit grass were very low and plantain and coloured brome were relatively low in winter yield.

Spring. Spring herbage production was low under drought conditions at Goulburn in 2019 with phalaris exceeded only by chicory, mountain rye and prairie grass (P<0.05; Table 4.2). In contrast, spring 2020 was very productive under high rainfall with many species yielding over 5 t DM/ha and the highest entry, Hummer tall fescue, 6.7 t/ha (Table 4.2). Tall fescue and perennial ryegrass yielded most in the first half of spring (21/10/2020 in Table 4.3) whereas cocksfoot and chicory yielded most in the second half of spring (30/11/2020 in Table 4.3). Chicory, tall fescue and prairie grass were highest for total spring production during the experiment but the differences between these and cocksfoot, perennial ryegrass and phalaris cultivars were small (Fig. 4.3). Grazing, pasture and coloured bromes were relatively low in total spring production and digit grass was very low (Fig. 4.3).

If the poorly persisting mountain rye is ignored, there was a trade-off between total summer and winter DM production at Goulburn indicated by a negative correlation between the two seasonal totals (r = -0.70, P<0.01). This trade-off is shown in Fig. 4.5a. Relative to other species, chicory and digit grass were specialised towards summer growth with little winter growth. For a combined summer + winter total of 9 t/ha, phalaris gave the best balance toward winter growth and summer-active cocksfoot the best balance towards summer growth with prairie grass and lucerne between these. Cocksfoot, tall fescue and perennial ryegrass produced about the same winter DM as each other with cocksfoot producing most in summer and in total, and perennial ryegrass the least due to its lower tolerance of the drought period. Grazing, pasture and coloured bromes and perennial veldt grass all produced a combined summer + winter total of about 7.5 t/ha, coloured brome producing the most in summer and grazing brome the most in winter. Perennial veldt grass was relatively winter-productive.

Table 4.2. Predicted seasonal herbage DM production (kg/ha) in the Goulburn non-legume core trial.

Bold values are significantly higher than phalaris with probability P>0.95.

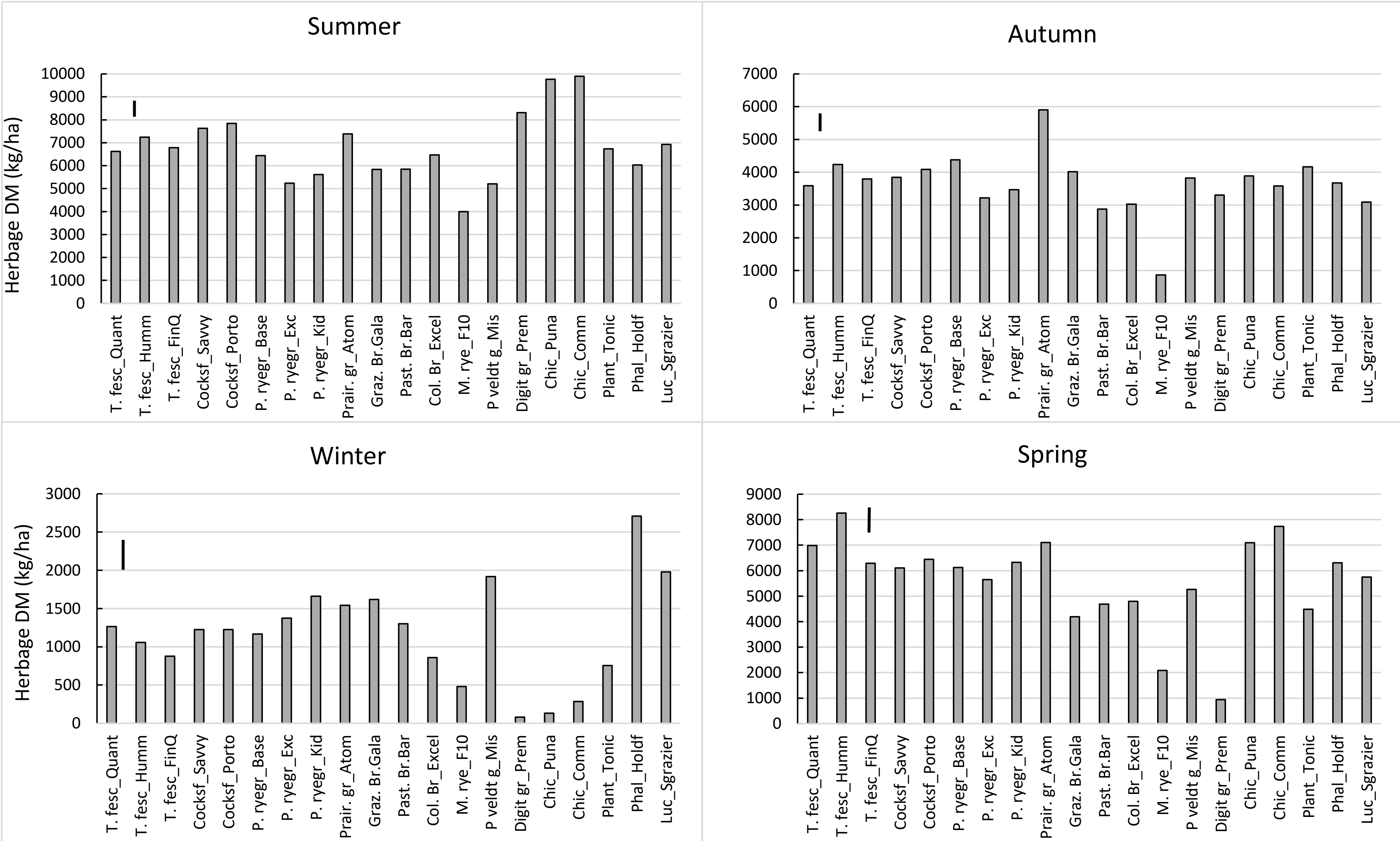
Species	Cultivar	Summer			Autumn			Winter		Spring	
		2018/19	2019/20	2020/21	2019	2020	2021	2019	2020	2019	2020
		3 harvests	11/03/2020	2 harvests	15/05/2019	22/04/2020	8/04/2021	4/09/2019	11/09/2020	18/11/2019	2 harvests
Tall fescue	Quantum II MaxP	**3352**	548	**2720**	**1224**	952	1409	455	811	1418	5564
Tall fescue	Hummer MaxP	**3563**	548	**3129**	**1090**	1115	**2031**	263	793	1554	**6706**
Tall fescue	Finesse Q	**3286**	503	**2994**	1044	961	**1789**	244	632	1163	5126
Cocksfoot	Savvy	**3164**	581	**3887**	859	1362	**1621**	351	875	611	5494
Cocksfoot	Porto	**3020**	986	**3841**	960	1510	**1614**	378	848	739	5706
Per. ryegrass	Base AR37	**3304**	301	**2830**	**1182**	1378	**1819**	343	823	907	5217
Per. ryegrass	Excess AR37	**2946**	78	2218	**1105**	943	1173	415	960	844	4808
Per. ryegrass	Kidman	2687	210	**2718**	1037	1059	1369	518	1143	657	5672
Prairie grass	Atom	**4267**	1144	1974	**1299**	**2210**	**2396**	590	951	**1609**	5495
Grazing brome	Gala	2744	889	2204	944	1517	**1555**	842	778	800	3389
Pasture brome	Bareno	**2910**	251	**2692**	717	1064	1095	394	907	422	4270
Coloured brome	Exceltas	**3174**	269	**3031**	648	924	**1450**	309	550	574	4227
Mountain rye	Family 10	**3754**	175	64	770	61	39	470	10	**1939**	145
Per. veldt grass	Mission	1713	846	**2652**	910	1408	**1504**	687	1232	536	4731
Digit grass	Premier	539	**2735**	**5035**	1031	852	**1420**	98	-18	652	289
Chicory	Puna	**2946**	**2601**	**4216**	694	1142	**2053**	-4	135	**1967**	5130
Chicory	Commander	**3845**	**2252**	**3805**	961	1083	**1534**	119	165	**2386**	5347
Plantain	Tonic	2640	1423	**2673**	732	1395	**2039**	295	459	1193	3295
Phalaris	Holdfast	2396	1584	2052	939	1601	1136	1204	1505	1244	5065
Lucerne	Sardi Grazer	1891	**2379**	**2654**	526	1779	784	422	1557	1020	4729
	av.s.e.d. × 2	*476*	*254*	*511*	*174*	*274*	*331*	*256*	*251*	*404*	*861*

Table 4.3. Predicted herbage DM production for individual harvests in the Goulburn non-legume core trial where multiple harvests were taken in a season.

Bold values are significantly higher than phalaris with probability P>0.95.

Species	Cultivar	Summer 2018/19			Spring 2020		Summer 2020/21	
		12/12/2018	15/01/2019	13/03/2019	21/10/2020	30/11/2020	13/01/2021	24/02/2021
Tall fescue	Quantum II MaxP	**1176**	1499	**677**	**3459**	2105	**1012**	1708
Tall fescue	Hummer MaxP	**1233**	1606	**724**	**4652**	2055	**1171**	**1958**
Tall fescue	Finesse Q	**1144**	1575	**566**	**3275**	1851	**1120**	**1874**
Cocksfoot	Savvy	**1188**	1526	450	2558	2936	**1570**	**2316**
Cocksfoot	Porto	**1118**	1436	466	2211	**3495**	**1405**	**2436**
Perennial ryegrass	Base AR37	**1348**	1621	335	2764	2454	**1315**	1515
Perennial ryegrass	Excess AR37	**1213**	1376	357	**3107**	1702	**819**	1400
Perennial ryegrass	Kidman	**1131**	1245	311	**3668**	2004	**1036**	1682
Prairie grass	Atom	**1212**	**2262**	**793**	2953	2542	**900**	1074
Grazing brome	Gala	**988**	1256	500	1313	2076	**1023**	1181
Pasture brome	Bareno	**1166**	1238	506	1925	2344	**1266**	1425
Coloured brome	Exceltas	**1292**	1383	499	1497	2729	**1607**	1423
Mountain rye	Family 10	**1170**	**1846**	**737**	36	110	31	33
Perennial veldt grass	Mission	790	580	343	2898	1833	**782**	**1870**
Digit grass	Premier	-332	-66	**938**	90	199	**1073**	**3962**
Chicory	Puna	560	1211	**1174**	1681	**3449**	**1757**	**2459**
Chicory	Commander	**839**	**1733**	**1273**	1819	**3528**	**1719**	**2086**
Plantain	Tonic	764	1435	441	1573	1721	731	**1942**
Phalaris	Holdfast	642	1372	382	2493	2571	565	1487
Lucerne	Sardi Grazer	245	1261	384	1770	2959	**755**	**1899**

Fig. 4.3. Predicted total herbage production over 3 years for summer and autumn and 2 years for winter and spring at Goulburn. Bars indicate average s.e.d. × 2.



Bombala

Seasonal herbage production and seedling sward growth at Bombala are shown in Table 4.4. In addition to starting a year later, fewer harvests were made at Bombala than at Goulburn due to longer duration of the 2019/20 drought and the drier late spring-summer in 2020/21 at Bombala.

Seedling sward DM observed 6.5 months after sowing was particularly high for perennial ryegrass (up to 3.55 t/ha) and grazing brome (2.45 t/ha; Table 4.4). Seedling swards of prairie grass and mountain rye were also relatively productive (Table 4.4). Subsequent regrowth after mowing was very low in all species as drought became more severe in spring 2020.

Summer. Summer herbage DM growth was low at Bombala in both years of the experiment due to low rainfall (Table 4.4). A small amount of growth occurred in response to rainfall from 9-12[th] February 2020 which was sampled in mid-March as "summer" growth (13/03/2020 in Table 4.4). Lucerne was the most productive species and it and Commander chicory were significantly (P<0.05) higher in harvested DM than phalaris. Harvested yields of all other species were very low (mean 100 kg/ha above cutting height). Chicory and lucerne were also clearly the most productive species in the second summer (11/02/2021 in Table 4.4), the high yield by Commander chicory being accompanied by stem development. Although averaging <500 kg/ha, most cultivars of tall fescue, cocksfoot and perennial ryegrass yielded significantly more (P<0.05) than phalaris during the 2020/21 summer (Table 4.4). The relatively high total summer production over two years by lucerne and chicory is evident in Fig. 4.4. Much less productive but significantly more so than phalaris (P<0.05) were cultivars of perennial ryegrass (Base AR37), cocksfoot (Savvy) and tall fescue (Quantum II MaxP).

Autumn. Residual moisture from the February rainfall allowed some growth in autumn 2020 (mean DM on 20/05/2020 = 600 kg/ha; Table 4.4). Perennial ryegrass and phalaris were the most productive species during this period. Autumn 2021 was much more productive following good rainfall in early February and mid-March 2021 with phalaris clearly the most productive species on 22/04/2021 (Table 4.4). Cocksfoot and chicory were also very productive in autumn 2021 followed by perennial ryegrass and prairie grass. Grazing, pasture and coloured bromes and mountain rye were very low in herbage DM partly due to low density. Productivity by lucerne in autumn 2021 was probably constrained by a dry soil profile coming out of summer since large edge effects were observed for this species. Total autumn production for the experiment was highest for phalaris and Commander chicory, followed by cocksfoot, perennial ryegrass and prairie grass (Fig. 4.4).

Winter. As at Goulburn, phalaris was the most productive species in winter with Hummer tall fescue also high probably because this harvest interval also included early spring (sampled 12/10/2020; Table 4.4; Fig. 4.4). Substantial yields by chicory, in particular Commander, were also due to this later sampling time. Prairie grass, Kidman perennial ryegrass, lucerne and Quantum II tall fescue were also relatively productive in winter-early spring.

Spring. Harvested herbage DM in the first spring was very low (mean 613 kg/ha) under increasingly severe drought. Mountain rye, Commander chicory and prairie grass were the most productive cultivars in this period. The second spring (late spring from 12 October to 4 December 2020) was much more productive after drought-breaking rains. Chicory and cocksfoot were clearly the most productive species in this period with phalaris, perennial ryegrass and prairie grass the next most productive species (4/12/2020 in Table 4.4). Total spring production for the experiment was highest for chicory and cocksfoot followed by phalaris, perennial ryegrass and prairie grass (Fig. 4.4).

The perennial bromes (grazing, pasture and coloured bromes) were relatively low in total herbage DM in all seasons due largely to low density particularly after drought (Fig. 4.4). Finesse Q tall fescue was less productive than the other tall fescue cultivars both as a seedling and at most harvests (Fig. 4.4). Mountain rye was the most productive species in the first spring but declined badly due to low drought survival. Plantain yielded moderately well in all seasons but was never among the higher yielding species (Fig. 4.4).

Across sites analysis
Clustering analysis of harvests from the combined FA7 analysis of both sites confirmed that, despite the differences in year of sowing and environmental differences between sites, there was a considerable degree of commonality in growth response by species between sites (Fig. 4.6). Harvests clustering close together in the dendrogram shown in Fig. 4.6 are more closely correlated than those further apart. The dendrogram broadly divided the harvests into two main groups, one containing the cool season period (late autumn, winter, early spring) when plants were vegetative, the second containing the warm season period (late spring, summer, early autumn) when reproductive growth was present in at least in some species. In general, harvests at similar times of year grouped together whether they were at Goulburn or Bombala.

The negative correlation between summer and winter growth observed at Goulburn was not significant (P>0.05) at Bombala (Fig. 4.5b) possibly because the single “winter” period also covered early spring when growth by some species was more active than expected solely in winter. Dry summers also constrained the expression of summer growth potential. Despite this, similarities between the two sites were evident. Chicory appeared as a “specialist” summer species at both sites, at Goulburn with digit grass and at Bombala with lucerne. Phalaris also gave the best balance towards winter growth with high combined summer + winter DM production at both sites. Tall fescue appeared as intermediate for summer and combined winter + summer growth at both sites. It had similar combined winter + summer DM to perennial ryegrass, cocksfoot and prairie grass at Bombala but higher than perennial ryegrass and less than cocksfoot and prairie grass at Goulburn. Grazing brome, perennial veldt grass and plantain formed a group with lower combined production at both sites. Coloured and pasture bromes were very low in combined winter + summer growth at Bombala due to lower establishment (coloured brome) and persistence through drought (both species) compared with Goulburn.

Table 4.4. Predicted seasonal herbage DM production and seedling sward DM (kg/ha) in the Bombala non-legume core trial.

Values for seedling growth are square root-transformed with back-transformed values in brackets. Bold values are significantly higher than phalaris with probability P>0.95.

Species	Cultivar	Seedling growth	Summer		Autumn		Winter/e. spring	Spring	
			2019/20	2020/21	2020	2021	2020	2019	2020
		9/10/2019	13/03/2020	11/02/2021	20/05/2020	22/04/2021	12/10/2020	12/12/2019	4/12/2020
Tall fescue	Quantum II MaxP	**32.9 (1080)**	153	**433**	589	2182	1885	568	2459
Tall fescue	Hummer MaxP	**32.3 (1040)**	77	**453**	564	2209	2505	727	2551
Tall fescue	Finesse Q	15.2 (230)	69	149	428	1481	1168	401	2624
Cocksfoot	Savvy	13.2 (175)	68	**507**	543	3451	1778	247	**4105**
Cocksfoot	Porto	13.5 (180)	97	**388**	536	3785	1547	365	**4373**
Perennial ryegrass	Base AR37	**45.3 (2050)**	116	**596**	**1053**	2863	1371	781	3240
Perennial ryegrass	Excess AR37	**55.9 (3125)**	108	**384**	951	2644	1765	622	2885
Perennial ryegrass	Kidman	**59.6 (3550)**	131	353	949	2850	2032	584	2967
Prairie grass	Atom	**43.9 (1925)**	97	364	634	2503	2172	**932**	2930
Grazing brome	Gala	**49.5 (2455)**	110	179	609	871	1711	535	1614
Pasture brome	Bareno	12.7 (160)	85	112	358	543	693	446	2167
Coloured brome	Exceltas	8.0 (65)	47	154	247	305	713	428	1978
Mountain rye	Family 10	**41.3 (1700**)	41	129	158	311	809	**1591**	1949
Per. veldt grass	Mission	11.1 (125)	41	125	602	1835	1510	485	2707
Digit grass	Premier	-	-	-	-	-	-	-	-
Chicory	Puna	7.9 (65)	143	**807**	751	2627	1150	520	**4203**
Chicory	Commander	17.4 (305)	**228**	**1477**	727	3980	1971	**1333**	**4578**
Plantain	Tonic	14.1 (200)	94	338	535	2389	1449	106	2542
Phalaris	Holdfast	23.9 (570)	146	246	846	4529	2821	713	3336
Lucerne	Sardi Grazer	10.5 (110)	**535**	**928**	399	1909	1894	265	2472
	av.s.e.d. × 2	*5.8*	*94*	*139*	*124*	*425*	*408*	*193*	*740*

Fig. 4.4. Predicted total herbage production over 2 years for summer, autumn and late spring, and 1 year for winter-early spring at Bombala. Bars = average s.e.d. × 2.

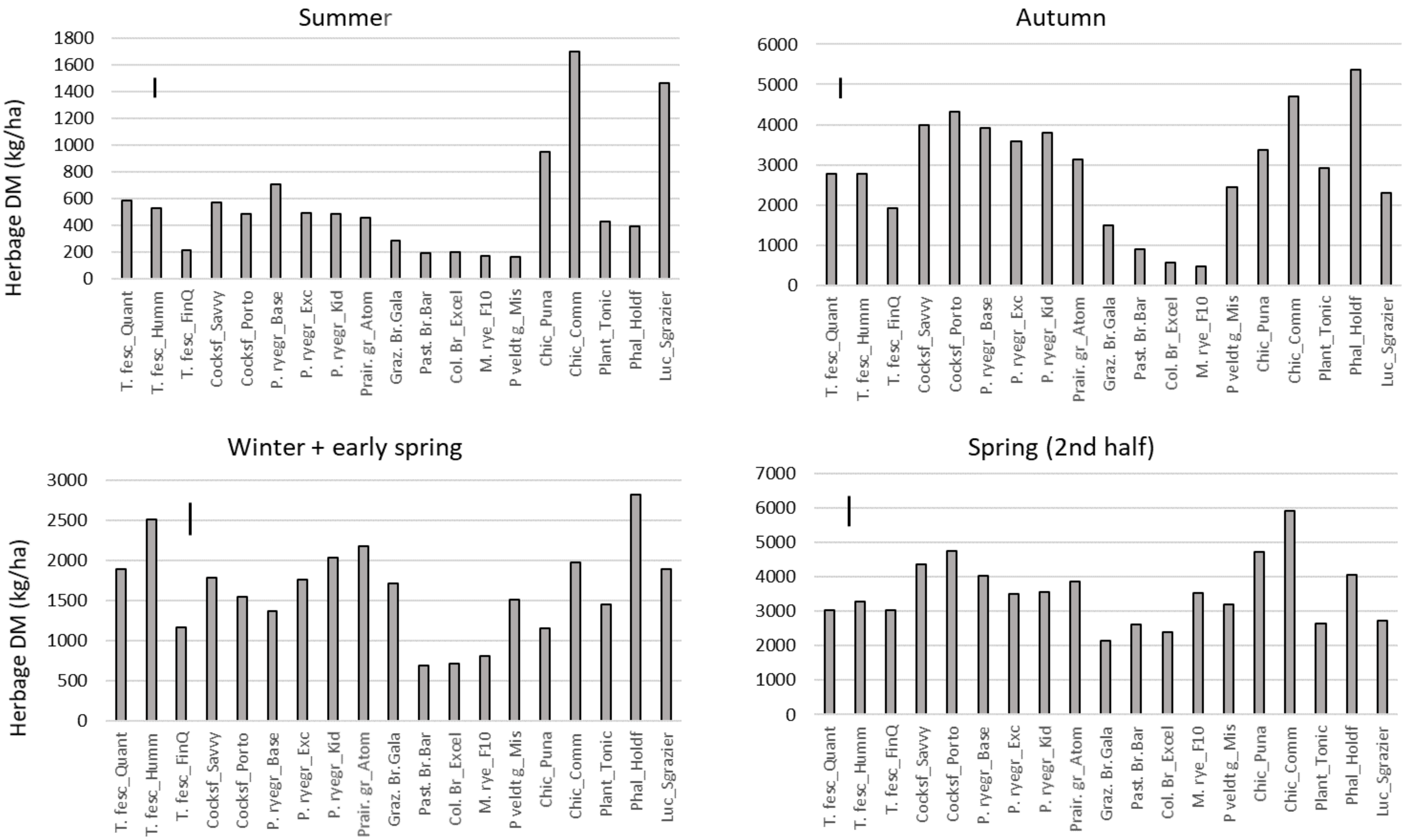
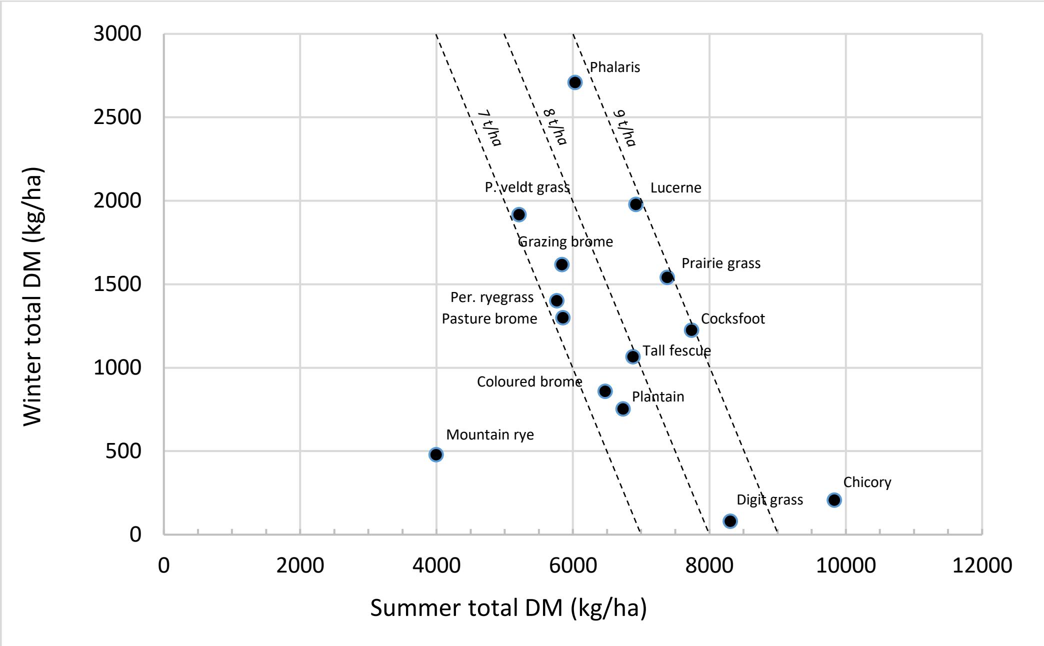


Fig. 4.5. Plot of predicted winter versus summer total herbage DM production at (a) Goulburn and (b) Bombala. Dashed lines indicate equal combined summer + winter total DM.

(a)



(b)

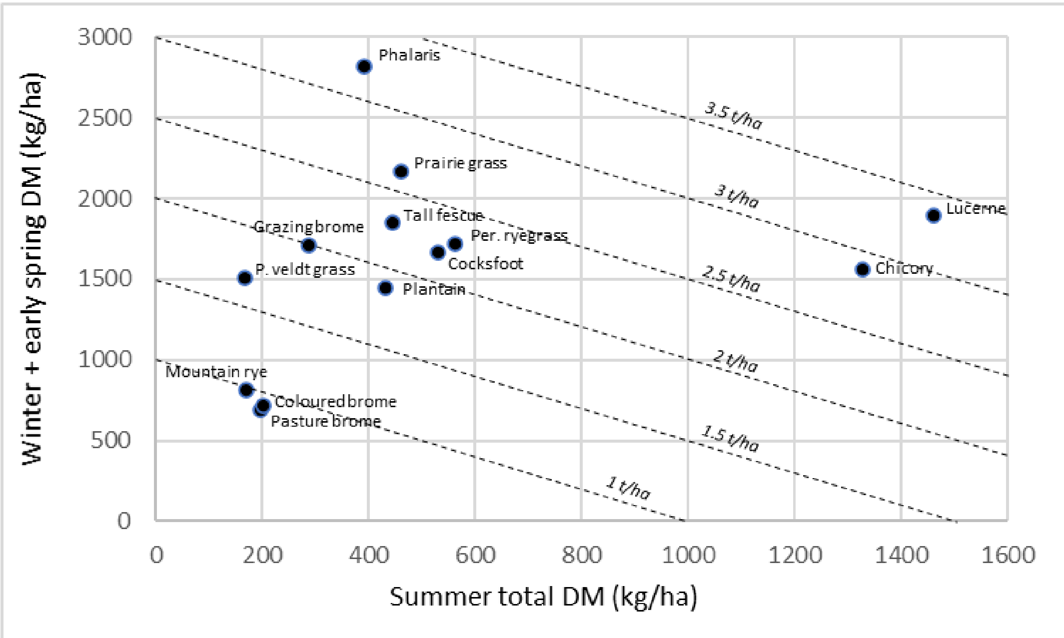
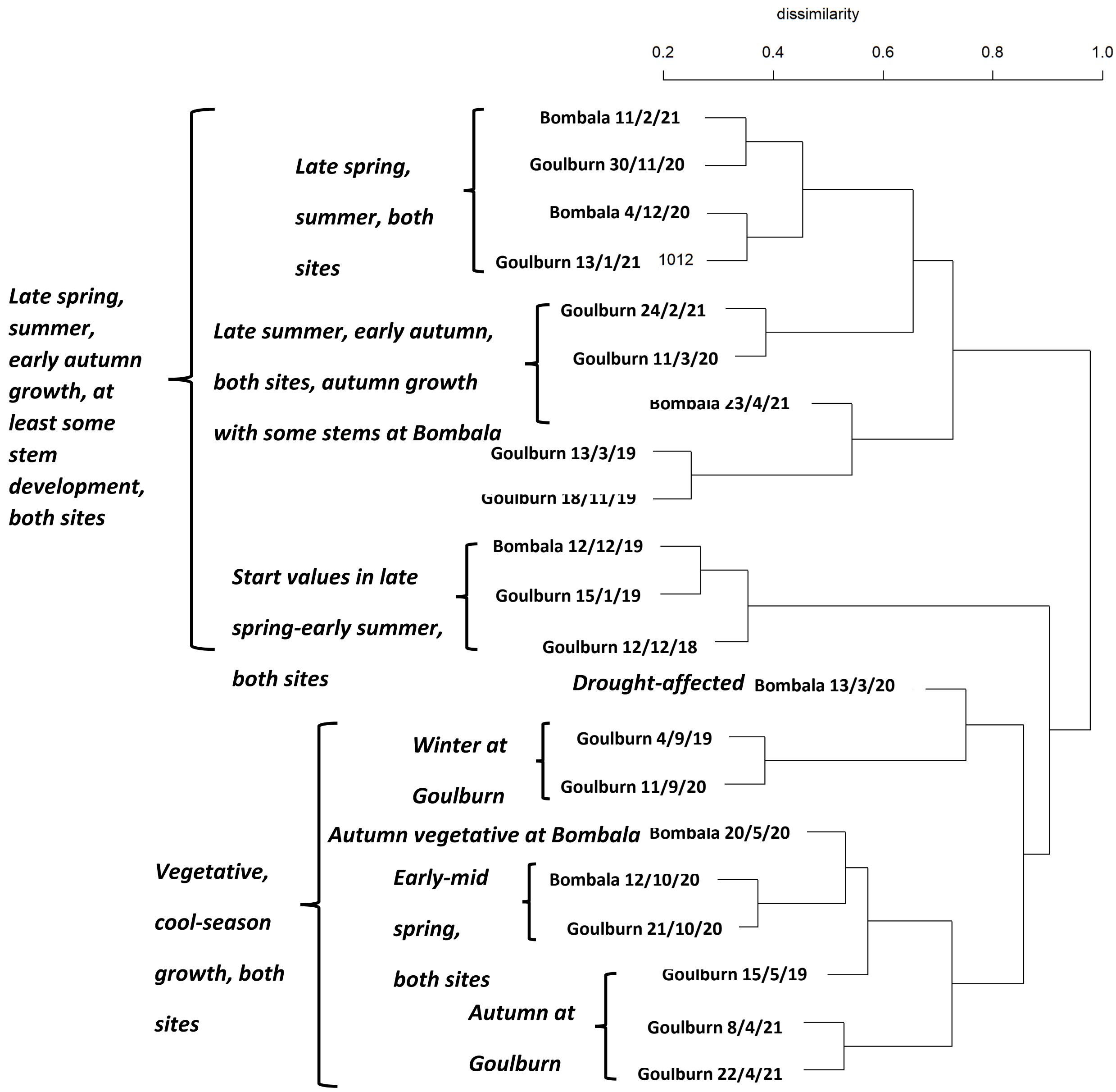


Fig. 4.6. Dendrogram of the dissimilarity matrix from the FA7 MET model (see Cullis et al. 2010 in De Faveri et al. 2015) fitted to herbage DM data from the Goulburn and Bombala core sites.



4.1.5 Nutritive quality

Nutritive quality traits related to supply of energy and protein are shown as metabolisable energy (ME) and crude protein content in Tables 4.5 and 4.6, respectively, for Goulburn and in Tables 4.9 and 4.10, respectively, for Bombala. Neutral detergent fibre (NDF) content, an important determinant of digestibility, feed intake and rumen function, is shown for Goulburn in Table 4.7 and for Bombala in Table 4.11. Acid detergent fibre and DM digestibility for both sites are shown in Appendix 8.1 to 8.4.

Effects of harvest date, cultivar and harvest date × cultivar interaction were highly significant (P<0.001) for all traits in analyses of each summer-autumn season at both sites. The cultivar effect was always much larger (approximately 10-fold larger in F value) than the interaction at Goulburn, suggesting that consistent cultivar effects were present despite some variation in relative levels from harvest to harvest. The cultivar main effect was only 2 to 5-fold larger in terms of F value than the interaction at Bombala except for ME for which the interaction slightly exceeded the cultivar effect.

The first sampling date at the end of spring in all years at both sites was typically low in ME and crude protein and high in NDF and ADF due to a high presence of mature stem material (see Table 4.8 for stem presence at Goulburn). Conversely, nutritive quality was typically highest in mid-late autumn (April or May) when there was low stem content and fresh growth under cooler conditions. Tall fescue, perennial ryegrass and cocksfoot displayed low aftermath heading and were largely vegetative after the late spring/early summer harvest. In contrast, phalaris, prairie grass and the other perennial bromes were much more likely to become reproductive again during summer. Tall fescue became reproductive very early each spring and did not produce many stems after this growth was removed, high stem presence in November 2019 occurring because plots were last mown in early September before stem elongation. Chicory was also prone to running to stem during summer. Once established, digit grass ran to rapidly to head.

In addition to low values at the end of spring, ME was also generally lower than ideal for rapid lamb growth during the first season (2018-19) at Goulburn, viz. in January which was 4 °C above the average maximum temperature, and in March 2019 following a period of moisture stress when some species (perennial ryegrass, perennial bromes, plantain, cocksfoot) displayed some wilting and senescence (Table 4.5). Values for ME of 10 MJ/kg or greater were rarely observed in any summer at Goulburn and were largely confined to autumn sampling dates. Only chicory exceeded 10 MJ/kg in January (2020-21 season; Table 4.5) although it reached 11.2 MJ/kg at the intermediate sampling in late February and late December 2020 before stem growth had commenced. Values for ME were generally higher at Bombala than at Goulburn in part because drier conditions prevented sampling until late summer and into autumn.

Chicory and perennial ryegrass were consistently the highest species in ME at Goulburn, with plantain and lucerne also high on average in the first and third seasons (Table 4.5). Chicory in particular was higher than other species in ME at the late spring/early summer sampling time. Of the other grasses, tall fescue was relatively high in ME content in the first season at Goulburn but not consistently in later seasons. Prairie grass and the other perennial bromes were often lower in ME depending on the level of stem growth but sometimes were similar to the grasses other than perennial ryegrass. While phalaris was typically low in ME at the first sampling time each season, it was usually equal to or not significantly lower than most other grasses except perennial ryegrass in later years. This included times when stems were present in phalaris but not in tall fescue, e.g. February and April 2021 (Tables 4.5, 4.8). Perennial veldt grass was usually similar to or higher in ME content than most other grasses after the first harvest of the season. As expected of a C_4 grass compared with C_3 species, digit grass was usually significantly lower in ME than other species except earlier in summer e.g. January 2020 and 2021, when stem growth in digit grass was less, or when the stem content of some other species was high at a particular date (e.g. some perennial bromes in March 2019 and January 2021). Sampling before stem elongation was critical for quality of digit grass with higher values for ME observed at intermediate harvests (9.9 MJ/kg 2.5 weeks after rain in February 2020 and 3 weeks after harvest in early April 2021 (not shown)). Similarly, sampling between main harvests of chicory and plantain in February 2020 and chicory again in December 2020 before any stem growth had occurred yielded markedly high ME values than waiting for the main harvest date when stems had started to form.

Similar to Goulburn, ME content of chicory and perennial ryegrass was high at Bombala in the first season (2019-20) with plantain, phalaris, lucerne and perennial veldt grass also high in March (Table 4.9). Most species were of high ME content in February of the second season (2020-21) with only the perennial bromes and prairie grass markedly lower. The perennial bromes, however, were relatively high at the next harvest in April along with tall fescue, mountain rye, and Puna chicory. The February harvest was taken early due to logistical constraints and consequently was low in herbage mass (see Table 4.4) and was largely vegetative. Commander chicory was relatively low in ME in April 2021 because of high stem content in contrast to Puna which had none. Phalaris was high in ME in both February and April 2021 (Table 4.9) despite being in early stem elongation at the April sampling.

Fundamental similarity in ME content of species between sites is shown by a high correlation (r=0.86, P<0.001) between means of all harvests at each site (Fig. 4.7a). This makes clear the relatively high average ME content of chicory, perennial ryegrass and lucerne. Plantain was lower, relatively, at Bombala than at Goulburn while phalaris and cocksfoot were higher. The lower content of prairie grass and the other brome species is also clear.

Crude protein levels at both sites were mostly above the 14-16 % DM level considered satisfactory for lamb production under the N application regime used apart from the first cut each season when mature stem content was high (Tables 4.6 and 4.10). Very low levels in November 2019 at Goulburn were in herbage with high stem content that was also senescing early under severe drought. As expected of the only legume in the experiment, lucerne was consistently high in crude protein at both sites and all dates. Of the non-legume species, perennial veldt grass was highest on average at Goulburn followed by the group of perennial bromes (pasture, coloured and grazing brome) and cocksfoot. At Bombala, cocksfoot and perennial veldt grass were also relatively high in crude protein content followed by phalaris. Species that tended to be lower in crude protein were plantain, digit grass, chicory, perennial ryegrass and prairie grass at one or both sites.

As with ME, there was a high correlation (r=0.86, P<0.001) between means of all harvests at each site (Fig. 4.7b). Fig. 4.7b clearly shows the superiority of lucerne in protein content. Perennial veldt grass and cocksfoot were highest of the remaining species, and Commander chicory and plantain were the lowest.

NDF levels always exceeded the suggested 27-30 % DM minimum needed for good rumen function and adequate intake (Jolly 2010; Tables 4.7 and 4.11). Chicory, plantain and lucerne were consistently lower in NDF than the grasses except for chicory and plantain in March 2020 at Goulburn. Perennial ryegrass was lowest in NDF among the perennial grasses although the difference was not large. Digit grass was highest in NDF particularly when sampled in late summer and autumn (Table 4.7) when presence of stems was high (Table 4.8). Perennial bromes (including prairie grass) and cocksfoot were highest among the temperate grasses. High values among the bromes were often due to presence of stem, for example in the 2018-19 season and in January 2021 at Goulburn (Tables 4.7, 4.8). However, this was not always the case, e.g. for prairie grass and grazing brome in March 2020. For cocksfoot, values higher than other temperate grasses occurred even when plots were largely vegetative, e.g. at Goulburn in March and May 2019, March and April 2020, February 2021 (Tables 4.7, 4.8).

The correlation of means of all harvests between sites for NDF was very high (r=0.95, P<0.001). Overall, chicory, plantain and lucerne were much lower in NDF content than the perennial grasses (Fig. 4.7c). Of the grasses, perennial ryegrass was the lowest and prairie grass, other perennial bromes and cocksfoot were highest.

ADF, the least digestible fibre fraction, averaged around 30 % DM at the first sampling time each season when stem presence was high, and 22-25 % DM at later sampling times (Appendix 8.1 and 8.3). Digit grass was the highest in ADF from mid-summer onwards each season. Of the temperate species, prairie grass and grazing brome were highest on average, followed by cocksfoot and pasture and coloured bromes. Perennial ryegrass was lowest among the grasses. Chicory and plantain were usually relatively low in ADF but not always depending on presence of stem tissue.

Among species with more than one cultivar, Puna chicory was often higher in ME and in crude protein, and lower in NDF and ADF than Commander chicory. This was associated with the lower propensity of Puna to form reproductive stems (Table 4.8). Base AR37 and Excess AR37 perennial ryegrass cultivars were usually slightly higher than Kidman in ME and lower in fibre content. Differences in perennial ryegrass were not ascribable to presence of stem. Savvy cocksfoot was less prone than Porto to form stems, but differences were often not large, and Savvy was not significantly higher (P<0.05) in ME or lower in NDF than Porto. Cultivars of tall fescue only rarely differed in ME and NDF (e.g. in November 2019 at Goulburn and April 2021 at Bombala).

In summary, chicory and perennial ryegrass displayed the highest nutritive quality in terms of higher ME and lower NDF. Plantain and lucerne were nearly as high but not consistently so, particularly plantain. Lucerne was consistently high in protein. Brome species were often lower than other temperate species in nutritive quality but sometimes were similar to them mostly depending on whether they had become reproductive. Once the spring growth was removed, phalaris was usually not significantly lower in quality than tall fescue despite a higher presence of stem in summer growth of phalaris. Cocksfoot tended to be higher in NDF but also higher in crude protein than tall fescue, phalaris and perennial ryegrass even when stem content was low. Nutritive quality of digit grass over summer and autumn was lowest of all species but this was markedly improved when sampled before stems formed.

Table 4.5. Metabolisable energy (MJ/kg DM) for 3 summer-autumn seasons at the Goulburn core non-legume site.

Harvest dates were 12-Dec-18, 15-Jan 19, 13-Mar-19, 15-May-19 (Season 2018-19), 18-Nov-19, 11 Mar-20, 22 Apr-20 (Season 2019-20), 30-Nov-20, 13 Jan 21, 24-Feb-21, 8-Apr-21 (Season 2020-21). Means ignore intermediate harvests of some species on 21-or 25-Feb-20 (Season 2019-20) and 21 Dec 2021 (Season 202-21).

Species	Cultivar	Season 2018-19					Season 2019-20					Season 2020-21					
		Dec	Jan	Mar	May	Mean	Nov	Feb	Mar	Apr	Mean	Nov	Dec	Jan	Feb	Apr	Mean
Tall fescue	Quantum II MaxP	7.1	9.1	9.1	10.0	8.8	7.7		9.8	10.2	9.2	9.0		9.4	9.7	9.8	9.5
Tall fescue	Hummer MaxP	6.5	9.1	9.3	9.9	8.7	7.8		9.9	10.4	9.4	9.1		9.3	9.7	10.0	9.5
Tall fescue	Finesse Q	6.9	9.0	9.3	10.0	8.8	8.7		9.9	10.3	9.6	8.9		9.4	9.7	9.9	9.5
Cocksfoot	Savvy	7.5	9.0	8.7	9.3	8.6	8.5		9.6	10.2	9.4	8.6		9.4	9.3	9.9	9.3
Cocksfoot	Porto	7.2	9.0	8.7	9.5	8.6	8.2		9.6	9.8	9.2	8.0		9.4	9.2	10.1	9.2
Per. ryegrass	Base AR37	7.5	9.3	9.4	10.8	9.3	9.5		9.9	11.0	10.1	9.8		9.5	10.9	11.1	10.3
Per. ryegrass	Excess AR37	7.2	9.5	9.3	10.7	9.2	9.0		10.2	11.1	10.1	9.7		9.6	10.7	11.1	10.3
Per. ryegrass	Kidman	7.0	9.3	9.4	10.7	9.1	8.3		9.9	10.9	9.7	9.4		9.6	10.6	10.6	10.0
Prairie grass	Atom	7.5	8.4	7.8	8.7	8.1	6.7		9.6	10.1	8.8	9.1		9.2	10.3	10.3	9.7
Grazing brome	Gala	6.9	9.2	8.1	9.0	8.3	6.9		9.7	10.1	8.9	9.0		9.0	9.9	10.2	9.5
Pasture brome	Bareno	7.1	9.0	8.3	9.0	8.4	8.2		10.0	10.8	9.7	8.3		8.8	9.8	10.0	9.2
Coloured brome	Exceltas	6.7	8.7	8.0	8.8	8.1	7.9		10.2	10.3	9.5	8.2		8.3	9.5	10.1	9.0
Mountain rye	Family 10	7.3	8.3	8.6	9.9	8.5	7.9		9.7	10.4	9.4						
Per. veldt grass	Mission	6.6	9.7	9.8	10.0	9.0	7.8		9.5	10.7	9.3	8.5		9.0	10.2	10.4	9.5
Digit grass	Premier		9.1	8.1	8.0		7.2	9.9	8.8	8.6	8.2	9.1	9.2	8.7	8.6	9.1	8.9
Chicory	Puna	8.7	9.8	10.1	10.3	9.7	10.0	11.2	9.4	11.0	10.2	10.7	11.2	10.5	11.2	11.3	10.9
Chicory	Commander	7.9	8.6	9.4	10.4	9.1	10.1	10.9	9.2	11.1	10.1	10.2	11.2	10.1	10.7	11.3	10.6
Plantain	Tonic	8.1	8.9	9.8	10.3	9.3	6.9	10.6	8.7	11.4	9.0	9.3		9.9	10.8	10.6	10.1
Phalaris	Holdfast	6.2	8.7	9.0	9.7	8.4	7.9		10.1	10.4	9.5	8.9		9.0	9.8	10.2	9.5
Lucerne	Sardi Grazer	9.0	8.9	9.2	9.7	9.2	8.6		9.4	10.4	9.5	10.0		10.2	10.1	10.5	10.2
	s.e.d. × 2		*0.5*			*0.3*		*0.5*			*0.3*		*0.4*				*0.2*

Table 4.6. Crude protein (% DM) for 3 summer-autumn seasons at the Goulburn core non-legume site.

Harvest dates were 12-Dec-18, 15-Jan 19, 13-Mar-19, 15-May-19 (Season 2018-19), 18-Nov-19, 11 Mar-20, 22 Apr-20 (Season 2019-20), 30-Nov-20, 13 Jan 21, 24-Feb-21, 8-Apr-21 (Season 2020-21). Means ignore intermediate harvests of some species on 21-or 25-Feb-20 (Season 2019-20) and 21 Dec 2021 (Season 202-21).

Species	Cultivar	Season 2018-19					Season 2019-20					Season 2020-21					
		Dec	Jan	Mar	May	Mean	Nov	Feb	Mar	Apr	Mean	Nov	Dec	Jan	Feb	Apr	Mean
Tall fescue	Quantum II MaxP	13.5	20.2	17.2	13.6	16.1	7.5		19.5	18.4	15.1	9.8		13.4	17.5	17.4	14.5
Tall fescue	Hummer MaxP	12.5	20.3	16.6	13.4	15.7	8.5		21.3	19.4	16.4	11.1		12.7	16.3	15.8	14.0
Tall fescue	Finesse Q	13.4	21.3	16.7	12.2	15.9	8.2		19.6	19.5	15.8	11.1		14.0	16.9	17.0	14.8
Cocksfoot	Savvy	14.6	21.1	18.8	16.1	17.6	11.7		21.0	20.6	17.8	11.8		15.0	16.0	16.7	14.9
Cocksfoot	Porto	13.1	22.0	18.8	17.8	17.9	10.9		19.8	19.4	16.7	9.4		17.1	15.9	18.0	15.1
Per. ryegrass	Base AR37	10.6	21.1	18.2	11.5	15.3	7.7		20.1	17.9	15.2	9.4		13.0	20.0	12.4	13.7
Per. ryegrass	Excess AR37	11.1	21.6	17.5	11.1	15.3	8.2		20.6	19.8	16.2	10.6		13.2	18.7	15.4	14.5
Per. ryegrass	Kidman	11.4	19.8	16.4	11.0	14.6	6.9		20.6	17.9	15.1	9.9		13.6	18.6	14.6	14.2
Prairie grass	Atom	13.3	18.7	12.6	11.2	13.9	5.4		18.0	17.8	13.7	10.9		15.8	21.6	14.8	15.7
Grazing brome	Gala	15.6	22.5	15.7	16.7	17.6	6.4		21.8	20.0	16.1	11.2		12.6	20.3	20.0	16.0
Pasture brome	Bareno	14.8	22.8	16.9	16.8	17.8	11.2		24.0	22.0	19.1	9.8		12.9	19.9	18.4	15.3
Coloured brome	Exceltas	13.9	22.1	16.5	15.8	17.1	10.9		23.0	22.5	18.8	10.7		12.0	20.0	17.5	15.1
Mountain rye	Family 10	13.0	19.6	15.9	15.7	16.1	6.3		21.3	24.0	17.2						
Per. veldt grass	Mission	9.9	25.1	19.5	18.6	18.3	9.8		21.3	21.9	17.7	12.7		16.2	21.7	21.1	17.9
Digit grass	Premier	nd	22.8	13.9	10.8		8.6	25.8	16.0	11.7	12.1	13.0	16.7	12.6	13.5	13.8	13.2
Chicory	Puna	12.9	19.5	16.8	15.0	16.1	13.7	22.3	15.9	15.2	14.9	12.1	18.6	13.3	13.3	15.3	13.5
Chicory	Commander	9.2	13.1	14.3	14.4	12.8	12.0	22.5	15.0	15.5	14.2	9.8	18.6	12.3	12.3	15.7	12.6
Plantain	Tonic	13.4	19.3	17.7	12.5	15.7	6.0	19.8	13.6	9.4	9.6	8.0		11.7	11.4	13.5	11.1
Phalaris	Holdfast	11.9	19.4	17.4	17.3	16.5	8.8		19.5	22.0	16.8	12.5		15.4	18.5	16.4	15.7
Lucerne	Sardi Grazer	19.6	20.7	19.8	22.6	20.7	14.0		21.7	27.1	20.9	19.9		21.7	24.0	28.6	23.5
	s.e.d. × 2		*2.4*			*1.6*			*2.6*		*1.7*			*2.0*			*1.1*

Table 4.7. Neutral detergent fibre (% DM) for 3 summer-autumn seasons at the Goulburn core non-legume site.

Harvest dates were 12-Dec-18, 15-Jan 19, 13-Mar-19, 15-May-19 (Season 2018-19), 18-Nov-19, 11 Mar-20, 22 Apr-20 (Season 2019-20), 30-Nov-20, 13 Jan 21, 24-Feb-21, 8-Apr-21 (Season 2020-21). Means ignore intermediate harvests of some species on 21-or 25-Feb-20 (Season 2019-20) and 21 Dec 2021 (Season 202-21).

Species	Cultivar	Season 2018-19					Season 2019-20					Season 2020-21					
		Dec	Jan	Mar	May	Mean	Nov	Feb	Mar	Apr	Mean	Nov	Dec	Jan	Feb	Apr	Mean
Tall fescue	Quantum II MaxP	62.9	50.6	55.2	43.3	53.0	62.0		42.0	45.6	49.9	53.6		50.2	49.2	47.2	50.0
Tall fescue	Hummer MaxP	66.9	51.6	54.5	44.9	54.5	61.9		40.6	47.1	49.9	53.2		52.2	48.9	47.6	50.5
Tall fescue	Finesse Q	62.9	49.7	53.7	42.1	52.1	55.0		40.4	46.4	47.3	54.5		50.3	49.5	47.3	50.4
Cocksfoot	Savvy	62.6	54.7	58.4	49.5	56.3	59.1		45.5	51.1	51.9	60.2		53.5	54.9	49.8	54.6
Cocksfoot	Porto	62.6	53.8	59.7	47.6	55.9	58.1		47.1	53.7	53.0	62.1		51.3	55.4	48.3	54.3
Per. ryegrass	Base AR37	59.3	48.6	51.5	38.3	49.5	51.4		37.3	41.9	43.5	47.7		48.4	40.7	42.6	44.8
Per. ryegrass	Excess AR37	62.2	47.0	53.4	38.8	50.4	54.9		36.0	41.7	44.2	48.7		48.0	41.3	40.9	44.7
Per. ryegrass	Kidman	64.9	49.3	52.4	39.7	51.6	59.4		37.8	44.0	47.0	51.4		48.1	43.3	44.5	46.8
Prairie grass	Atom	61.7	56.5	65.7	55.0	59.7	69.8		45.5	48.0	54.4	53.2		51.6	42.5	44.7	48.0
Grazing brome	Gala	67.1	55.4	67.1	54.7	61.1	72.0		44.5	54.0	56.8	56.8		56.9	48.0	46.3	52.0
Pasture brome	Bareno	64.7	55.5	62.9	51.4	58.6	60.0		37.8	43.0	46.9	57.9		54.2	48.0	46.1	51.6
Coloured brome	Exceltas	67.5	56.5	64.3	54.0	60.6	62.5		38.5	47.0	49.3	59.5		57.7	50.3	46.4	53.5
Mountain rye	Family 10	58.7	52.9	55.9	45.1	53.2	57.0		40.4	42.3	46.5						
Per. veldt grass	Mission	63.4	43.6	43.8	40.8	48.1	58.4		42.6	47.5	49.5	56.8		52.4	44.1	45.2	49.6
Digit grass	Premier	nd	48.1	59.7	61.4		59.5	47.7	54.9	57.8	57.4	54.5	51.0	55.8	59.1	54.0	55.8
Chicory	Puna	45.0	40.5	37.4	29.4	38.1	36.7	33.4	41.1	38.5	38.8	36.9	35.3	38.9	34.4	31.8	35.5
Chicory	Commander	50.4	48.1	41.4	28.5	42.1	34.7	36.7	41.7	38.0	38.1	41.1	36.2	39.9	34.4	31.5	36.7
Plantain	Tonic	48.0	40.1	36.1	30.8	38.8	53.9	33.1	44.0	33.0	43.6	45.1		37.8	34.5	33.4	37.7
Phalaris	Holdfast	65.1	52.5	52.7	43.6	53.5	60.6		41.9	43.0	48.5	55.2		53.4	48.3	45.9	50.7
Lucerne	Sardi Grazer	41.6	41.0	38.6	34.5	38.9	42.8		39.0	36.4	39.4	38.7		38.2	35.8	32.5	36.3
	s.e.d. × 2		*4.0*			*2.1*		*4.0*			*2.3*			*2.9*			*1.7*

Table 4.8. Proportion of plots (%) with reproductive stems present at the Goulburn core non-legume site.

Species	**Cultivar**	**Season 2018-19**				**Season 2019-20**			**Season 2020-21**			
		Dec	**Jan**	**Mar**	**May**	**Nov**	**Mar**	**Apr**	**Nov**	**Jan**	**Feb**	**Apr**
Tall fescue	Quantum II MaxP	0	0	0	1	100	0	1	10	2	0	1
Tall fescue	Hummer MaxP	0	0	2	2	95	0	4	8	3	1	1
Tall fescue	Finesse Q	6	0	0	1	48	0	0	14	11	2	1
Cocksfoot	Savvy	6	0	0	0	6	0	2	74	3	1	2
Cocksfoot	Porto	80	13	0	4	6	1	23	99	9	18	13
Per. ryegrass	Base AR37	83	7	4	2	0	0	0	44	53	1	0
Per. ryegrass	Excess AR37	58	3	4	2	0	0	0	54	25	1	1
Per. ryegrass	Kidman	15	5	6	4	41	0	0	60	41	0	1
Prairie grass	Atom	66	75	100	86	100	0	0	15	18	17	39
Grazing brome	Gala	2	3	38	25	100	0	0	19	3	0	0
Pasture brome	Bareno	63	23	23	24	13	3	0	88	88	8	6
Coloured brome	Exceltas	60	29	30	25	9	0	0	93	98	16	3
Mountain rye	Family 10	95	90	73	5	100						
Per. veldt grass	Mission	0	11	1	2	78	2	3	95	89	1	0
Digit grass	Premier		1	86	86	0	90	100	0	90	100	95
Chicory	Puna	61	33	7	6	41	0	1	64	44	3	1
Chicory	Commander	68	50	45	26	53	1	6	86	60	53	15
Plantain	Tonic	63	65	16	6	100	1	0	95	78	9	2
Phalaris	Holdfast	7	85	61	18	63	1	19	70	68	43	41
Lucerne	Sardi Grazer	6	26	2	1	19	1	0	0	0	1	0
Mean		*38.9*	*26.0*	*24.9*	*16.3*	*48.5*	*5.2*	*8.3*	*51.9*	*40.9*	*14.4*	*11.6*

Table 4.9. Metabolisable energy (MJ/kg) at the Bombala core non-legume site.

Species	Cultivar	Season 2019-20			Season 2020-21			
		Dec	Mar	Mean	Dec	Feb	Apr	Mean
Tall fescue	Quantum II MaxP	8.0	10.4	9.2	7.7	10.8	10.8	9.8
Tall fescue	Hummer MaxP	7.6	10.4	9.0	7.6	10.9	10.2	9.5
Tall fescue	Finesse Q	8.0	10.7	9.4	7.5	11.0	11.1	9.9
Cocksfoot	Savvy	8.1	10.5	9.3	7.5	10.7	10.2	9.5
Cocksfoot	Porto	8.1	10.9	9.5	8.0	10.8	10.0	9.6
Per. ryegrass	Base AR37	9.2	11.4	10.3	8.4	10.7	10.3	9.8
Per. ryegrass	Excess AR37	8.9	11.3	10.1	8.1	10.8	10.4	9.7
Per. ryegrass	Kidman	8.5	11.0	9.8	7.8	10.7	10.1	9.5
Prairie grass	Atom	7.0	10.4	8.7	7.8	10.9	10.1	9.6
Grazing brome	Gala	6.9	10.2	7.6	7.1	10.6	10.9	9.5
Pasture brome	Bareno	7.6	10.4	9.0	7.4	9.5	10.5	9.1
Coloured brome	Exceltas	6.9	9.8	8.4	7.1	9.1	10.8	9.0
Mountain rye	Family 10	7.8	9.9	8.9	8.5	9.9	11.0	9.8
Per. veldt grass	Mission	7.4	11.2	9.3	7.4	9.4	10.6	9.1
Digit grass	Premier							
Chicory	Puna	9.0	11.3	10.1	9.6	10.4	10.7	10.2
Chicory	Commander	8.7	11.4	10.1	10.1	10.2	9.9	10.1
Plantain	Tonic	7.5	11.6	9.6	8.2	10.3	10.6	9.7
Phalaris	Holdfast	8.3	11.2	9.7	7.8	11.1	10.5	9.8
Lucerne	Sardi Grazer	8.8	11.1	10.0	9.1	11.0	9.6	9.9
	s.e.d. × 2	*0.4*		*0.3*	*0.6*			*0.3*

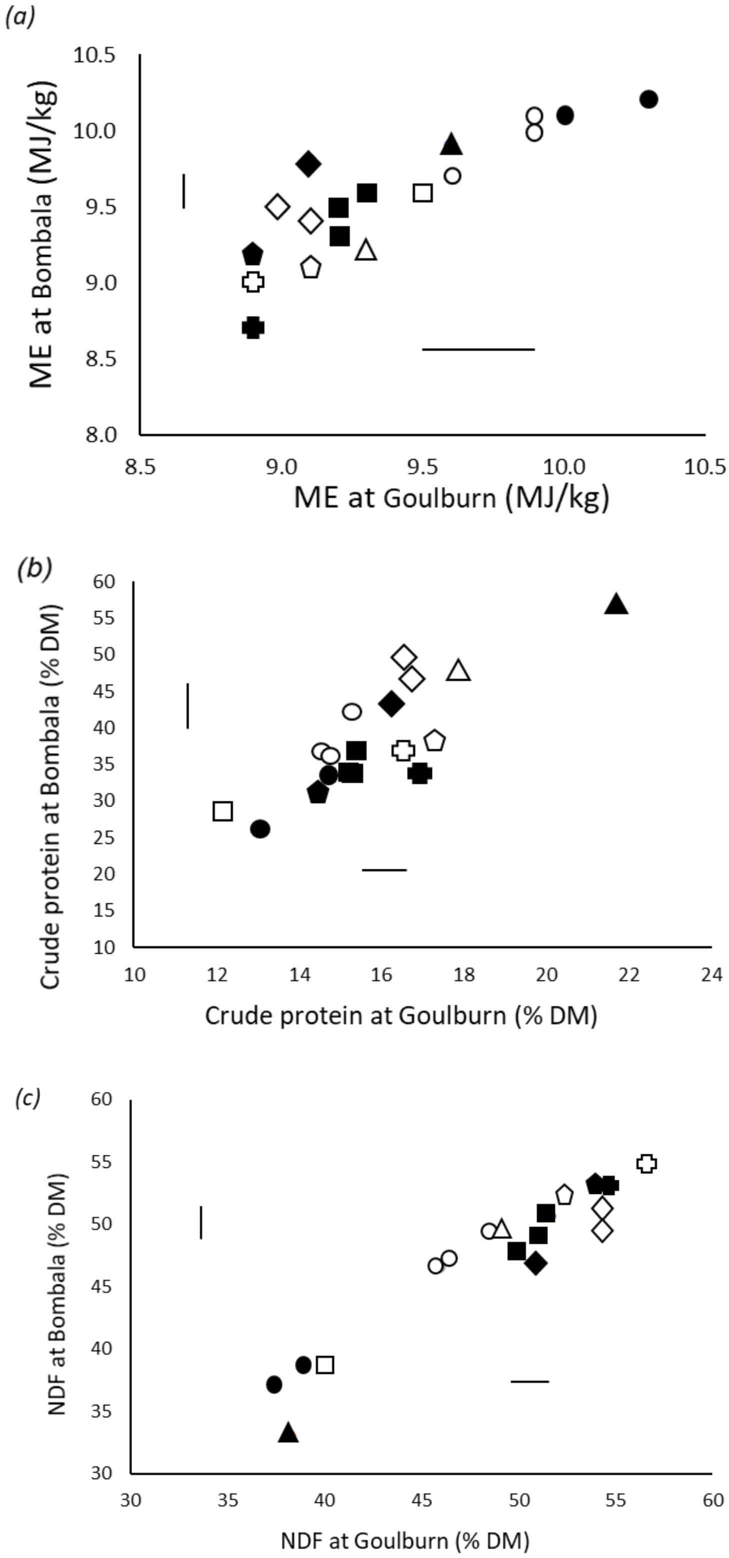
Table 4.10. Crude protein (% DM) at the Bombala core non-legume site.

Species	Cultivar	Season 2019-20			Season 2020-21			
		Dec	Mar	Mean	Dec	Feb	Apr	Mean
Tall fescue	Quantum II MaxP	9.9	23.8	16.9	8.7	19.9	14.8	14.5
Tall fescue	Hummer MaxP	9.5	22.6	16.1	8.1	22.8	15.4	15.4
Tall fescue	Finesse Q	10.1	23.4	16.8	8.5	22.3	17.0	15.9
Cocksfoot	Savvy	11.8	28.5	20.2	9.6	25.2	17.4	17.4
Cocksfoot	Porto	11.6	30.3	20.9	9.9	26.2	17.1	17.7
Per. ryegrass	Base AR37	12.1	26.4	19.3	7.0	22.2	10.8	13.4
Per. ryegrass	Excess AR37	13.1	27.8	20.5	7.1	23.5	13.6	14.7
Per. ryegrass	Kidman	12.1	25.8	18.9	7.2	23.8	10.8	13.9
Prairie grass	Atom	7.5	23.5	15.5	7.8	22.7	13.8	14.8
Grazing brome	Gala	9.2	23.4	16.3	7.7	22.7	19.1	16.5
Pasture brome	Bareno	12.2	22.7	17.5	8.3	20.9	19.0	16.0
Coloured brome	Exceltas	10.0	21.1	15.5	8.8	19.8	19.3	16.0
Mountain rye	Family 10	8.7	20.0	14.3	10.4	18.7	15.2	14.8
Per. veldt grass	Mission	11.2	28.5	19.9	9.3	22.1	22.8	18.1
Digit grass	Premier							
Chicory	Puna	11.2	19.4	15.3	13.3	19.8	14.8	16.0
Chicory	Commander	9.1	19.1	14.1	11.9	17.6	11.2	13.6
Plantain	Tonic	11.1	18.1	14.6	8.7	19.6	14.5	14.2
Phalaris	Holdfast	8.1	29.3	18.7	9.8	24.5	17.6	17.3
Lucerne	Sardi Grazer	15.1	28.8	22.0	15.9	25.1	19.5	20.2
	s.e.d. × 2	*2.0*		*1.5*		*2.0*		*1.0*

Table 4.11. Neutral detergent fibre (% DM) at the Bombala core non-legume site.

Species	Cultivar	Season 2019-20			Season 2020-21			
		Dec	Mar	Mean	Dec	Feb	Apr	Mean
Tall fescue	Quantum II MaxP	59.5	44.2	51.8	60.9	40.6	37.9	46.4
Tall fescue	Hummer MaxP	60.9	44.3	52.6	61.9	42.1	42.3	48.8
Tall fescue	Finesse Q	57.6	42.0	49.8	62.6	38.8	35.7	45.7
Cocksfoot	Savvy	56.6	46.0	51.3	63.2	44.7	45.9	51.2
Cocksfoot	Porto	54.4	43.9	49.2	60.7	42.1	47.1	50.0
Per. ryegrass	Base AR37	52.7	41.0	46.8	56.6	41.0	41.2	46.3
Per. ryegrass	Excess AR37	54.7	40.7	47.7	59.2	39.4	41.7	46.7
Per. ryegrass	Kidman	59.3	41.5	50.4	61.0	39.2	44.2	48.1
Prairie grass	Atom	67.5	45.0	56.3	62.4	41.8	45.4	49.9
Grazing brome	Gala	69.3	46.5	57.9	67.9	45.7	41.5	51.7
Pasture brome	Bareno	61.9	46.0	53.9	62.8	46.0	43.2	50.7
Coloured brome	Exceltas	65.4	48.5	57.0	63.3	44.1	39.6	49.0
Mountain rye	Family 10	56.3	48.7	52.5	55.5	46.7	38.6	46.9
Per. veldt grass	Mission	57.8	43.9	50.9	60.3	44.1	39.3	47.2
Digit grass	Premier							
Chicory	Puna	43.3	39.1	41.2	36.6	34.8	28.4	33.3
Chicory	Commander	45.9	39.1	42.5	34.1	35.8	36.6	35.5
Plantain	Tonic	50.7	28.8	39.7	48.4	36.4	28.4	37.7
Phalaris	Holdfast	56.2	38.0	47.1	60.9	38.0	42.4	47.1
Lucerne	Sardi Grazer	40.0	24.5	32.3	38.1	29.7	33.3	33.7
	s.e.d. × 2	*3.1*		*2.4*		*4.0*		*2.3*

Fig. 4.7. Mean of all sampling dates for *(a)* metabolisable energy (ME), *(b)* crude protein and *(c)* neutral detergent fibre (NF) at Goulburn and Bombala core non-legume sites. Symbols indicate ● chicory, ○perennial ryegrass, ■tall fescue, □plantain, ▲lucerne, △perennial veldt grass, ◆ phalaris, ◇ cocksfoot, ⬟ prairie grass, ⬠ pasture brome, ✚ coloured brome, ✚ grazing brome. Bars = average s.e.d. × 2.



4.2 Core site trials - Legumes

4.2.1 Seedling density

Seedling densities were considerably higher at Bombala than at Goulburn (Table 4.12). In part this reflected the excellent germination conditions at Bombala, but seedling counts in some species at Bombala may also have been inflated by carryover of one of the smaller-seeded clover species in the seed drill. Establishment frequency counts when seedings were larger and more identifiable are therefore a better indication of species establishment at Bombala. At Goulburn, strawberry clover and to a lesser extent white clover and talish clover were low.

Table 4.12. Sowing rate and seedling density in the Goulburn and Bombala core site legume experiments.

Species	Cultivar	Sowing rate (kg/ha)	Seedling density (plants/m^2)	
			Goulburn	Bombala
White clover	Haifa	2	36	59
	Nomad	2	43	156
	Trophy	2	36	93
Red clover	Astred	5	104	126
	Rubitas	5	93	156
Talish clover	Permatas	4	44	79
Caucasian clover	Kuratas	6	64	106
Caucasian × white clover	Aberlasting	2	62	125
Strawberry clover	Palestine	4	18	97
Lucerne	Sardi Grazer	8	93	100
	Titan 9	8	91	188
Subterranean clover	Leura	10	52	72
Lsd (P=0.05)			*22*	*43*

4.2.2 Frequency

Red clover and lucerne established at highest frequencies at both sites (Fig. 4.8). Following from their low seedling densities, initial frequency was low for strawberry clover, white clover and talish clover at Goulburn. Initial frequencies were higher for all species at Bombala than at Goulburn with only Haifa white clover being <60 % in frequency at Bombala.

White clover, talish clover, caucasian × white clover and strawberry clover increased considerably in the second year at Goulburn through stoloniferous spread (Fig. 4.8a). The shortly stoloniferous red clover cultivars and non-stoloniferous caucasian clover spread less. Leura subterranean clover did not set seed in the first year after re-sowing in September and was reseeded by hand in autumn of the second year.

Frequency of live plant base of white clover, caucasian x white clover, red clover and subterranean clover was very low (<10 %) at Goulburn 2.5 weeks after the 2019-20 drought period ended (Feb-20 in Fig. 4.8a). In contrast, frequency of lucerne and caucasian clover was unaffected by the drought period and talish clover and strawberry clover declined much less. Presence of live plants in stoloniferous species, and the seedbank in subterranean clover, were evidently sufficient for regeneration since all species had recovered by spring 2020 at Goulburn under high rainfall (Fig. 4.8a). Weakly stoloniferous red clover recovered the least to remain at low frequency (<40 %; Fig. 4.8a). Some species, e.g. white clover, declined in frequency over the final summer 2020-21. The reason is unknown but may be linked to only 61 mm of rain falling between 25 Nov 2020 to 29 Jan 2021. There was only one hot period just prior to the late January rainfall but possibly this was sufficient to affect white clover. Swards became invaded by the warm-season grass *Eleusine tristachya* (goosegrass) in the final summer and competition from this may also have affected legume growth. The small decline in frequency of lucerne in the final year at Goulburn appeared to be due to waterlogging during 2020 weakening plants with some wilting symptoms observed indicative of crown or root rot. Subterranean clover remained high in frequency after the drought.

Similar to Goulburn, caucasian clover, talish clover, strawberry clover and lucerne persisted well during the drought period from spring 2019 to winter 2020 at Bombala (Fig. 4.8b). White clover, red clover and caucasian × white clover had declined considerably in frequency when measured in May 2020. Leura subterranean again failed to set seed due 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 frequency levels in May 2021. Red clover recovered the least with its limited capacity for stoloniferous spread but unlike at Goulburn remained at reasonably high frequency post-drought (50-60 %, Fig. 4.8b).

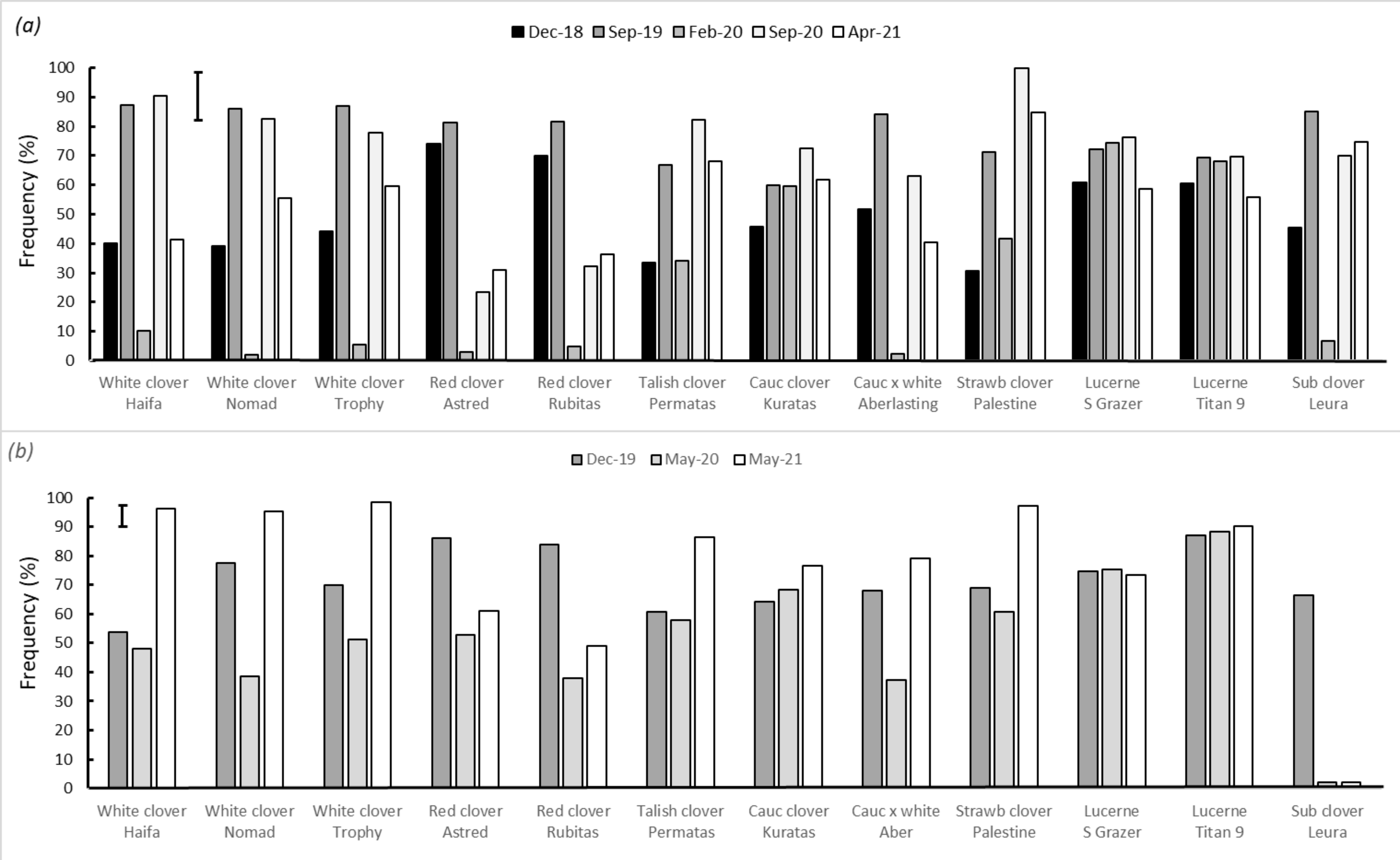


Figure 4.8. Predicted frequency of live plant base in Goulburn and Bombala core site legume experiments. Bars = average s.e.d. x 2.

4.2.3 Herbage production

Lucerne was the most productive species during summer at each sampling time (Table 4.13) and in total at Goulburn (Fig. 4.9). This was particularly evident coming out of drought in late summer 2020. Only once, in January 2021, was another cultivar, Haifa white clover, not significantly less than (P<0.05) either lucerne cultivar (Table 4.13). White clover and red clover were more productive in the first summer than the slowly establishing talish and caucasian clovers and also strawberry clover which had low establishment density (8/03/20, Table 4.13). However, talish, caucasian and strawberry clovers were more productive than all other clovers in the second summer immediately after the drought period (10/03/20, Table 4.13). White clover was higher-yielding and talish and caucasian clovers lower-yielding in the first half of the third summer. Differences among clovers were relatively small in the second half of this summer (Table 4.13).

Lucerne continued to be the most productive species post-drought in autumn 2020 at Goulburn followed by strawberry clover and then by caucasian and talish clovers and Haifa white clover (21/04/20, Table 4.13). However, lucerne was no more productive than any of the clover species in autumn 2021 and was itself exceeded in herbage DM by strawberry clover in April 2021 (23/04/20, Table 4.13). This followed high rainfall in March (222 mm) which resulted in wet soils and possible waterlogging. Lucerne and strawberry clover had the highest total autumn production during the experiment (Fig. 4.9).

Lucerne, white clover and red clover were the most productive species in winter of year 2 (2019) and caucasian and talish clover were the least productive (Table 4.13). Strawberry clover followed by Haifa white clover and then subterranean clover were the most productive cultivars in the wet winter of year 3 (2020). Lucerne herbage DM was not high during this winter because of waterlogging. Caucasian and caucasian × white clovers were the least productive species (Table 4.13). Total winter production over the whole experiment was highest for Haifa white clover, Trophy white clover and Palestine strawberry clover, and lowest for caucasian clover (Fig. 4.9).

Total spring production for the experiment was highest for Haifa white clover, strawberry clover and lucerne at around 7500 kg/ha with the remaining species around 5500 kg/ha except for caucasian × white clover 4400 kg/ha (Fig. 4.9). Haifa white was the most productive cultivar in spring 2019 and the second half of spring 2020 (Fig. 4.13). Strawberry clover was particularly productive in the first half of spring 2020 during the wet winter-early spring period, with talish clover and subterranean clover also high in herbage DM (20/10/20, Table 4.13). White clover and lucerne were the most productive species in the second half of spring 2020.

Leura subterranean clover failed to set seed under drought conditions in the first year at Bombala and was absent for the rest of the experiment. Like Goulburn, lucerne far outyielded the clover species during both summers at Bombala (Table 4.14, Fig. 4.10). Herbage DM of clover species was very low under drought in the first summer and low again in the second summer again under low rainfall (Table 4.14). Among the clover species, herbage DM in the second summer was highest for Astred red clover followed by strawberry clover and was lowest (ignoring subterranean clover) for caucasian × white clover (Table 4.14). Total yield over two summer seasons was highest among the clover species for Astred red clover, strawberry clover, talish clover and Trophy white clover (Fig. 4.10). Aberlasting caucasian × white clover gave the lowest yield but was not significantly less than Nomad white clover, caucasian clover and Rubitas red clover.

Herbage DM was also very low in the first autumn under drought with lucerne again the highest-yielding species (**Table 4.14**). Under contrasting conditions in the moist second autumn, most of the clover species had higher herbage DM yields than lucerne with highest levels observed in red clover and white clover and high levels also observed in strawberry and talish clovers. Kuratas caucasian clover yielded only about 50 % of the most productive clover cultivars. Large edge effects where plots adjoined clear buffer strips were observed in lucerne plots in the second autumn suggesting that soil moisture had been exhausted within the plots during the summer. Total DM yield over two autumn seasons was highest for red clover and Haifa and Trophy white clover and was lowest for caucasian clover and caucasian × white clover (**Fig. 4.10**).

Observations on winter and spring herbage DM were taken in one year only at Bombala (**Table 4.14**). Herbage DM in winter 2020 was restricted to late winter-early spring after drought-breaking rain in mid-July. Herbage DM of lucerne was double that of the highest-yielding clover species which were white clover (Haifa, Trophy), red clover, strawberry clover and talish clover (**Table 4.14**). Under good growth conditions in spring 2020, talish clover was the most productive species followed by red clover and Titan 9 lucerne (**Table 4.14**). Caucasian × white clover was clearly the least productive species (ignoring subterranean clover) while white clover, caucasian clover and strawberry clover were all productive and not significantly lower ($P<0.05$) in herbage DM than red clover (**Table 4.14**).

Total production over all seasons for each site were higher correlated ($P<0.01$, Fig. 4.11) with lucerne the highest in DM and caucasian × white clover, caucasian clover and Nomad white clover the lowest. The higher ranking of red clover and talish cover at Bombala compared with Goulburn in total herbage DM production is evident in **Fig. 4.11**.

Table 4.13. Predicted seasonal herbage DM production (kg/ha) in the Goulburn core site legume experiment.

Species	Cultivar	Summer				Autumn		Winter		Spring		
		2018/19	2019/20	2020/21		2020	2021	2019	2020	2019	2020	
		8/03/19	10/03/20	12/01/21	22/02/21	21/04/20	23/04/21	3/09/19	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
White clover	Nomad	639	-73	642	282	174	587	1512	1200	1409	1308	2624
White clover	Trophy	835	-11	848	361	329	819	2116	1532	1745	1426	2886
Red clover	Astred	756	151	733	407	316	612	1736	1098	2057	1388	2301
Red clover	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
Cauc x white clover	Aberlasting	555	-11	530	322	73	582	1200	885	1151	1226	2003
Strawberry clover	Palestine	325	653	665	580	1640	1013	1197	2504	1447	3498	2760
Lucerne	Sardi Grazer	1271	2318	1020	1281	1983	607	2025	1109	1925	2156	3028
Lucerne	Titan 9	1515	2905	1166	1189	2401	706	2356	1018	2166	2203	3141
Subterranean clover	Leura	-126	-62	223	478	229	1075	258	1706	228	2910	2136
	av.sed x 2	*178*	*302*	*136*	*198*	*289*	*216*	*359*	*441*	*418*	*494*	*425*

Fig. 4.9. Predicted total herbage production over 3 years for summer and 2 years for autumn, winter and spring in the Goulburn core site legume experiment. Bars = average s.e.d. × 2.

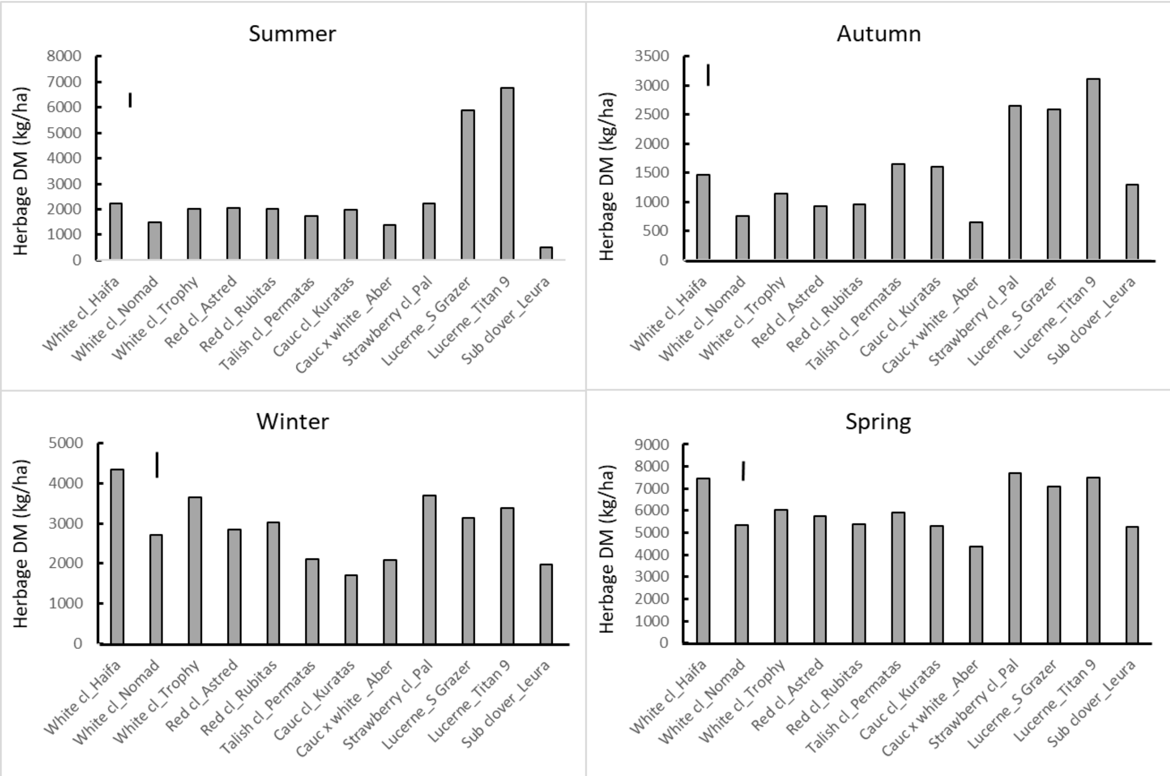


Table 4.14. Predicted total herbage DM production (kg/ha) in the Bombala core site legume experiment.

Species	Cultivar	Summer		Autumn		Winter	Spring
		2019/20	2020/21	2020	2021	2020	2020
		12/03/20	9/02/21	20/05/20	19/04/21	2/10/20	2/12/20
White clover	Haifa	202	768	333	3352	1201	3040
White clover	Nomad	115	536	237	2437	837	2926
White clover	Trophy	250	744	328	3249	1215	3033
Red clover	Astred	210	987	360	3442	1292	3627
Red clover	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
Cauc x white clover	Aberlasting	85	488	200	1987	698	2290
Strawberry clover	Palestine	274	834	341	2765	1271	3105
Lucerne	Sardi Grazer	966	1245	557	1973	2395	3106
Lucerne	Titan 9	1069	1444	630	2167	2695	3467
Subterranean clover	Leura	4	4	24	26	77	194
	av.s.e.d. × 2	*76*	*163*	*54*	*356*	*209*	*593*

Fig 4.10. Predicted total summer and autumn herbage DM production (kg/ha) over two years in the Bombala core site legume experiment. Bars = average s.e.d. × 2.

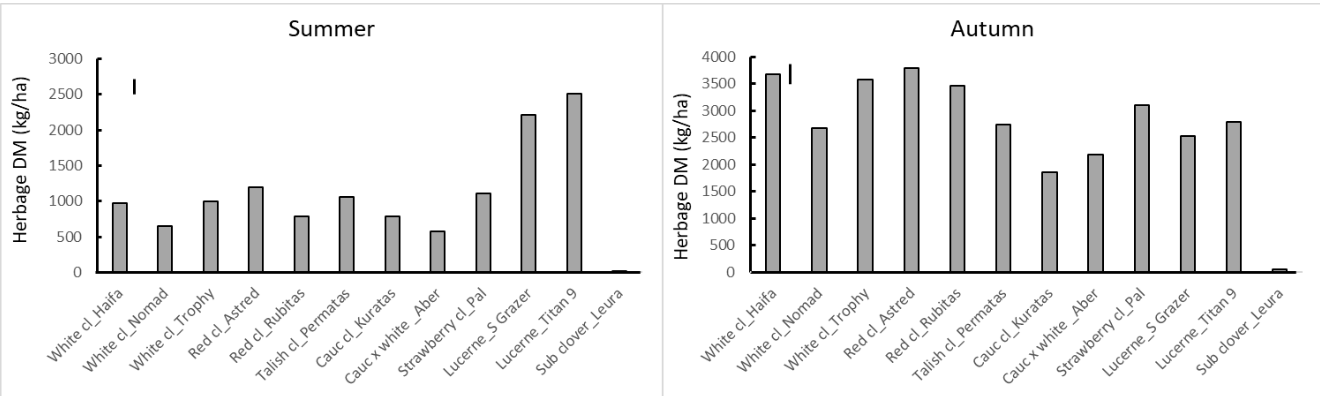
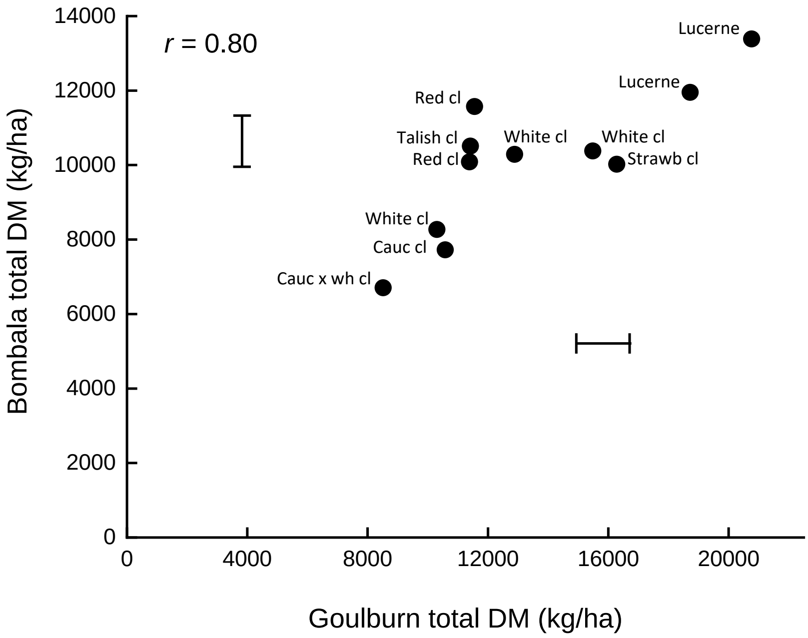


Fig 4.11. Predicted total herbage DM production (kg/ha) for the Goulburn and Bombala core site legume experiments. Bars = average s.e.d. × 2.

Subterranean clover is excluded because it did not establish at Bombala.



4.2.4 Nutritive quality

Metabolisable energy (ME), crude protein and neutral detergent fibre (NDF) content of herbage from the Goulburn legume experiment are shown in Tables 4.15, 4.16 and 4.17, respectively, and from the Bombala legume experiment in Tables 4.18, 4.19 and 4.20, respectively. Effects of cultivar and sampling date × cultivar interaction were highly significant (P<0.001) at both sites for all traits in each summer-autumn season except for the sampling date × cultivar interaction for crude protein at Goulburn in the 2019-20 season, which was not significant at P≤0.05. F value for the cultivar effect was usually at least twice that of the interaction. One exception was for NDF at Goulburn in 2019-20 where the interaction exceeded the cultivar main effect.

ME levels were high in all species at Goulburn in March and April 2020 following drought-breaking rainfall in early February (Table 4.15). Highest levels ≥11 MJ/kg were recorded in white clover, talish clover, caucasian clover, caucasian × white clover and strawberry clover. Red clover was 0.4-0.6 MJ/kg lower in ME than these species and lucerne was around 1 MJ/kg lower associated with higher stem and NDF content (Table 4.15). Conditions at Bombala were much drier than those at Goulburn in March 2020 and ME levels were slightly lower (Table 4.18). In contrast to Goulburn, red clover and lucerne were as high as or higher than other species probably due to less floral (red clover) and stem (lucerne) development under the drier conditions. ME content was markedly lower at two dates in the 2020-21 season, early December at Bombala (Table 4.18) and mid-January at Goulburn (Table 4.15). Both were associated with a high degree of flowering in the clovers 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 one 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 4.15). Conversely, lower ME levels for red clover and strawberry clover in February 2021 at Bombala were associated with more floral development than in other species. ME content 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 around 10.5 MJ/kg (Tables 4.15, 4.18). Levels were consistently high in white clover but were around 0.5-0.8 MJ/kg lower in red clover than in the other species.

Crude protein was around or in excess of 20 % of DM for all species and sampling dates except for mid-January 2021 at Goulburn (Table 4.16) and early December 2020 at Bombala (Table 4.19) when floral development was high and ME content lower. Lucerne often had the highest crude protein content at individual sampling dates and was highest (P<0.05) on average (25 % vs. 21 % for the mean of all clovers at Goulburn and 24 % vs. 20 % for mean of all clovers at Bombala). There was a consistent tendency for red clover and caucasian × white clover to be slightly lower in crude protein content at Goulburn (Table 4.16) but this was less evident at Bombala (Table 4.19).

NDF of legumes was mostly in the range 30-35 % of DM at both sites except for two times, January 2021 at Goulburn and December 2020 at Bombala, when levels were in the range 35-40 % DM associated with high levels of flowering in clovers as noted previously. Levels were lowest on average in April in all site-seasons with values for some species <30 % DM. At Goulburn, red clover, talish clover, strawberry clover and lucerne were higher on average in NDF content than white clover, caucasian clover and caucasian × white clover (Table 4.17). At Bombala, strawberry clover, red clover and talish clover also tended to be higher and caucasian clover lower in NDF, but lucerne was the lowest in contrast to Goulburn (Table 4.20). However, differences between species at either site were not large compared to variation observed in the non-legume experiment.

Table 4.15. Metabolisable energy (MJ/kg) at the Goulburn core site legume experiment.

Species	Cultivar	Season 2019-20			Season 2020-21				
		Mar	Apr	Mean	Nov	Jan	Feb	Apr	Mean
White clover	Haifa	11.0	11.1	11.1	10.1	9.2	10.9	10.9	10.2
White clover	Nomad	11.5	11.3	11.4	10.1	9.0	10.9	10.7	10.2
White clover	Trophy	11.0	11.1	11.4	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
Red clover	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 x 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
Lucerne	Sardi Grazer	9.7	10.5	10.1	10.2	9.9	10.7	10.8	10.2
Lucerne	Titan 9	9.8	9.9	9.8	10.4	10.1	10.5	10.5	10.4
Subterranean clover	Leura				10.6		11.0	10.7	
	s.e.d. x 2	*0.23*		*0.19*			*0.3*		*0.2*

Table 4.16. Crude protein (% DM) at the Goulburn core site legume experiment.

Species	Cultivar	Season 2019-20			Season 2020-21				
		Mar	Apr	Mean	Nov	Jan	Feb	Apr	Mean
White clover	Haifa	23.7	22.1	22.9	21.2	16.9	21.7	22.6	20.6
White clover	Nomad	24.2	23.4	23.8	22.0	16.3	22.1	21.7	20.5
White clover	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
Red clover	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 x 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
Lucerne	Sardi Grazer	26.5	30.1	28.3	23.0	21.5	22.9	25.5	23.2
Lucerne	Titan 9	26.4	24.5	25.5	23.8	21.9	23.4	25.4	23.6
Subterranean clover	Leura				21.2		21.0	21.9	
	s.e.d. x 2	*2.8*		*1.9*		*1.6*			*0.9*

Table 4.17. Neutral detergent fibre (% DM) at the Goulburn core site legume experiment.

Species	Cultivar	Season 2019-20			Season 2020-21				
		Mar	**Apr**	**Mean**	**Nov**	**Jan**	**Feb**	**Apr**	**Mean**
White clover	Haifa	32.7	29.5	31.1	33.9	40.0	32.1	27.8	33.5
White clover	Nomad	25.5	29.1	27.3	34.0	40.3	31.8	28.9	33.8
White clover	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
Red clover	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 x 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
Lucerne	Sardi Grazer	39.6	30.8	35.2	35.9	36.5	35.1	30.5	34.5
Lucerne	Titan 9	38.3	35.6	37.0	35.5	35.6	34.4	29.8	33.6
Subterranean clover	Leura				32.3		32.5	29.9	
	s.e.d. x 2	*4.4*		*3.8*		*2.4*			*1.3*

Table 4.18. Metabolisable energy (MJ/kg) at the Bombala core site legume experiment.

Species	Cultivar	Season 2019-20	Season 2020-21			
		Mar	**Dec**	**Feb**	**Apr**	**Mean**
White clover	Haifa	10.8	8.7	10.2	10.6	9.8
White clover	Nomad	10.1	8.9	10.1	10.4	9.8
White clover	Trophy	10.6	8.9	10.1	10.7	9.9
Red clover	Astred	10.9	9.1	9.5	9.9	9.5
Red clover	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 x 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
Lucerne	Sardi Grazer	10.9	9.4	11.0	10.4	10.3
Lucerne	Titan 9	10.6	9.4	10.9	10.4	10.3
Subterranean clover	Leura					
	s.e.d. x 2	*0.4*		*0.4*		*0.2*

Table 4.19. Crude protein (% DM) at the Bombala core site legume experiment.

Species	Cultivar	Season 2019-20	Season 2020-21			
		Mar	Dec	Feb	Apr	Mean
White clover	Haifa	20.6	14.9	19.8	19.7	18.2
White clover	Nomad	21.4	15.5	21.7	20.3	19.2
White clover	Trophy	20.1	15.5	20.8	19.1	18.5
Red clover	Astred	20.4	15.0	19.3	18.7	17.6
Red clover	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 x 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
Lucerne	Sardi Grazer	28.0	17.9	22.8	21.3	20.7
Lucerne	Titan 9	26.3	17.9	23.3	21.9	21.0
Subterranean clover	Leura					
	s.e.d. x 2	*2.6*		*1.7*		*1.0*

Table 4.20. Neutral detergent fibre (% DM) at the Bombala core site legume experiment.

Species	Cultivar	Season 2019-20	Season 2020-21			
		Mar	Dec	Feb	Apr	Mean
White clover	Haifa	30.6	41.2	32.6	27.2	33.7
White clover	Nomad	35.5	39.3	33.3	29.2	33.9
White clover	Trophy	32.1	38.8	32.4	26.8	32.7
Red clover	Astred	36.3	35.9	34.4	31.7	34.0
Red clover	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 x 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
Lucerne	Titan 9	26.9	35.9	28.3	29.5	31.2
Subterranean clover	Leura					
	s.e.d. x 2	*2.7*		*2.4*		*1.3*

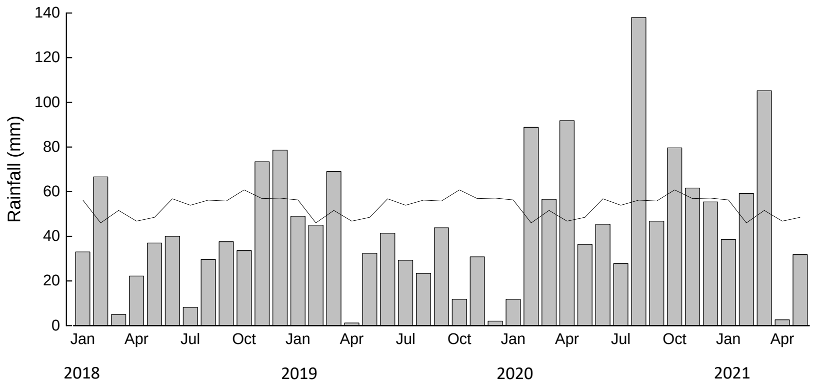
4.3 Supplementary site trials – Gunning mixtures experiment

4.3.1 Rainfall

Rainfall was well below average in the 5 months after establishment but was above average in the first summer period from November 2018 to March 2019 (Fig. 4.12). Increasingly severe drought developed during the second year (2019) which ended on 9th February 2020. Rainfall was generally average to well-above average after that to the end of the experiment (Fig. 4.12).

Fig. 4.12. Actual (bars) and long-term monthly (line) rainfall at Gunning

Source: Bureau of Meteorology



4.3.2 Establishment and persistence

Density of non-legume species at establishment was satisfactory with a mean of 136 plants/m^2. There was no effect of companion legume on non-legume seedling density (companion legume effect, *P*>0.05; Table 4.21). For legume species, seedling densities were higher (*P*<0.05) for lucerne than for subterranean clover, reflecting higher numbers of sown seed for lucerne, but all legume species were considered satisfactory with a mean density of 104 plants/m^2 (Table 4.21). Legume seedling density was higher with tall fescue than with phalaris and chicory.

Seedling density of sown plus other legume species were low in April of the second year, reflecting low seed production the previous spring (Table 4.21). Volunteer legume species consisting mostly of subterranean clover in white clover and lucerne plots, and white clover in subterranean clover plots indicated an existing seedbank. Seedling density was highest on average for subterranean clover and was much lower with companion non-legume species than without.

Seedlings of subterranean clover and white clover were observed after the break of season in the third and fourth years but no lucerne seedlings (Table 4.21). Seedling density of volunteer species increased further in the third year over the previous year. On average, densities were lower in phalaris plots in the third year than in plots of tall fescue and chicory, both of which were at low density after the drought, and in legume only plots. Subterranean clover was clearly the densest species by the fourth year.

Table 4.21. Seedling density of sown species at establishment and of sown or sown + other species (in brackets) legumes after break of season in later years.

Only main effects are shown because sown × companion species interaction terms were not significant at *P*<0.05.

Sown species	Companion species	Seedling density (/m2)			
	Date:	3-Sep-18	9-Apr-19	26-Feb-20	19-Feb-21
Phalaris		127			
Tall fescue		154			
Chicory		127			
l.s.d. (P=0.05)		*ns*			
Subterranean clover		89	(123)	208 (323)	528
White clover		109	(28)	206 (253)	90
Lucerne		114	(38)	0 (175)	0
l.s.d. (P=0.05)		*21*	*(51)*	*71 (87)*	*66*
	Nil	111	(116)	194 (278)	291
	Phalaris	90	(48)	79 (141)	317
	Tall fescue	123	(43)	143 (262)	272
	Chicory	92	(44)	135 (321)	351
l.s.d. (P=0.05)		*24*	*(59)*	*ns (101)*	*ns*

Effect of years, species and the year × species interaction were highly significant (*P*<0.001) for frequency of non-legume species but effects due to companion legume and their interactions were not significant (P>0.05). Therefore, only main effects are shown in Fig. 4.13. For frequency of sown legume species, effects of year, species, companion species and their interactions were all significant at *P*<0.001.

The perennial grasses had higher frequency than chicory in the establishment year. Phalaris was persistent for the duration of the experiment but tall fescue and chicory both declined severely in frequency during the 2019-20 spring-summer drought period (Fig. 4.13). For tall fescue this appeared to be due to death of plants because of drought. Loss of chicory plants was caused by damage from rabbits and kangaroos chewing the crowns below the soil surface in late January when chicory was the only green herbage available.

Main effects for legume species showed that frequency remained high and increased for subterranean clover whether sown or from the existing seedbank. White clover declined in the drier years but partly recovered under higher rainfall in 2020. Lucerne frequency declined in year 2 and had virtually disappeared by year 3 (Fig. 4.13). During the dry second year, frequency of both clover species was lower when grown with a companion non-legume species than when grown alone (Table 4.22). This effect of companion species was also observed in the fourth year for white clover but not for subterranean clover. In the third year, white clover frequency was lowest when grown with phalaris, which was present at high density, compared with growing with tall fescue and chicory (Table 4.22).

Fig. 4.13. Main effect for frequency of live base of sown species averaged over companion species in years 1 to 4 (2019-21) of Gunning mixtures experiment.

Bars = average s.e.d × 2 for non-legumes and legumes.

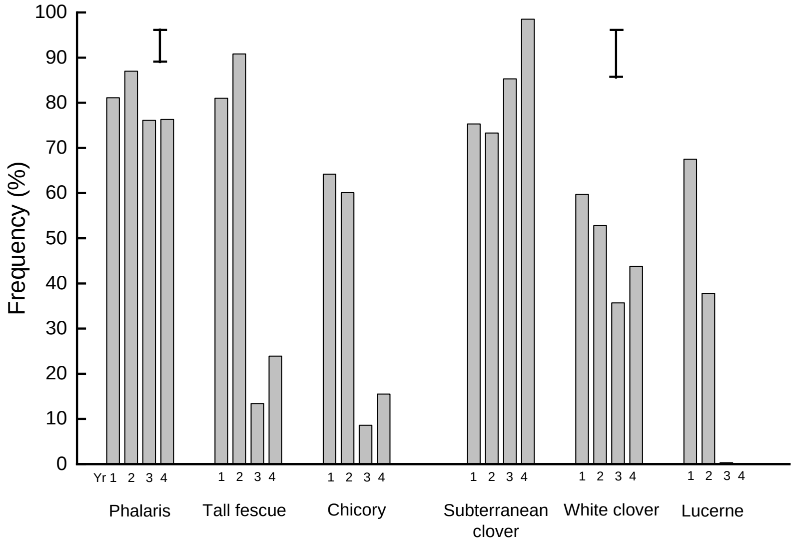


Table 4.22. Frequency of legume species grown with a companion non-legume species or grown alone (nil companion species) in the Gunning mixtures experiment (2018-2021).

Legume species	**Companion species**	**Frequency (%)**			
		2018	**2019**	**2020**	**2021**
Subterranean clover	Nil	77	89	80	99
	Phalaris	75	76	81	99
	Tall fescue	76	68	89	98
	Chicory	74	60	92	98
White clover	Nil	66	79	31	67
	Phalaris	67	37	20	47
	Tall fescue	56	48	51	20
	Chicory	50	48	41	41
Lucerne	Nil	77	42	0	0
	Phalaris	65	29	0	0
	Tall fescue	61	34	0	0
	Chicory	67	46	1	0
l.s.d. (P=0.05)			*21*		

4.3.3 Herbage mass of sown species

Effects of sampling date, species and their interaction on herbage biomass of non-legume species were highly significant (*P*<0.001) in each time period but there was no effect (*P*>0.05) of companion legume species. Herbage DM of tall fescue and phalaris were similar, and higher than chicory, in the first spring after sowing (Fig. 4.14). Tall fescue was more than twice as productive as phalaris and chicory during the first summer and autumn and remained the most productive of the three species in spring of the second year. Phalaris became clearly the most productive species in the autumn and winter after the 2019-20 spring-summer drought period ended, initially due to its better survival and then also to its higher winter activity. The very low winter activity of chicory was obvious in July 2020. Both tall fescue and chicory made a partial recovery by the final summer of the experiment and differences among species were smaller during summer as phalaris became partially dormant and the more summer-active species grew more vigorously. Chicory was equally as productive as phalaris in late spring 2020 despite its much lower density. Phalaris once again became the highest-yielding species under cooler conditions in autumn 2021.

Effects of sampling date, species, companion non-legume species and most of their interactions were significant (*P*<0.05) for biomass of legume species in all time periods. The main effect averaged over companion species shows the very low legume biomass from establishment onwards except for subterranean clover in the third and fourth years (Fig. 4.15). Lucerne grew very poorly from the start and virtually died out, presumably because of deep soil acidity. The attempt to increase legume content by oversowing bare patches in the second year was unsuccessful under drought conditions. Subterranean clover became highly productive once the drought ended. White clover was the only legume species with green growth in January of the final summer but yields were low.

There was a strong effect of companion non-legume on growth of legume species (Fig. 4.16). In the first time period from spring 2018 to autumn 2019, biomass was higher when legumes were grown alone except for lucerne in the first spring. This trend continued in spring of the second time period (spring 2019 to autumn 2020) when legume growth also tended to be higher with chicory than with the perennial grasses. Once drought conditions ended from May 2020, growth of clovers was markedly lower when grown in dense, competitive phalaris stands than when grown alone or with less competitive chicory stands. Tall fescue plots also had less legume growth in the final year. Relatively, these effects of the non-legume species were much more evident for white clover than for subterranean clover. Thus, in May of the fourth year (3 years after sowing), herbage DM of white clover was 1200 kg/ha when grown alone, 440 kg/ha when grown with chicory and only 50 kg/ha when grown with either perennial grass. Since the frequency of tall fescue was much lower than that of phalaris, low white clover content in the fourth year may have been due to a carryover effect from when the tall fescue was at high density in years 1 and 2.

Fig. 4.14. Herbage mass of sown non-legume species, phalaris (black), tall fescue (dark grey) and chicory (light grey) averaged over companion legume treatments in four growth periods.

Columns with the same latter in each growth period are not significantly at *P*≤0.05 on the square root transformed scale.

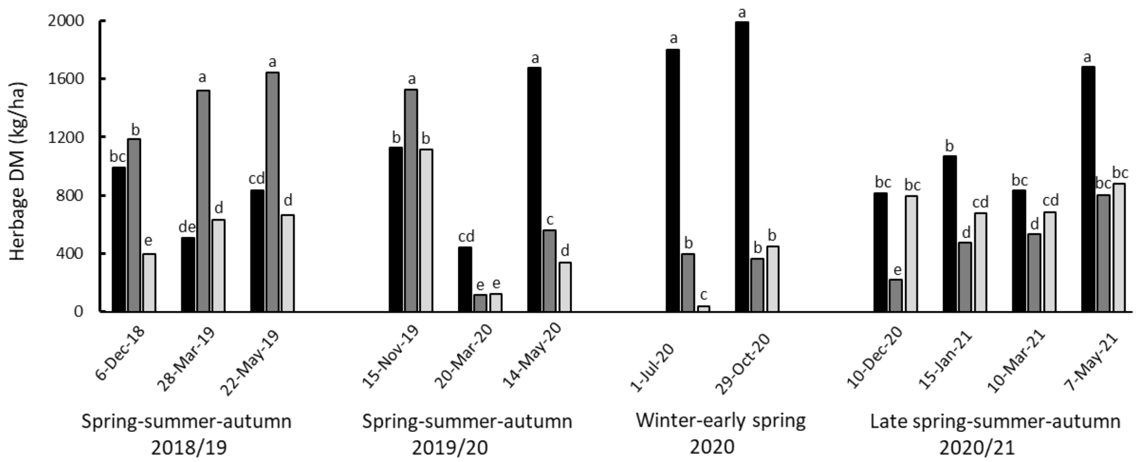


Fig. 4.15. Herbage mass of sown legume species, subterranean clover (black), white clover (dark grey) and lucerne (light grey) averaged over companion non-legume treatments in four growth periods.

Columns with the same latter in each growth period are not significantly at *P*≤0.05 on the square root transformed scale.

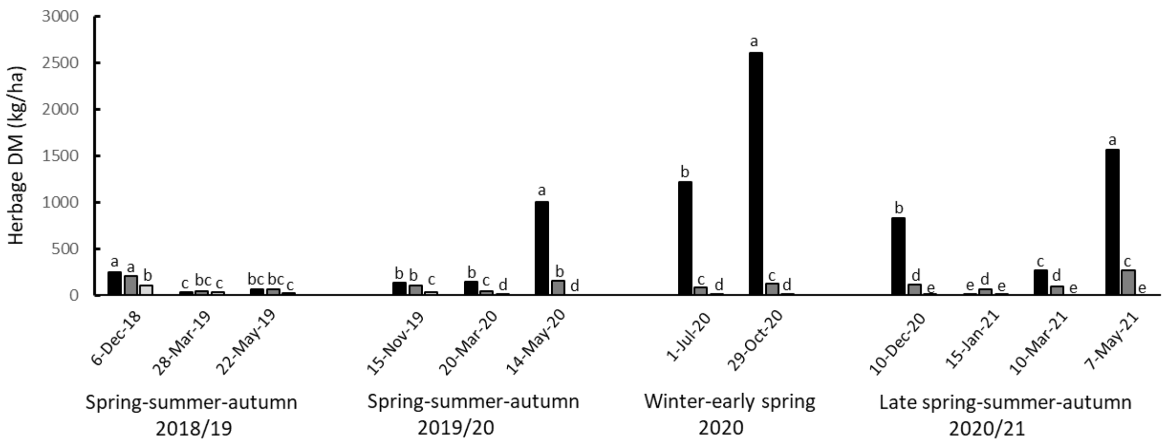
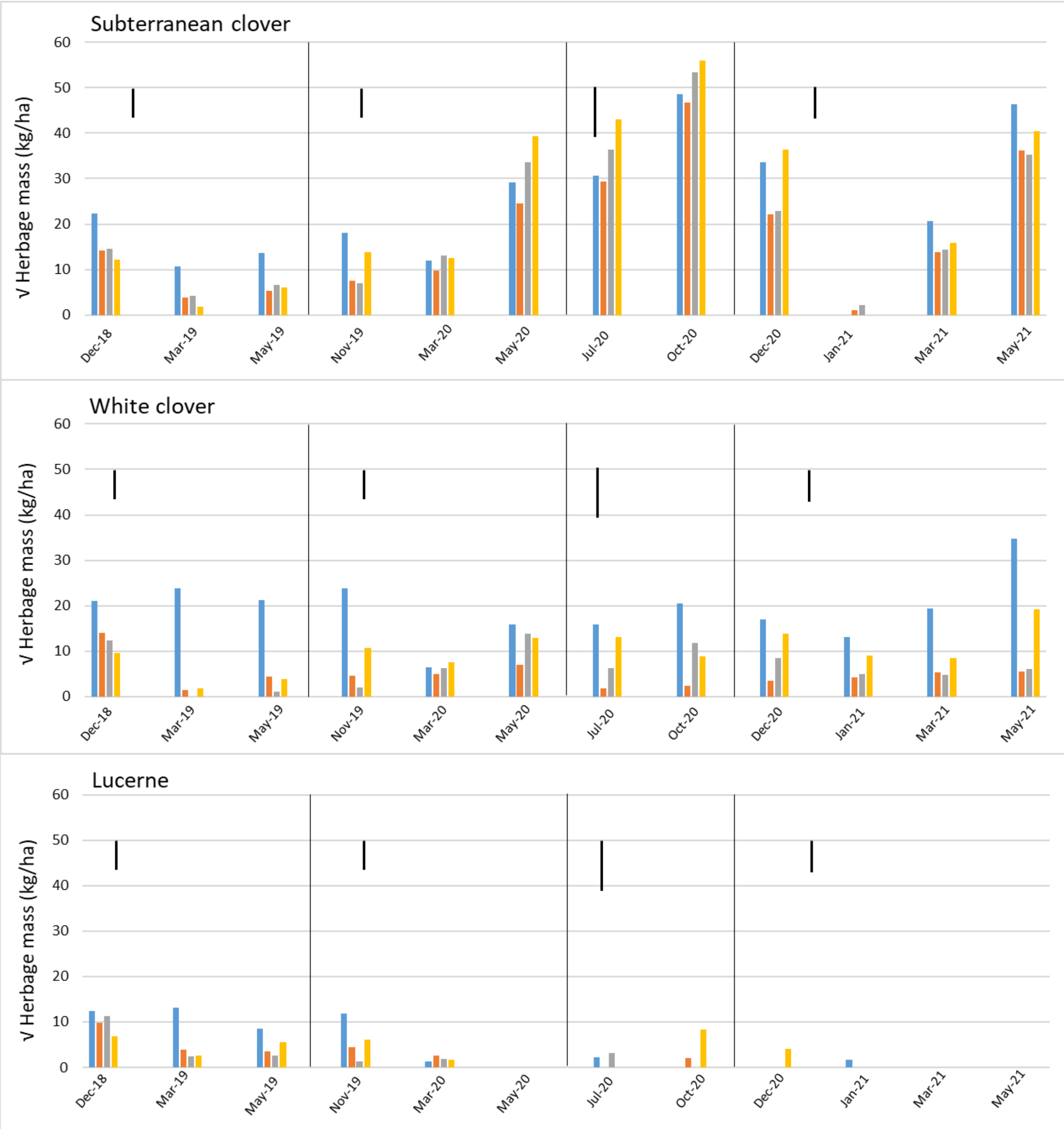


Fig. 4.16. Herbage mass square-root transformed for sown legume species sown alone (blue) or with companion phalaris (orange), tall fescue (grey) or chicory (yellow) at 12 dates in 4 times periods.

Bars = average s.e.d × 2 for each time period.

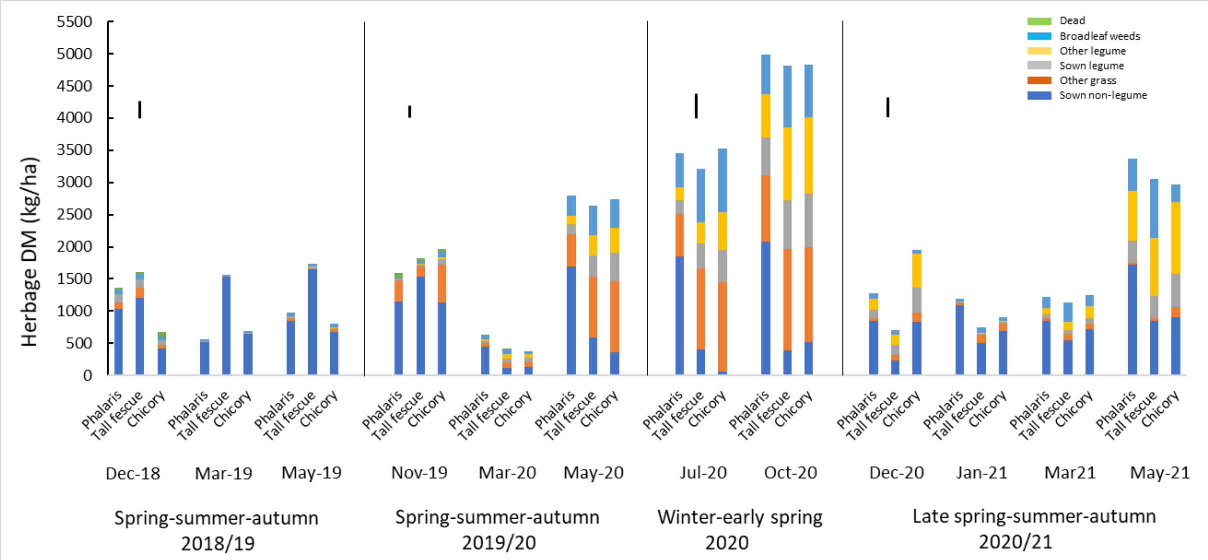


4.3.4 Sward herbage mass and composition

The effect of non-legume treatment and its interaction with sampling date on total sward DM were highly significant (P<0.001) in all spring-summer-autumn time periods but not in winter-early spring 2020. The influence of companion legume on total sward DM of non-legume treatments was small, with the legume treatment effect significant only in the final summer-autumn period (P<0.05) when total DM with nil legumes yielded higher possibly due to previous application of nitrogen to non-legume treatment grown alone.

Fig. 4.17. Total sward herbage DM and DM of sward components for non-legume treatments (phalaris, tall fescue, chicory) averaged over companion legume treatments.

Bars = average s.e.d. × 2 for total sward herbage DM.

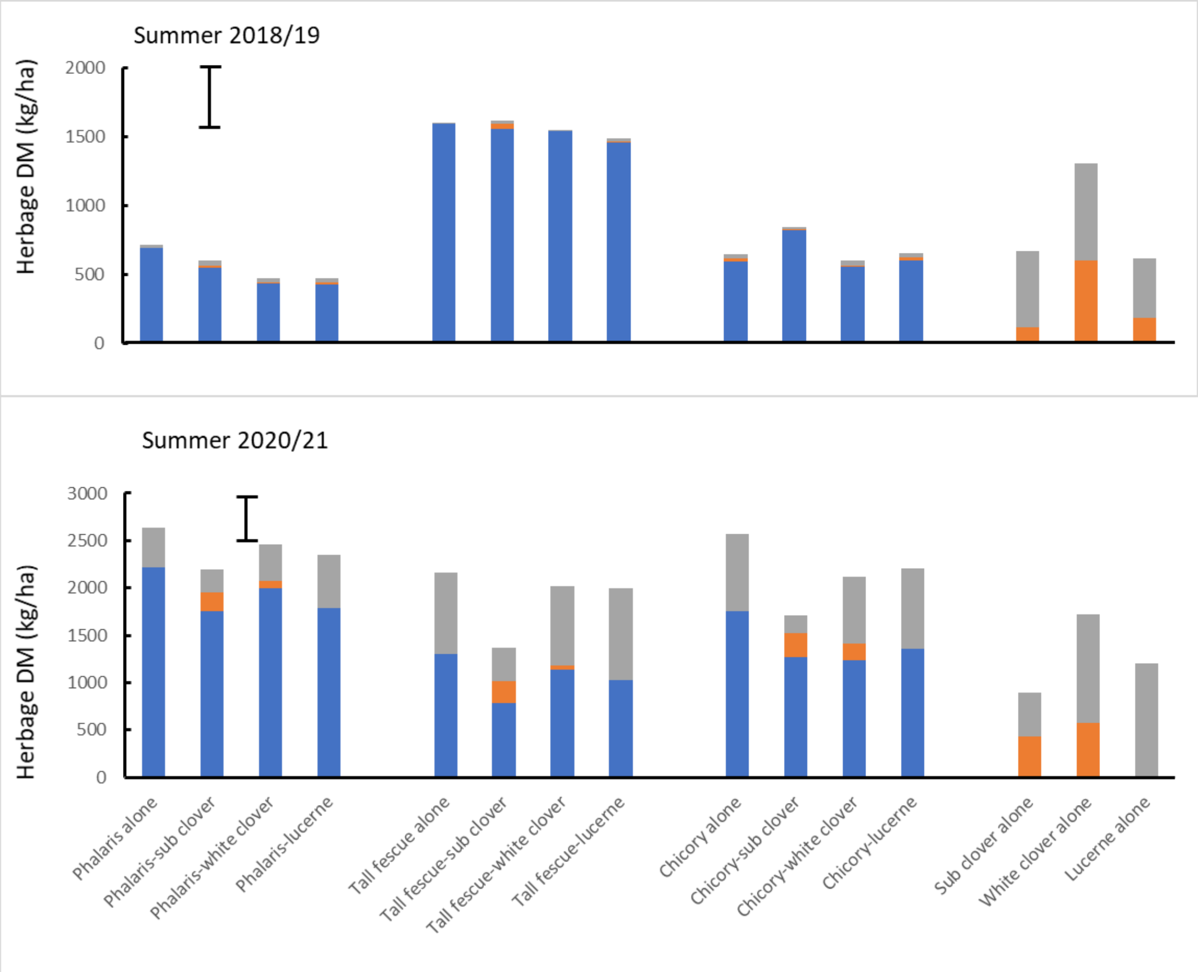


Total sward DM and its components averaged across companion legume treatments is shown in Fig. 4.17. Total DM was generally low (≤ 1-1.5 t/ha) in each summer (see Mar-19, Mar-20, Jan-21 in Fig. 4.17) and depended mainly on the yield of the non-legume component in the first summer and by the sown non-legume and sown and other legume components in the final summer. Despite the sown non-legume component of tall fescue and chicory treatments declining severely during drought, total sward yields in the following cool season (May-29, Jul-20, Oct-20) did not differ from that of phalaris -based swards due to the large contribution of annual grass (mainly ryegrass and soft brome), sown and volunteer (mainly subterranean clover) legume and broadleaf weed (mainly capeweed) components.

Since summer production was central to the aim of the experiment, total DM for the first and third summers are shown in Fig. 4.18, the third summer being the sum of DM on 15 Jan and 11 Mar 2021. The second summer is ignored because of very low yield (mean 456 kg/ha). While still dense in the first summer, tall fescue swards yielded approx. 1 t/ha more than phalaris and chicory swards. There was no effect of companion legume. Swards based solely on white clover yielded nearly as much as tall fescue swards, but half of this was due to broadleaf weeds. Sward yield in the third summer was only partly related to yield of the non-legume perennial, most mixtures not differing significantly (P<0.05) due to contributions from non-sown sward components. As expected of a cool-season annual clover, plots containing subterranean clover were lower yielding at his time.

Fig. 4.18. Total sward herbage DM and DM of sward components (sown non-legume, blue; sown legume, orange; other species, grey) for non-legume treatments (phalaris, tall fescue, chicory) averaged over companion legume treatments.

Bars = average s.e.d. × 2 for total sward herbage DM.



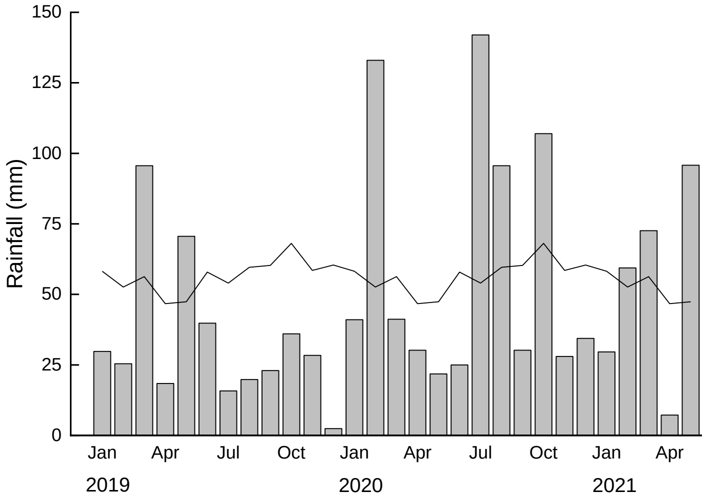
4.4 Supplementary site trials – Dry Plain evaluation experiment

4.4.1. Rainfall

Rainfall was favourable at sowing in March 2019 but was very much below average for the second half of 2019 during the 2019-20 drought (Fig. 4.19). Drought-breaking rainfall started on 18th January 2020. Rainfall after that was variable with high and low months but soil moisture was generally favourable until the end of the experiment.

Fig. 4.19. Actual (bars) and long-term monthly (line) rainfall for Dry Plain site

Source: Actual rainfall from Farming Forecaster for Muniong, 5.5 km SW of trial site. Mean rainfall for Adaminaby from Bureau of Meteorology.



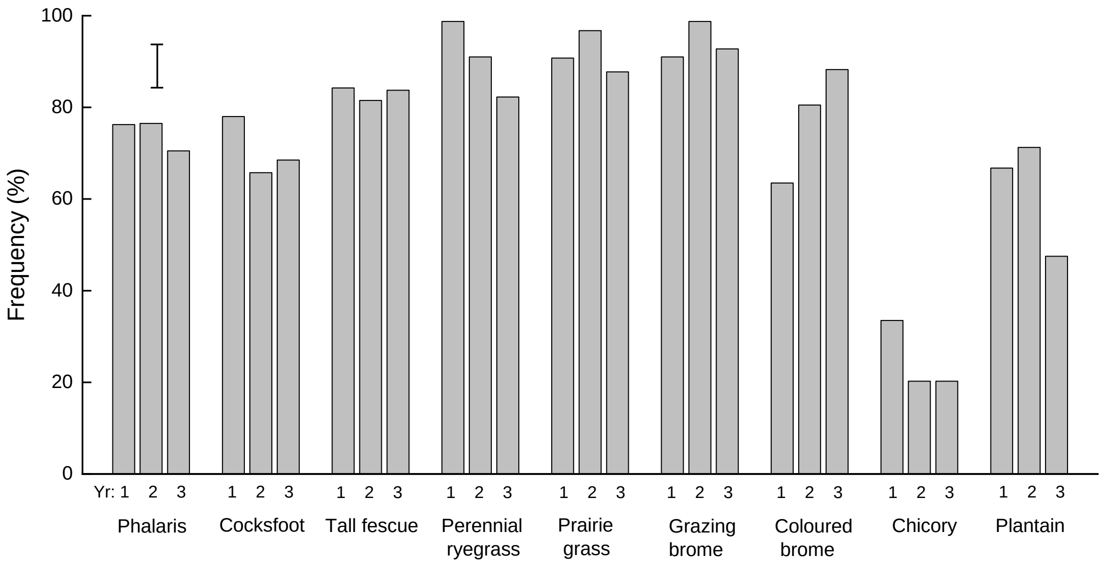
4.4.2 Establishment and persistence

Seedling density at establishment were: phalaris 78, cocksfoot 131, tall fescue 193, perennial ryegrass 306, prairie grass 132, grazing brome 134, coloured brome 44, chicory 55 and plantain 102 per m^2 (lsd = 34). Coloured brome was considered low and chicory fairly low. Perennial veldt grass did not establish and is not considered further.

All species established at reasonably high to high frequency except for chicory (Fig. 4.20). Despite drought in the first year, by the third year only perennial ryegrass, chicory and plantain declined significantly ($P<0.05$) relative to maximum levels. Damage from cattle grazing and weed control measures may have contributed to decline in year 3. Seedling recruitment as well as survival of existing plants contributed to persistence in all brome species.

Fig. 4.20. Frequency of live base in years 1 to 3 (2019-21) of Dry Plain experiment.

Bar = average s.e.d × 2.



4.4.3 Herbage mass of sown species

Plantain was very productive relative to all other species in the first summer (Table 4.23). It remained productive in autumn of year 2 (2020) when perennial ryegrass, prairie grass and tall fescue became the highest-yielding species. Prairie grass remained the most productive species during winter and spring of 2020 with grazing brome and tall fescue also high in winter-early spring (9-Oct-20, Table 4.23) and perennial ryegrass in late spring (16-Nov-20). Production by chicory was low through 2020 because of low establishment frequency and little growth in winter.

Perennial ryegrass was the most productive species in the first half of summer 2020/21 followed by cocksfoot and plantain (22-Jan-21, Table 4.23). Perennial ryegrass and cocksfoot were also highly productive in the second half of summer but were not significantly higher (P<0.05) in DM on 5-Mar-21 than tall fescue, plantain and prairie grass (Table 4.23).

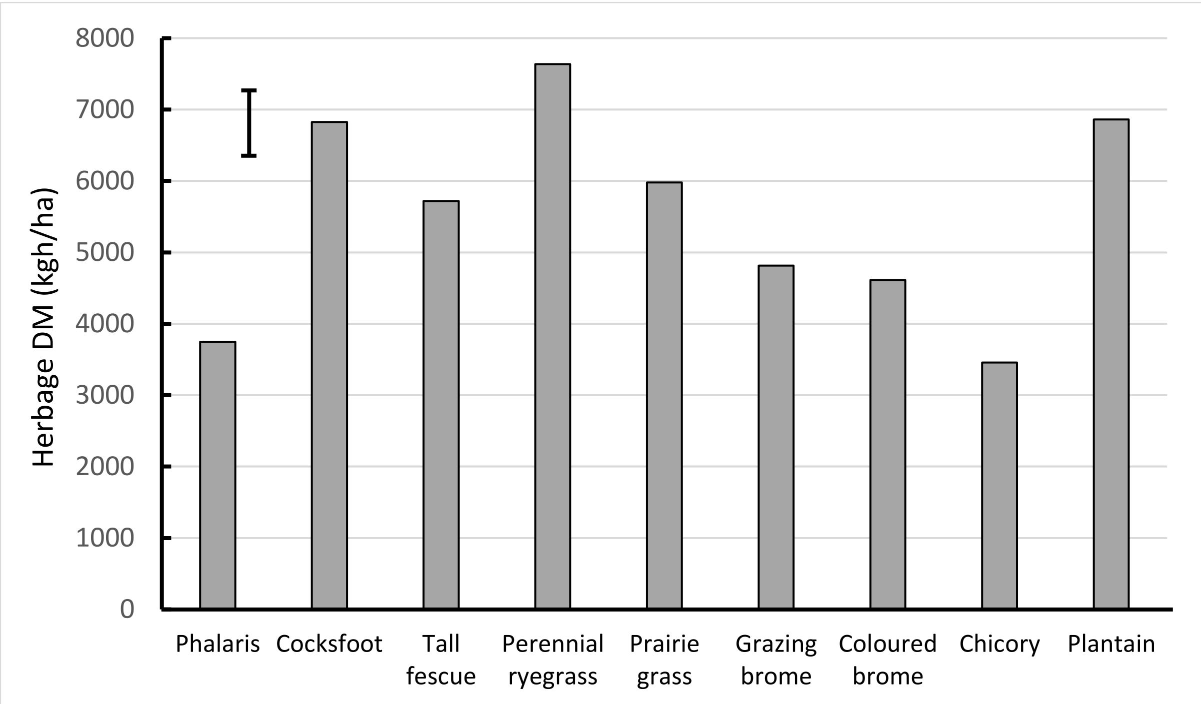
Total production over two summers was highest for perennial ryegrass, cocksfoot and plantain with prairie grass not significantly (P<0.05) less than cocksfoot or plantain (Fig. 4.21). Tall fescue was lower in total summer production than cocksfoot but higher than grazing and coloured bromes. Phalaris and chicory were the least productive species. With only 25-50 % of the frequency, chicory had 50-75 % of the total summer production of the more productive species indicating high production from the plants that were present.

Table 4.23. Seasonal herbage DM production in the Dry Plain species evaluation experiment

Means followed by the same letter are not significantly different (P<0.05).

Species	Herbage DM (kg/ha)					
	28/02/20	24/04/20	9/10/20	16/11/20	22/01/21	5/03/21
Phalaris	482 bc	1708 bc	1229 c	5078 b	1056 c	2211 c
Cocksfoot	582 b	1394 c	1735 c	4562 b	1897 ab	4345 a
Tall fescue	460 bc	2300 ab	3129 ab	4699 b	1575 bc	3684 ab
Perennial ryegrass	716 b	2928 a	2632 b	6924 a	2537 a	4382 a
Prairie grass	803 b	2806 a	3716 a	7280 a	1611 bc	3565 ab
Grazing brome	807 b	1857 bc	3357 ab	5498 b	1219 c	2787 bc
Coloured brome	448 bc	1379 c	2579 b	4668 b	1045 c	3121 b
Chicory	217 c	546 d	156 d	2354 c	1133 c	2105 c
Plantain	1370 a	1943 bc	1389 c	4974 b	1879 ab	3612 ab

Fig. 4.21. Total production over two summer seasons in the Dry Plain species evaluation experiment. Bar = average s.e.d.



4.5 Canberra pilot species evaluation experiment

4.5.1 Rainfall

The experiment was sown in a year with above average rainfall (2016 annual rainfall 950 mm) but the subsequent years were increasingly below average in rainfall (2017, 2018, 2019 annual rainfall 603, 511, 368 mm, respectively). Rainfall in the years 2017 and 2018 was well below average in the autumn to spring period and above average in the 2017-18 and 2018-19 summers (Fig. 4.22). However, the 2018-19 summer was one of the hottest on record in Canberra with a January 2019 mean maximum of 34.4°C which is 5.4°C above average. Spring 2019 and summer 2019-20 was a severe drought period which ended in February 2020 (Fig. 4.22).

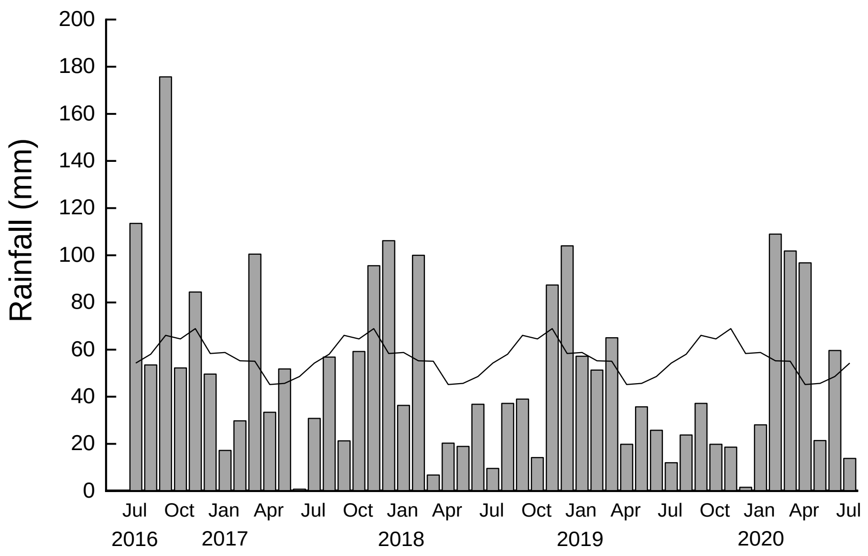


Fig. 4.22. Actual (bars) and long-term monthly (line) rainfall at Ginninderra Experiment Station during the pilot species evaluation experiment.

4.5.2 Establishment and persistence

Seedling densities in November 2016 were satisfactory for the grasses (tall fescue mean 145/m^2, phalaris mean 84/m^2, grazing brome 85/m^2, pasture brome 115/m^2, coloured brome 119/m^2) except cocksfoot (Savvy 52/m^2, Porto 35/m^2) for which two plots of Savvy and four plots of Porto were resown the following autumn. Plantain (43/m^2), chicory (25/m^2), lucerne (18/m^2) and red clover (10/m^2) were lower, and most plots of these species were resown.

All cultivars had established satisfactorily at a mean frequency around 60% in August 2017 with grasses higher on average (63 %) than herbs and legumes (50 %). Frequencies remained high in 2018 except for red clover which declined from 53% to 40% (*P*<0.05; Fig. 4.23). Coloured and pasture bromes increased in frequency in 2018 due to seedling recruitment but many existing plants died under drought in 2019 and 2020. Grazing brome recruited sufficiently to maintain frequency in 2018 and 2019 and recruited extensively in 2020 to have the highest frequency of any cultivar (Fig. 4.23). Seedling recruitment was not observed in any species other than the perennial bromes.

Lucerne was the most persistent species if seedling recruitment by brome species is overlooked (Fig. 4.23). In contrast, red clover and plantain declined each year and had virtually died out by 2020. Both tall fescue cultivars and Savvy cocksfoot were also present at very low levels by 2020 (Fig. 4.23). Tall fescue remained stable in its frequency for one year but then declined significantly in 2019 and very severely in 2020 to be less persistent than the three phalaris cultivars and Porto cocksfoot which also declined in the final severe drought period. Savvy cocksfoot declined more in frequency during the final drought period than Porto. Chicory and plantain persisted similarly up to 2019 but chicory declined less in the final year. Considerable within plot variation was observed for phalaris and chicory, with outer rows surviving much better than inside rows where frequency measurements were taken.

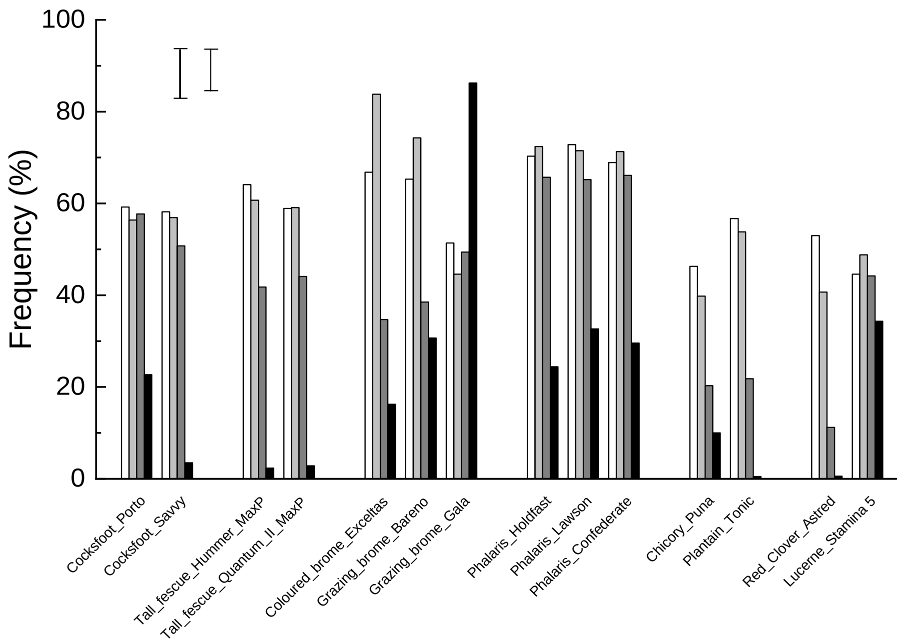


Fig. 4.23. Frequency of live plant base for 14 cultivars in 10 species for the years 2017 (white), 2018 (light grey), 2019 (dark grey) and 2020 (black) in the Canberra pilot species evaluation experiment.

L.s.d. (*P*=0.05) indicated by left-hand bar except when comparing the same cultivar (right-hand bar).

4.5.3 Herbage DM production

Seasonal herbage DM from autumn 2018 to autumn 2020 is shown in Fig. 4.24. Main effects of year, season and cultivar and their interactions including the three-way interaction were all highly significant ($P<0.001$) for seasonal herbage DM analysed on the square root scale, indicating differences among species in their response to the increasing drought intensity during this period.

The first summer covered the period 18-Dec-2018 to 22-Feb-2019. Although following high rainfall in mid-December, temperatures were high throughout this time. Lucerne and cocksfoot were the highest-yielding species under these conditions (Fig. 4.24). An intermediate-yielding group comprising tall fescue, chicory and pasture brome all yielded less than lucerne (*P*<0.05 on square-root scale) but not cocksfoot. Phalaris, coloured and grazing bromes, plantain and red clover formed a slightly lower-yielding group again. The second summer covered the period 25-Nov-2019 to 17-Mar2020 but growth occurred only after drought-breaking rainfall on 10-Feb-2020. Lucerne and chicory were outstanding in their recovery from drought due to their high summer activity and survival. Phalaris cultivars were substantially less productive than lucerne and chicory but at had least double the yield of the next best cultivar, Porto cocksfoot (*P*<0.05 on square-root scale), due to their higher survival of drought. Phalaris cultivars did not differ from each other (*P*>0.05). All other cultivars were very low yielding due to low survival of mature plants.

Cocksfoot, tall fescue, plantain and phalaris were the highest-yielding species in autumn 2018 (Fig. 4.24). The perennial bromes, chicory, red clover and lucerne formed a lower yielding group although pasture brome and red clover were not lower-yielding than phalaris (*P*>0.05 on square-root scale). A similar pattern was observed in autumn 2019 except that chicory was higher-yielding than plantain due to differences in survival. Hummer tall fescue was also less productive as its survival declined and was similar in yield to plantain and lucerne. Perennial bromes and red clover were very low-yielding.

Phalaris and chicory were the was the most productive species in autumn 2020 season following breaking of the drought (Fig. 4.24). Porto cocksfoot and Gala grazing brome were the next most productive cultivars and significantly more productive (*P*<0.05 on square-root scale) than Savvy cocksfoot, tall fescue, coloured and pasture bromes, plantain and red clover all of which lacked persistence. As in the two previous autumn seasons, Stamina 5 lucerne was relatively less productive in autumn 2020 than in summer.

Winter herbage DM for 2018 and 2019 was similar between years (Fig. 4.24). Phalaris, cocksfoot and tall fescue were the highest-yielding species in winter, with phalaris higher than tall fescue in 2019 (*P*<0.05 on square-root scale). Red clover and lucerne formed an intermediate-yielding group followed by the perennial bromes. Plantain and chicory were the lowest-yielding species in winter. Red clover was the only species in which winter DM yield in 2019 was lower than that in 2018.

Cocksfoot was high-yielding in spring of both years (Fig. 4.24). Lucerne DM was high in spring 2018 but lower in 2019. Tall fescue and phalaris were also high-yielding in spring of both years. Chicory, plantain and red clover were similar in herbage DM to phalaris in spring 2018 but plantain and red clover were much lower yielding in 2019 due to their lower persistence. The perennial bromes formed a low-yielding group in both years (Fig. 4.24).

Herbage DM production for the experiment is summarised as total summer and annual production over two years in Fig. 4.25. The superior summer production of lucerne and chicory is clear. All other species were relatively unproductive in summer over the period of measurement with phalaris and cocksfoot the best because of combined persistence or growth activity. Phalaris, cocksfoot and lucerne were the most productive species year-round, with tall fescue and chicory intermediate, and the perennial bromes, red clover and plantain the least productive due to low persistence or productivity.

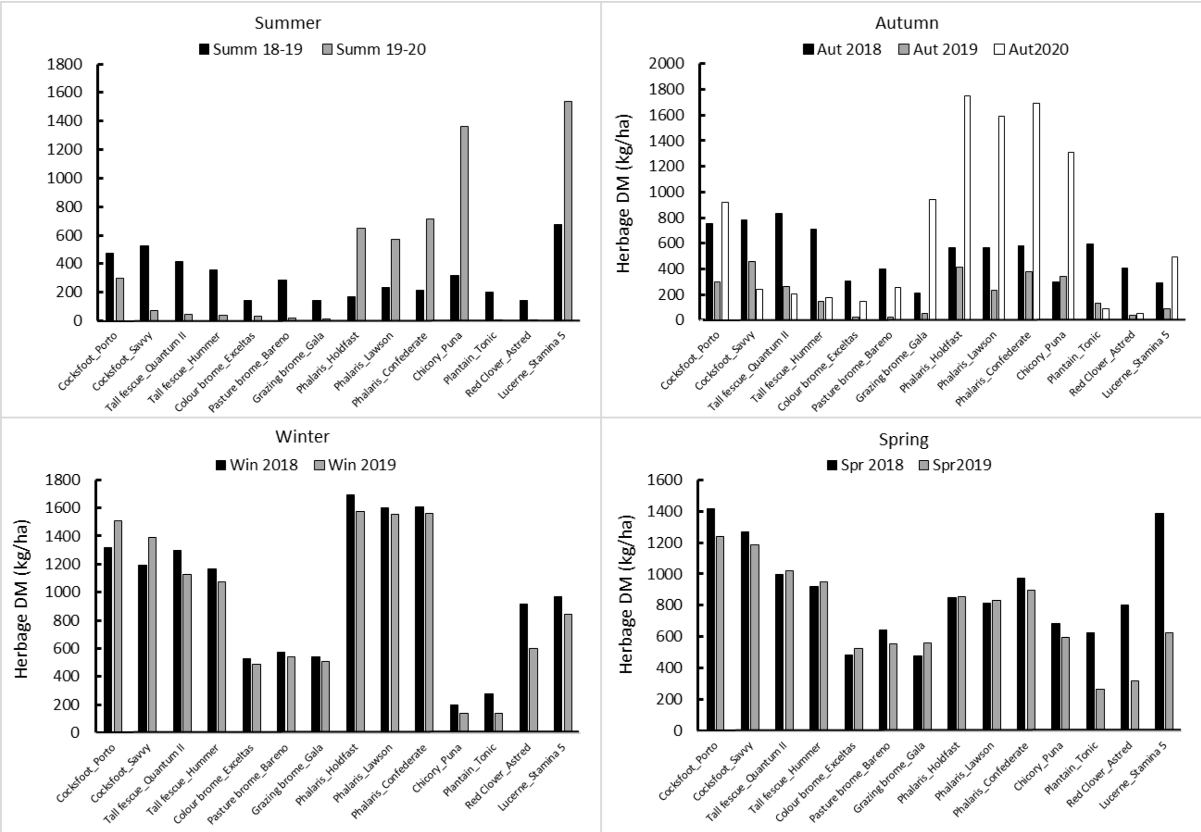


Fig. 4.24. Seasonal herbage DM back-transformed from the square-root scale for 14 cultivars in 10 species in the Canberra pilot species evaluation experiment.

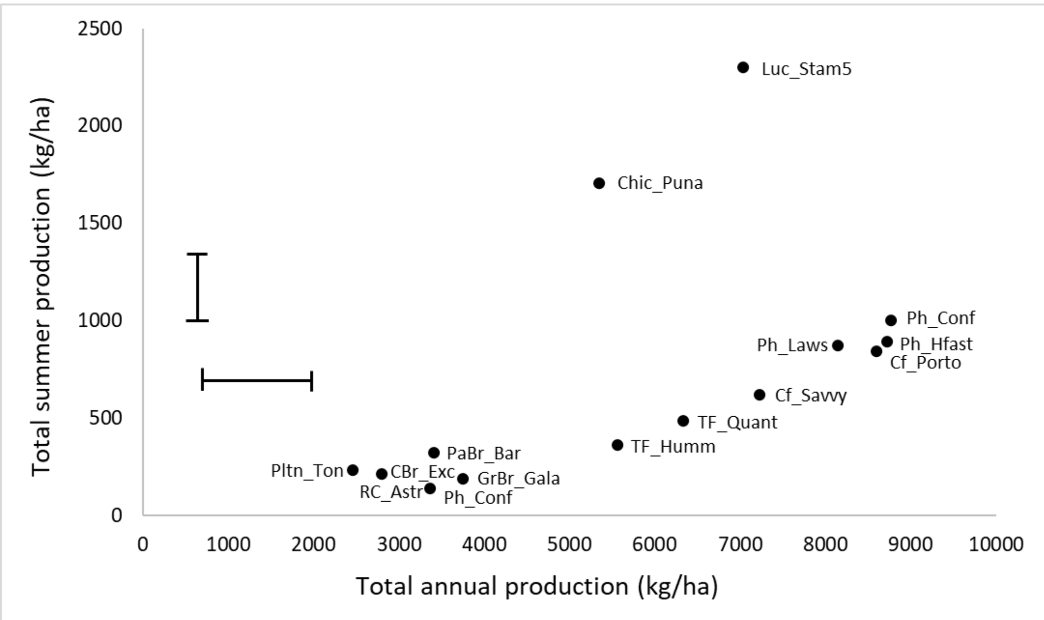


Fig. 4.25. Total summer DM production (y) versus total annual production (x) over two years for 14 cultivars in 10 species in the Canberra pilot species evaluation experiment. Bars indicate l.s.d. (*P*=0.05).

4.6 Grazing study component

4.6.1 Herbage production & composition

Poor quantity and quality of all treatments except brassica in January and February 2020 resulted in a delayed start to the grazing trial in early March. The feed on offer at the start of the trial was greatest on the brassica treatment, with a total DM of 4 t/ha (3.6 t DM/ha green feed; **Fig. 4.26**). Intermediate DM was available on the herb-legume (2.6 t/ha) and tall fescue-legume (2.5 t/ha) treatments, with lucerne phalaris-legume (1.9 t/ha) and brome-cocksfoot-legume (1.8 t/ha) offering the least DM. Meanwhile, the herb-legume and tall fescue-legume plots had produced DM in excess of 2.5 t/ha, greater than the DM production on lucerne (2.1 t/ha), phalaris-legume (1.9 t/ha) and brome-cocksfoot-legume (1.8 t/ha). DM increased in the first two weeks on all plots due to rapid plant growth in response to more rain. Removal of DM by grazing lambs exceeded plant growth between Weeks 2 and 4, except on phalaris and tall-fescue plots. Additional animals were added to plots in Week 5.

The grass-based pastures contained a substantial proportion of legumes that persisted over the trial period, while the small proportion of legumes present in the herb-legume pasture declined (**Fig. 4.26**). Poor persistence of legumes in herb mixtures, possibly due to shading, may be a limitation of this forage mix. The percentage of DM comprising dead plant material was initially high in the grass-based pastures, particularly in brome-cocksfoot-legume pastures, declined towards the middle of the trial (early April) when plant growth rates were high, and then increased again. In contrast, the non-grass-based treatments started with a low percentage of DM as dead material that increased over the trial period. The increase in dead material towards the end of the trial is likely related to both depletion of green plant material by the lambs and lodging; the latter may have been avoided with higher stocking rates. Notably, both of the “cropping” options, lucerne and brassica, showed minimal incursion by weeds compared to other treatments.

Brassica again had the highest green biomass at the commencement of grazing in January 2021, with a mean DM of 2.1 t/ha of green sown feed and 2.4 t/ha of total green feed (**Fig.4.27**). In comparison, less than 2 t/ha of green sown feed (0.8-1.8 t/ha) was available on the other forage treatments, with phalaris-legume pastures the lowest and tall fescue-legume the highest. Tall fescue pasture, however, contained a lot of senescent carry-over material from spring. In 2021, our initial stocking rate of 33/ha was found to be too high which resulted in low levels of feed on offer by week 4 (Fig. 17). In response to this we initially reduced stocking rate to 17/ha after 2 weeks and then completely de-stocked at 3.5 weeks after starting for a period of 2.5 weeks, after which stocking rate was set at 25/ha (6 weeks from start). Stocking rate was further lifted a fortnight later (8 weeks from start) to 36/ha on 9 plots in which green feed on offer exceeded 2 t/ha by a considerable margin. This equalised feed on offer across treatments to approx. 70 kg/head during a period of rapid pasture growth

Following good rainfall from 29th January to 6th February 2021, pasture growth outpaced grazing on all treatments except brassica through February (weeks 6 and 8 in **Fig. 4.27**). The dominant legume in all treatments was lucerne, apart from late-February to the end of May in the brome-cocksfoot-legume treatment when clovers dominated. Legumes persisted in the herb-legume treatment despite our concerns in the previous summer about being shaded out by chicory and plantain; in contrast to last summer, chicory started as the dominant herb in the mix in Year 2 and appeared to have been selectively grazed over the trial period. Brassica plots did not grow as well as in the first year of the experiment and became seriously depleted by week 10 (**Fig. 4.27**).

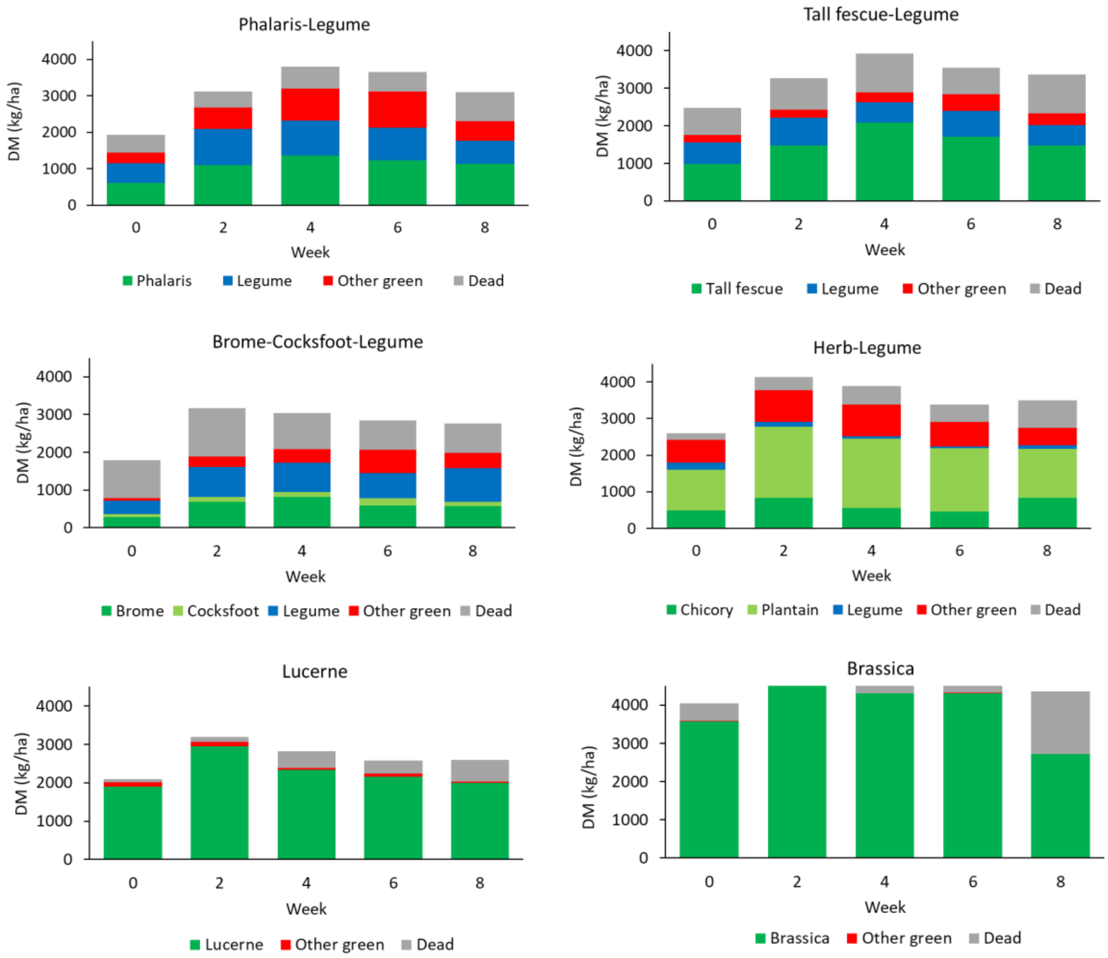


Fig. 4.26. Mean biomass and composition of herbage treatments in autumn 2020.

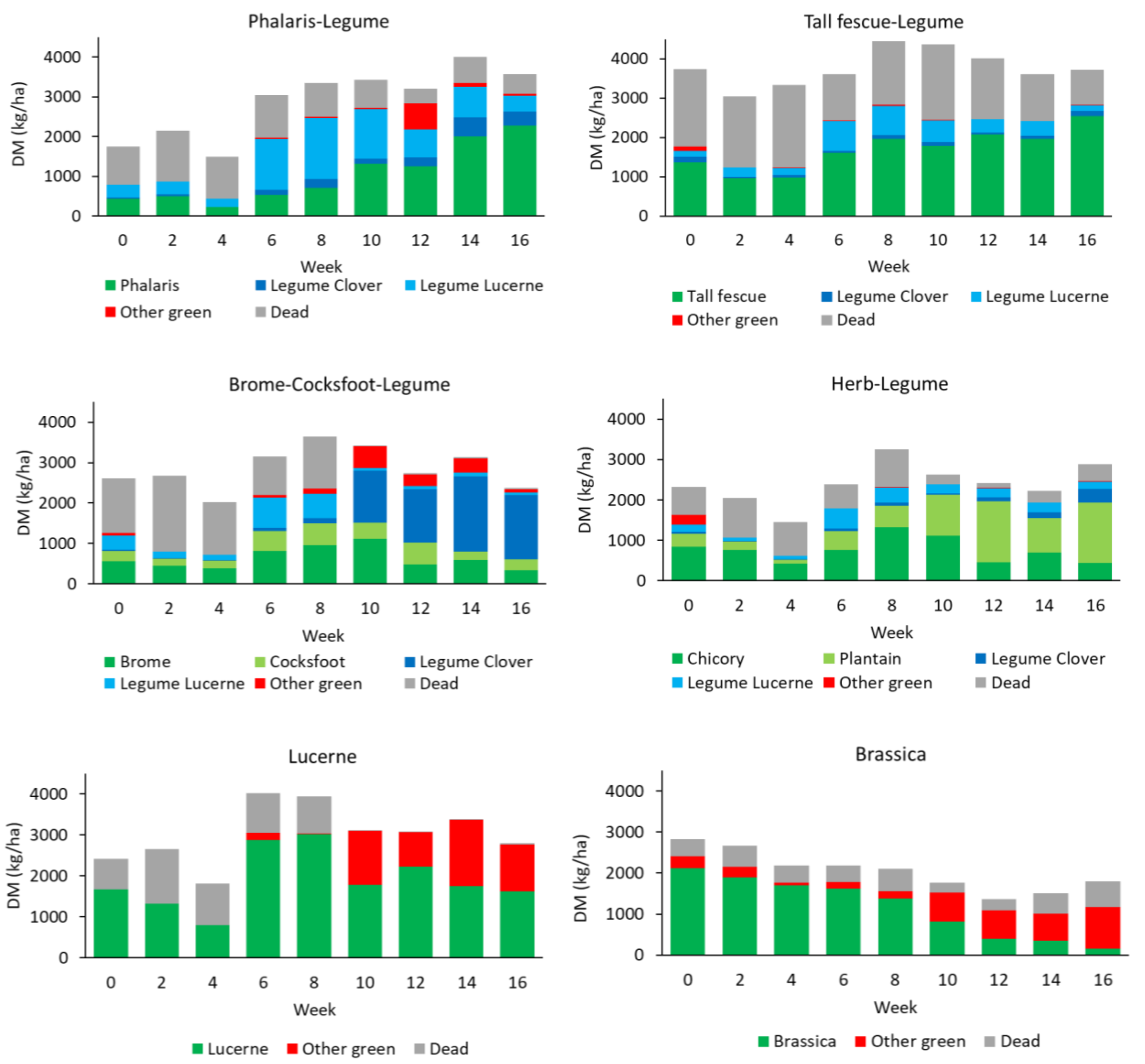


Fig. 4.27. Mean biomass and composition of forage treatments in summer-autumn 2021. All treatments were destocked for the period between 4 and 6 weeks after the grazing trial commenced.

Table 4.24. Herbage growth estimated via exclosures for each month of grazing (mean ± SE).

	Herbage growth (kg DM/ha/day)											
	Year 1 (2020)				Year 2 (2021)							
Treatment	**Mar**		**Apr**		**Jan**		**Feb**		**Mar**		**Apr**	
Phalaris-Legume	72	± 42	46	± 31	17	± 8	75	± 8	2	± 18	76	± 8
Tall fescue-Legume	78	± 37	104	± 35	26	± 16	54	± 22	14	± 8	42	± 5
Brome-Cocksfoot-Legume	81	± 21	69	± 9	26	± 13	73	± 20	48	± 13	29	± 8
Herb-Legume	36	± 33	74	± 21	16	± 6	54	± 25	-1	± 18	37	± 27
Lucerne	60	± 15	30	± 14	-6	± 8	82	± 4	-17	± 9	41	± 8
Brassica	41	± 47	-23	± 31	17	± 5	51	± 13	27	± 5	31	± 10

4.6.2 Herbage quality

In autumn 2020, only the chicory and plantain components of the herb-legume treatment and the brassica in the brassica treatment met the ME requirement for finishing lambs of 10.5 MJ/kg DM (**Table 4.24**). All green sown components met the recommended minimum CP content of 14% except the plantain. NDF was significantly lower in the herb-legume and brassica treatments than all other treatments, but no animal health issues related to insufficient fibre were observed.

In summer 2021, nutritive values were significantly lower across most forage components compared to the previous autumn, except in the brome-cocksfoot legume treatment (**Table 4.25**). None met the ME requirement for finishing lambs. The CP content was below 14% for all sown non-legume components of the grass- and herb-based pastures except the brome-cocksfoot-legume. NDF content was also substantially higher across treatments.

In autumn 2021, ME improved in the components of the grass- and herb-based pastures, remained the same for lucerne, and decreased for brassica (**Table 4.26**). CP dropped below 14% in some components of the grass- and herb-based pastures (tall fescue, cocksfoot, chicory and plantain) and in brassica.

Table 4.25. Nutritive values of components in each forage treatment from March – April 2020 (autumn). ME = Metabolizable Energy, CP = Crude Protein, NDF = Neutral Detergent Fibre.

Treatment	ME		CP		NDF	
Component	Mean ± SE	Range	Mean ± SE	Range	Mean ± SE	Range
Phalaris-Legume						
Phalaris	10.0 ± 0.1	9.5 - 10.5	20.9 ± 0.9	16.4 - 26.3	43.7 ± 0.8	37.8 - 48.5
Legume	9.5 ± 0.1	8.9 - 10.5	20.0 ± 0.7	16.3 - 23.8	39.7 ± 0.8	34.9 - 45.8
Other green	7.7 ± 0.2	6.5 - 8.7	13.6 ± 0.6	9.4 - 17.1	46.7 ± 0.8	42.8 - 53.7
Dead	5.3 ± 0.2	4.1 - 6.7	10.2 ± 0.5	6.9 - 13.8	68.1 ± 1.1	61.0 - 77.3
Tall fescue-Legume						
Tall fescue	10.0 ± 0.1	9.5 - 10.4	14.6 ± 1.0	9.2 - 21.2	45.4 ± 0.8	39.7 - 51.5
Legume	9.6 ± 0.1	9.3 - 10.1	20.4 ± 0.4	18.3 - 24	38.8 ± 0.4	35.9 - 43.0
Other green	9.2 ± 0.2	7.1 - 10.9	15.6 ± 1.0	8.6 - 21.3	43.5 ± 1.7	33.4 - 59.7
Dead	5.5 ± 0.1	4.9 - 6.2	13.0 ± 0.7	7.3 - 18.1	64.4 ± 0.8	60.1 - 70.2
Brome-Cocksfoot-Legume						
Brome	9.7 ± 0.1	9.0 - 10.1	18.6 ± 0.8	13.9 - 23.6	48.9 ± 0.9	41.8 - 54.5
Cocksfoot	9.6 ± 0.1	9.0 - 10.2	15.8 ± 1.2	8.6 - 22.4	51.3 ± 0.9	45.9 - 56.0
Legume	9.8 ± 0.1	9.3 - 10.3	21.9 ± 0.4	18.7 - 24.9	37.9 ± 0.7	32.7 - 41.8
Other green	8.8 ± 0.4	6.7 - 10.8	16.6 ± 1.4	7.4 - 25.7	44.6 ± 2.0	34.1 - 61.1
Dead	5.2 ± 0.1	4.4 - 6.0	13.0 ± 0.6	9 - 17.3	65.5 ± 0.8	59.8 - 71.8
Herb-Legume						
Chicory	11.3 ± 0.2	9.3 - 11.7	14.4 ± 0.6	9.3 - 18.1	29.6 ± 0.7	26.5 - 38.2
Plantain	11.2 ± 0.1	10.7 - 11.7	12.0 ± 0.6	9.3 - 16.5	28.9 ± 0.5	24.5 - 32.4
Legume	9.1 ± 0.2	8.0 - 10.1	16.4 ± 0.6	12.1 - 19.8	45.3 ± 1.3	35.1 - 52.9
Other green	6.9 ± 0.2	5.9 - 8.1	11.9 ± 0.6	9.6 - 16.3	45.5 ± 1.3	38.7 - 53.5
Dead	7.9 ± 0.4	6.0 - 11.0	10.2 ± 0.4	8.3 - 13.7	44.3 ± 1.9	28.6 - 55.8
Lucerne						
Lucerne	9.2 ± 0.2	8.3 - 10.0	19.3 ± 0.9	14.3 - 28.2	42.1 ± 1.2	36.1 - 51.1
Other green	7.9 ± 0.3	6.8 - 9.8	14.0 ± 1.4	9 - 22.2	49.0 ± 2.3	37.9 - 60.6
Dead	5.6 ± 0.1	4.5 - 6.6	11.7 ± 0.8	6.3 - 18.8	63.2 ± 1.2	53.9 - 69.8

Brassica						
Brassica	11.6 ± 0.1	10.8 - 12.2	17.3 ± 0.5	15.3 - 21.3	24.9 ± 0.8	18.2 - 30.9
Other green	7.5	n.a.	13.6	n.a.	49.4	n.a.
Dead	11.2 ± 0.2	9.8 - 12.6	10.8 ± 0.7	7 - 15.7	35.1 ± 1.9	21.9 - 46.4

Table 4.26. Nutritive values of components in each forage treatment from January – February 2021 (summer). ME = Metabolizable Energy, CP = Crude Protein, NDF = Neutral Detergent Fibre.

Treatment	**ME**		**CP**		**NDF**	
Component	Mean ± SE	Range	Mean ± SE	Range	Mean ± SE	Range
Phalaris-Legume						
Phalaris	7.6 ± 0.3	6.2 - 10.0	11.7 ± 1.8	5.1 - 24.4	61.7 ± 2.0	47.7 - 70.1
Legume	8.7 ± 0.3	7.1 - 10.4	17.6 ± 1.2	12.9 - 24	44.5 ± 2.1	34.7 - 55.5
Other green	10.1	n.a.	22.1	n.a.	38.3	n.a.
Dead	4.6 ± 0.2	3.4 - 5.4	6.7 ± 0.6	2.7 - 9.6	73.9 ± 0.9	67.5 - 79.2
Tall fescue						
Tall fescue	9.2 ± 0.1	8.5 - 10.0	13.2 ± 0.7	10.3 - 17.6	53.8 ± 1.0	49.0 - 60.0
Legume	8.6 ± 0.4	6.6 - 10.3	17.0 ± 1.3	11 - 22.9	45.4 ± 2.2	35.9 - 55.7
Other green	9.1	n.a.	18.2	n.a.	41.9	n.a.
Dead	5.0 ± 0.2	4.1 - 6.1	7.5 ± 0.6	4.5 - 10.5	70.7 ± 1.2	63.8 - 76.6
Brome-Cocksfoot-Legume						
Brome	9.8 ± 0.1	9.2 - 10.5	17.5 ± 1.2	12 - 22.5	53.2 ± 0.7	48.2 - 57.1
Cocksfoot	9.6 ± 0.1	8.9 - 10.1	15.7 ± 0.9	10.2 - 19.7	53.9 ± 0.8	50.1 - 60.0
Legume	8.9 ± 0.3	7.3 - 10.2	18.6 ± 1.1	12.9 - 23.4	43.2 ± 1.9	34.5 - 51.5
Other green	8.4 ± 0.2	8.2 - 8.5	13.8 ± 2.9	10.9 - 16.6	55.5 ± 4.8	50.7 - 60.2
Dead	5.1 ± 0.2	4.1 - 5.9	8.3 ± 0.6	4.3 - 11.7	70.1 ± 1.3	62.6 - 76.8
Herb-Legume						
Chicory	8.7 ± 0.4	6.4 - 10.2	12.6 ± 0.8	8.5 - 17.8	42.6 ± 2.7	32.7 - 57.7
Plantain	8.9 ± 0.2	7.5 - 9.8	12.2 ± 0.8	9.1 - 17.5	41.0 ± 1.5	33.8 - 51.0
Legume	9.2 ± 0.3	7.6 - 10.9	18.4 ± 1.2	11.8 - 26.1	41.8 ± 2.1	33.6 - 53.5
Other green	9.5	n.a.	18.7	n.a.	37.2	n.a.
Dead	4.3 ± 0.2	2.8 - 5.5	7.1 ± 0.5	4.1 - 9.5	63.8 ± 1.1	56.9 - 72.1
Lucerne						
Lucerne	8.9 ± 0.3	7.4 - 10.2	17.7 ± 1.1	12.6 - 23.6	43.7 ± 1.5	35.9 - 54.0
Other green	8.3	n.a.	21.3	n.a.	42.9	n.a.
Dead	4.5 ± 0.2	2.7 - 5.5	7.6 ± 0.6	4.3 - 11.4	74.9 ± 1.2	67.6 - 84.6
Brassica						
Brassica	10.1 ± 0.2	8.8 - 10.7	14.5 ± 0.5	12.4 - 17.8	36.5 ± 1.4	31.7 - 46.7
Other green	7.6 ± 0.7	5.1 - 10.5	15.1 ± 1.8	10.3 - 21.9	44.8 ± 2.4	36.9 - 52.5
Dead	8.1 ± 0.6	3.8 - 10.3	6.5 ± 0.9	2.2 - 12.7	44.5 ± 3.3	28.4 - 60.6

Table 4.27. Nutritive values of components in each forage treatment from March – April 2021 (autumn). ME = Metabolizable Energy, CP = Crude Protein, NDF = Neutral Detergent Fibre.

Treatment	**ME**		**CP**		**NDF**	
Component	Mean ± SE	Range	Mean ± SE	Range	Mean ± SE	Range
Phalaris-Legume						
Phalaris	9.9 ± 0.1	8.9 - 11	18.8 ± 0.6	14.8 - 22.8	47.0 ± 1.0	39.7 - 54.6
Legume	8.9 ± 0.3	7.1 - 10.5	17.5 ± 0.8	12.0 - 21.7	43.5 ± 1.8	32.0 - 55.0
Other green	9.0 ± 0.2	8.8 - 9.1	16.5 ± 0.4	16.1 - 16.8	40.8 ± 2.2	38.7 - 43.0
Dead	4.6 ± 0.2	2.9 - 5.4	7.4 ± 0.4	4.5 - 10.1	69.8 ± 0.8	65.3 - 74.9
Tall fescue						
Tall fescue	9.5 ± 0.1	8.9 - 10.1	12.3 ± 0.2	10.3 - 14.4	49.8 ± 0.7	46.0 - 55.0
Legume	8.6 ± 0.2	7.1 - 9.7	16.7 ± 0.5	13.0 - 20.1	45.7 ± 1.3	38.4 - 55.4
Other green	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Dead	5.1 ± 0.2	3.7 - 6.1	6.5 ± 0.3	3.7 - 8.3	66.1 ± 0.8	62.4 - 72.5
Brome-Cocksfoot-Legume						
Brome	9.8 ± 0.1	9.2 - 10.3	15.6 ± 0.5	11.9- 18.9	51.0 ± 0.6	46.1 - 55.1
Cocksfoot	9.2 ± 0.1	8.5 - 9.9	13.2 ± 0.4	10.6 - 15.7	54.1 ± 0.8	48.4 - 59.1
Legume	8.7 ± 0.2	7.4 - 9.5	17.4 ± 0.4	15.0 - 19.7	45.1 ± 1.0	39.3 - 51.4
Other green	9.3 ± 0.3	9 - 9.6	13.9 ± 1.1	12.8 - 15.0	43.0 ± 2.8	40.2 - 45.8
Dead	5.3 ± 0.2	3.8 - 6.5	8.9 ± 0.5	4.1 - 11.7	64.5 ± 1.1	59.6 - 72.6
Herb-Legume						
Chicory	8.8 ± 0.3	5.8 - 10.8	12.7 ± 0.7	6.7 - 17.7	41.0 ± 2.1	29.7 - 58.2
Plantain	9.7 ± 0.1	8.6 - 10.5	12.0 ± 0.6	9.1 - 15.5	36.0 ± 0.9	30.6 - 43.7
Legume	8.9 ± 0.3	7.5 - 10.7	17.9 ± 0.9	13.9 - 24.9	43.9 ± 1.8	31.7 - 54.2
Other green	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Dead	4.5 ± 0.3	2.6 - 6	8.1 ± 0.4	5.7 - 10.4	60.1 ± 0.9	53.8 - 65.9
Lucerne						
Lucerne	8.9 ± 0.4	6.8 - 10.9	18.5 ± 1.4	4.9 - 11.8	44.5 ± 2.6	30.7 - 56.6
Other green	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Dead	4.6 ± 0.3	2.8 - 6.9	8.1 ± 0.5	11.6 - 27.0	71.9 ± 1.4	59.7 - 77.0
Brassica						
Brassica	8.5 ± 0.4	7.2 - 11.6	12.8 ± 0.7	10.0 - 20.6	45.8 ± 2.3	25.3 - 55.3
Other green	8.7 ± 0.5	5.5 - 10.9	14.6 ± 0.7	10.9 - 19.2	40.9 ± 1.9	32.6 - 55.8
Dead	7.3 ± 0.4	5 - 9.8	11.1 ± 0.6	5.6 - 15.1	54.6 ± 2.0	39.7 - 62.7

4.6.3 Lamb production

The mean liveweight of core lambs entering the grazing trial in early March 2020 was 35.2 kg (± 0.4 SE). In 2021, lambs were added to plots in early January with the mean liveweight of core lambs at 33.7 kg (± 0.2 SE). The initial mean liveweight of core lambs did not differ significantly between treatments in either year (2020: $\chi^2_5 = 2.64$, P = 0.76; 2021: $\chi^2_5 = 1.01$, P = 0.96).

The rate of LWG per head differed between treatments in both years (2020: $\chi^2_5 = 21.74$, P < 0.001; 2021: $\chi^2_5 = 33.90$, P < 0.001), with only lambs on the herb-legume treatment growing significantly faster than those on the traditional phalaris-legume pasture (P < 0.05; **Fig. 4.28**).

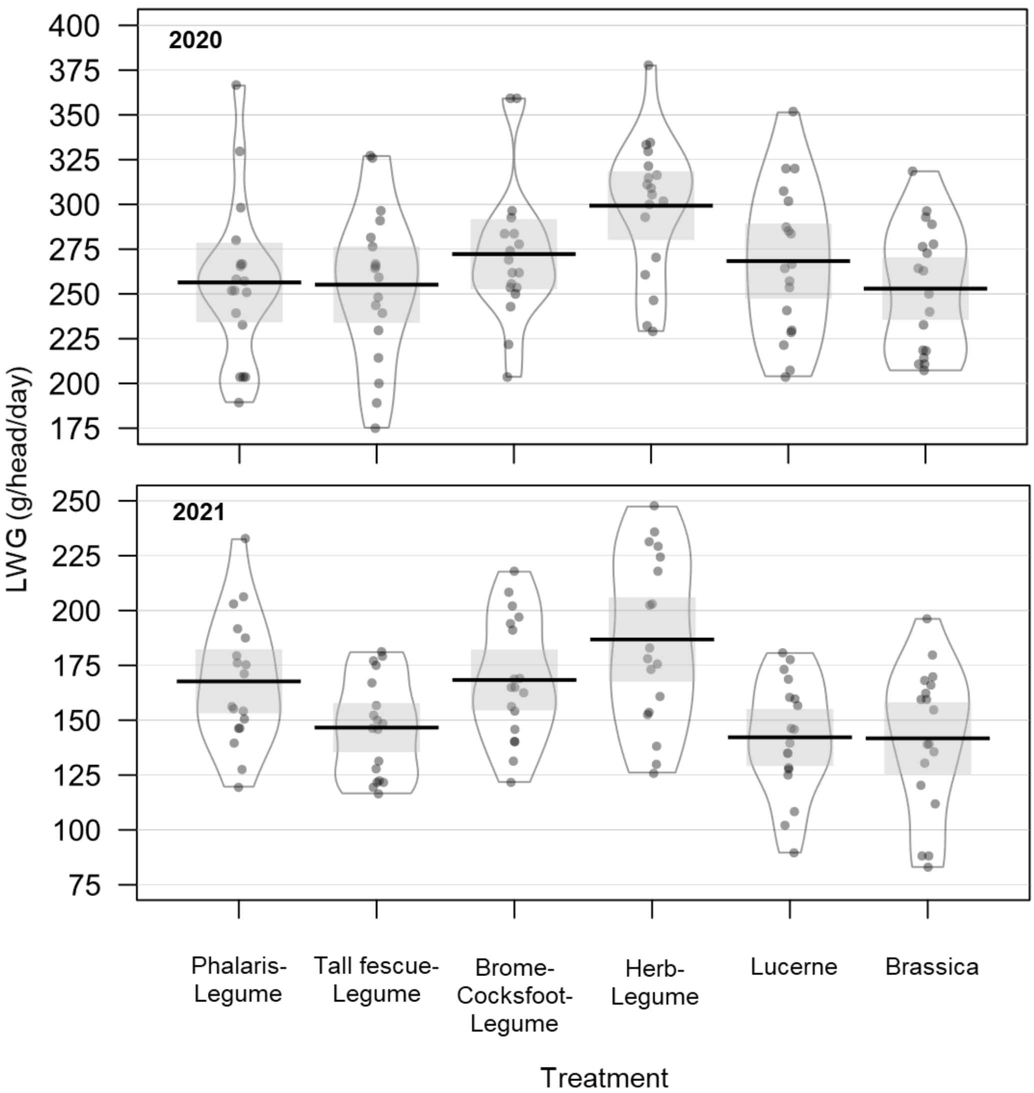


Figure 4.28. Rate of liveweight gain of core lambs over autumn 2020 and summer-autumn 2021. Points represent individual lambs; black horizontal lines are treatment means and grey shaded areas show 95% confidence intervals.

Final liveweights achieved by core lambs at the end of April were significantly different between treatments in both years (2020: χ^2_5 = 17.66, P = 0.003; 2021: χ^2_5 = 22.69, P < 0.001). Only the lambs on the herb-legume treatment achieved mean liveweights significantly greater than those on the phalaris-legume treatment and were the only cohort to meet the target mean weight of 52 kg by the end of April (a typical sale date for this cohort of lambs; **Fig. 4.29**).

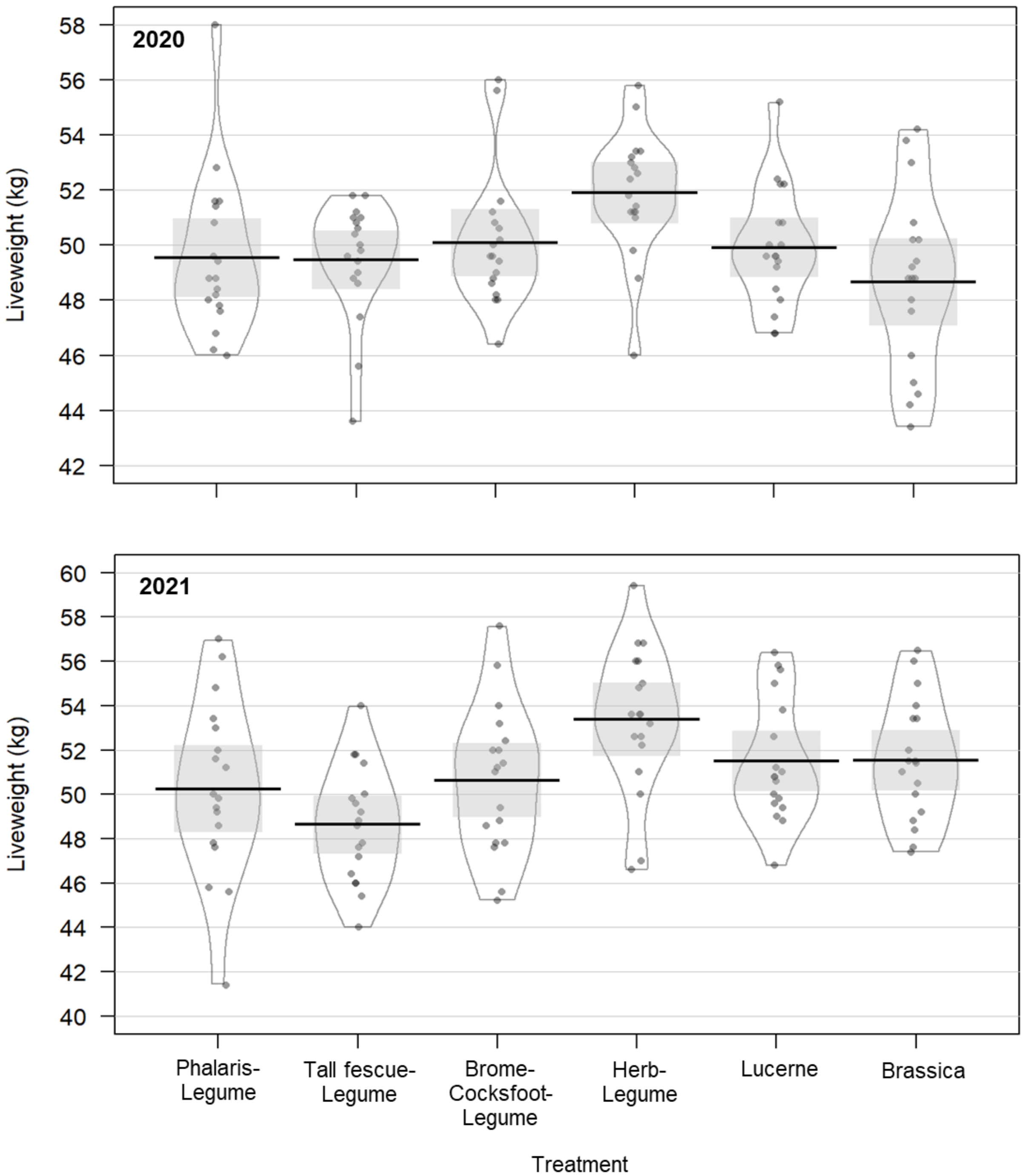


Fig. 4.29. Final weights of core lambs at the end of April 2020 and 2021 by forage treatment. Points represent individual lambs, black horizontal lines are treatment means and grey shaded areas show 95% confidence intervals.

In the autumn trial of 2020, the herb-legume treatment achieved the greatest total lamb LWG per hectare (including core and additional lambs) with treatment differences approaching statistical significance ($\chi^2_5 = 10.71$, $P = 0.057$; **Table 4.27**). Total LWG differed significantly between treatments over the summer-autumn trial in 2021 ($\chi^2_5 = 35.58$, $P < 0.0001$; **Table 4.27**), with brome-cocksfoot-legume producing the greatest and brassica the lowest total LWG.

Table 4.28 Total lamb liveweight gain (LWG) per hectare of all lambs during grazing trials in 2020 (8 weeks) and 2021 (14 weeks; excludes LWG during 2 weeks off-plot). Values are treatment means across blocks ± SE; treatments differing significantly (P < 0.05) from phalaris-legume are marked with an asterisk.

Treatment	**Total LWG (kg/ha)**	
	2020	2021
Phalaris-Legume	278 ± 23	389 ± 12
Tall fescue-Legume	284 ± 22	454 ± 47
Brome-Cocksfoot-Legume	261 ± 10	461 ± 20
Herb-Legume	331 ± 32	415 ± 57
Lucerne	266 ± 8	293 ± 18*
Brassica	305 ± 22	198 ± 25*

4.7 Modelling component

4.7.1 Forage production estimates

The simulations of the different forages demonstrate quite distinctive annual growth patterns amongst them (Fig. 4.30). In particular, the model confirmed the capacity for lucerne and spring sown brassicas to provide fresh forage growth during summer and early autumn at a time of year when the production of the summer-dormant grasses is low. This also shows that potential of forage brassicas to provide high growth rates at times of the year when other forages are less productive.

Overall, the mean annual production predicted for cocksfoot and phalaris were around 9-9.4 t DM/ha/yr on good soil, and 5.5-5.7 t DM/ha/year on the lower fertility soil at Goulburn (Fig. 4.31). Bombala produced around 1 t DM/ha/yr less. Mean simulated production from lucerne was around 7.5 t DM/ha/yr on average and the forage brassicas were around 5.4-5.6 t DM/ha/yr across both sites. The mean simulated chicory production was lower than the other forage options throughout the year, and significantly lower (4.2-4.4 t DM/ha/yr) than production reported in the experiments (data not shown). For this reason, we did not use the simulated chicory production data in our subsequent analyses, but we applied the same production simulated for lucerne (which is very similar based on experimental data) but with the higher quality attributes found for chicory in experiments.

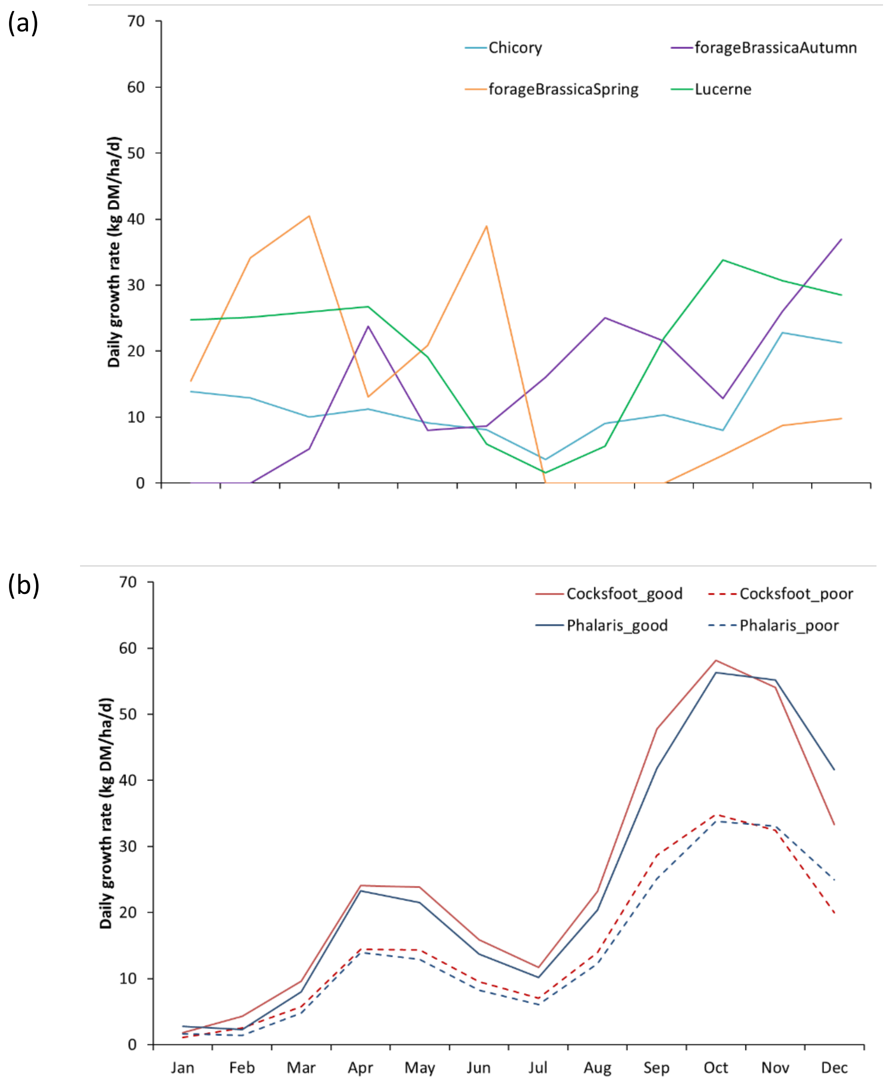


Fig. 4.30. Average simulated growth rates of (a) short-lived forage options and (b) grass-based pastures on high productivity (good) and lower productivity (poor) soil at Goulburn, NSW.

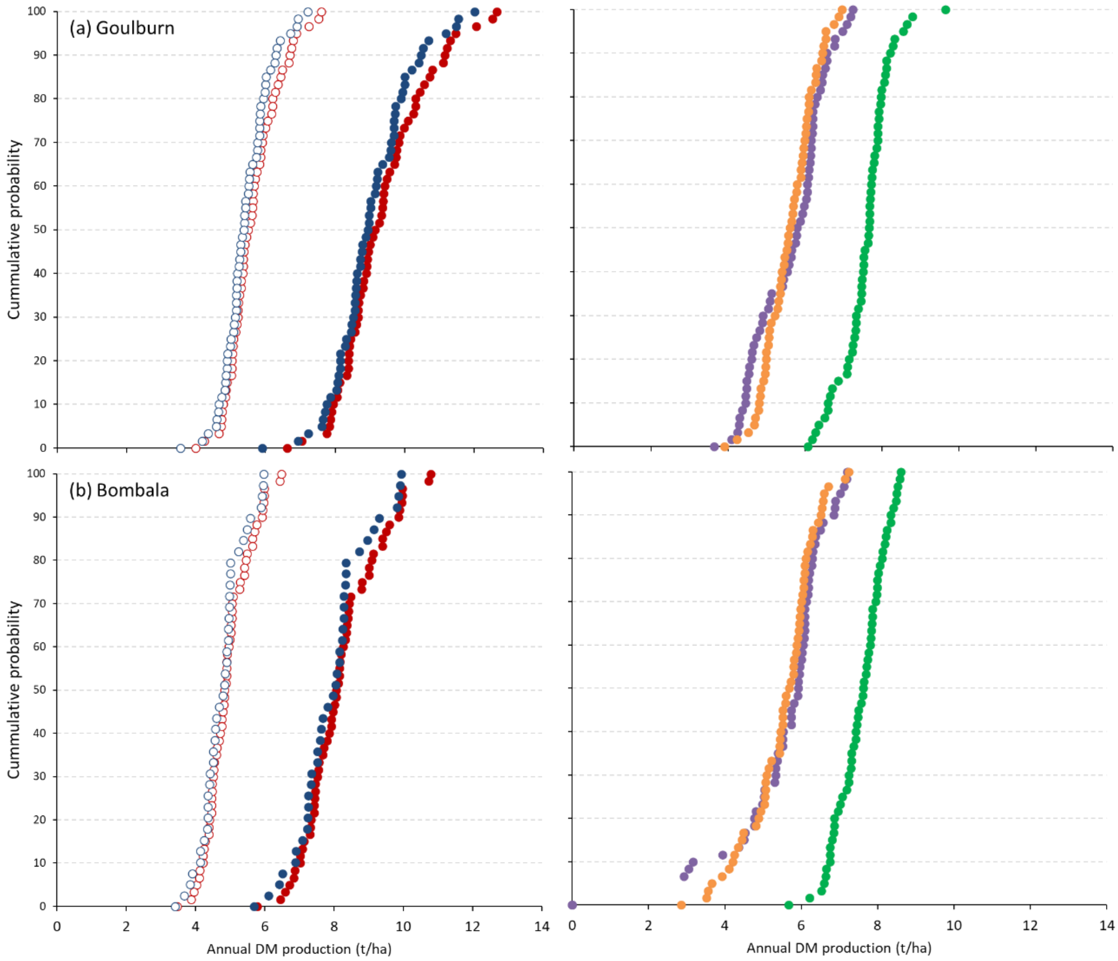


Figure 4.31. Variation in simulated annual production (t DM/ha) over 50 simulated years for summer-dormant pasture grasses (LEFT: Phalaris – blue and Cocksfoot – red under high (solid) and lower (open) fertility soil) and sown forage options (RIGHT: lucerne – green, spring-sown forage brassica – orange, autumn-sown forage brassica – purple) at two locations on the Southern Tablelands of NSW.

4.7.2 Feed system risk of store lamb vs fat lamb system

Altering the sheep production enterprise to change from selling store lambs at weaning (December) to keeping these lambs through the summer with the aim of finishing them for the following autumn brought about a significant change in the livestock demand imposed on the farm feedbase (Table 4.29). While this change is expected to provide a significant opportunity to intensify the productivity and profitability of these livestock systems, without changing the farm feed-base this comes with a significant increase in risk and potential costs. The demand for energy (and farm grazing days) increased by about 30%, and mean utilisation of the farm feedbase increased from 40% to over 50% (Table 4.29). On a farm relying on summer-dormant grasses this resulted a significant increase in the frequency of a farm feed deficit that would require significant supplementary feeding or a reduction in stock numbers to satisfy livestock demand; this increased to 7% of the time at Goulburn and 14% of the time at Bombala.

Table 4.29. Expected livestock production (target) and feedbase risk outcomes for changing from a store lamb enterprise (lambs sold in Dec @ 28 kg/hd LW) to a fat lamb enterprise (lambs sold in April @ 55 kg/hd LW) at two locations on the Southern Tablelands of NSW. Livestock revenue estimated at $2.75/kg LW for store lambs, $2.50/kg LW for fat lambs and $2.00/kg LW for cull ewes.

Expected outcomes	Goulburn		Bombala	
	Store lamb	Fat lamb	Store lamb	Fat lamb
LIVESTOCK PRODUCTION				
Lambs sold (kg/ha/yr)	20	40	17.6	35
Livestock sale revenue ($/ha/yr)	70	115	63	101
Farm grazing days (DSE/ha)	7.8	10.3	6.9	9.1
Mean annual demand (GJ ME/ha)	24.6	32.3	21.7	28.5
FEEDBASE				
Median utilisation	39	52	40	53
% months with fresh feed deficit	25	29	31	34
% months with farm feed deficit (incl. carry over)	0	7	1	14

Both the store lamb and the fat lamb system experienced shortages of fresh feed over summer (January to March) and in mid-winter (July and August) due to the low productivity of the summer-dormant grasses at these times (Fig. 4.32 a, b). However, due to the higher demand imposed by the additional weaner lambs this risk is increased further during autumn (e.g. March and April) when pasture growth is highly variable (Fig 4.32 c, d). This means that livestock will be reliant on surplus forage carried forward from previous months to meet their requirements at these times.

In the store lamb system, there is sufficient surplus feed available that is carried forward from previous months to meet livestock requirements in over 95% of all years (red bars in Fig. 4.32 e, f). In contrast, the fat lamb system imposed significant risks of farm forage shortages occurring in March and April at both locations (blue bars in Fig. 4.32 e, f). A farm feed deficit requiring supplementation or reducing stock numbers in March was estimated to occur in over 70% of years at Bombala, and around 60% of years at Goulburn. This clearly demonstrates that a significant risk of a feed gap at this time of year is likely to constrain the ability of farmers in these districts to transition to a fat lamb enterprise where they rely on a feedbase consisting entirely of summer-dormant grasses (e.g. phalaris or Currie-type cocksfoot). Of course, such a system may be accommodated by reducing stock numbers (i.e. less ewes per ha) or via use of supplementary feeding but these will come at a significant reduction to the potential productivity or profitability of the system.

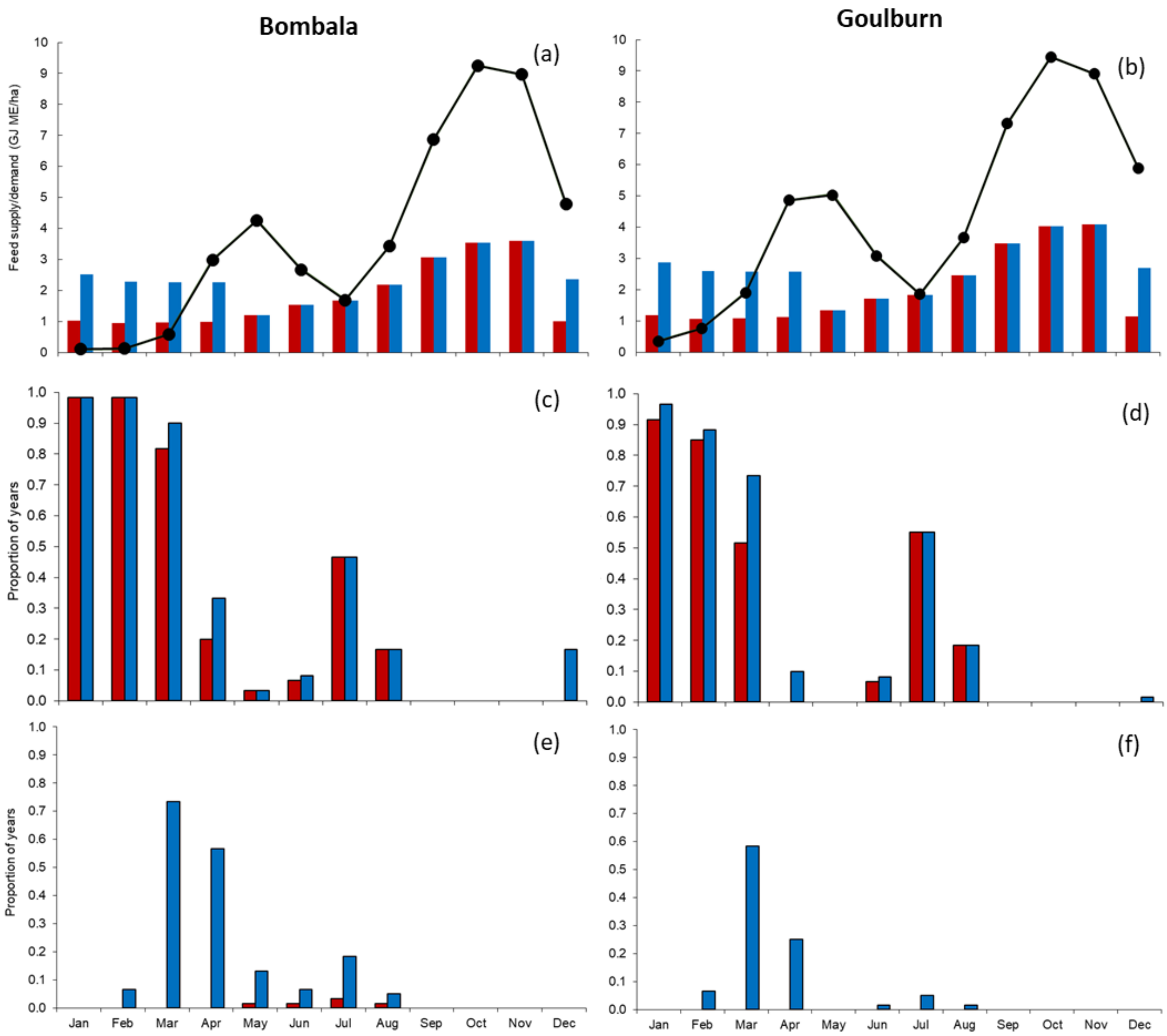


Fig. 4.32. Farm feed balance risk comparing livestock enterprises where lambs are sold in December each year (red) or are finished for sale in April (blue) at Bombala (left) and Goulburn (right) that relies entirely on a summer-dormant grass feedbase. The top graphs (a & b) show the balance of monthly farm feed supply (black line) compared to the monthly forage demand (bars), the middle graphs (c & d) show the frequency of a deficit in fresh forage supply in each month and the bottom graphs (e & f) show the frequency of a farm feed deficit where insufficient forage is available to meet animal requirements.

4.7.3 Can alternative forage systems support a fat lamb system?

Given the clear feed gaps during summer and early autumn constraining fat lamb systems, here we demonstrate there is significant potential to utilise alternative forages that provide high quality summer forage to fill these gaps in supply and hence support a shift to these higher productivity and profit systems.

Incorporating a summer active forage like lucerne or chicory into the farm feed-base increased the provision of high-quality forage during Jan-March. Figure 4.33 demonstrates how much the whole-farm forage supply changes from replacing 20% of the higher fertility land with a lucerne pasture. While there is still significant variability in total monthly production across the range of simulated years, the lucerne provides a reliable feed source over summer. However, it does come at a cost to reduced farm forage production during winter and spring.

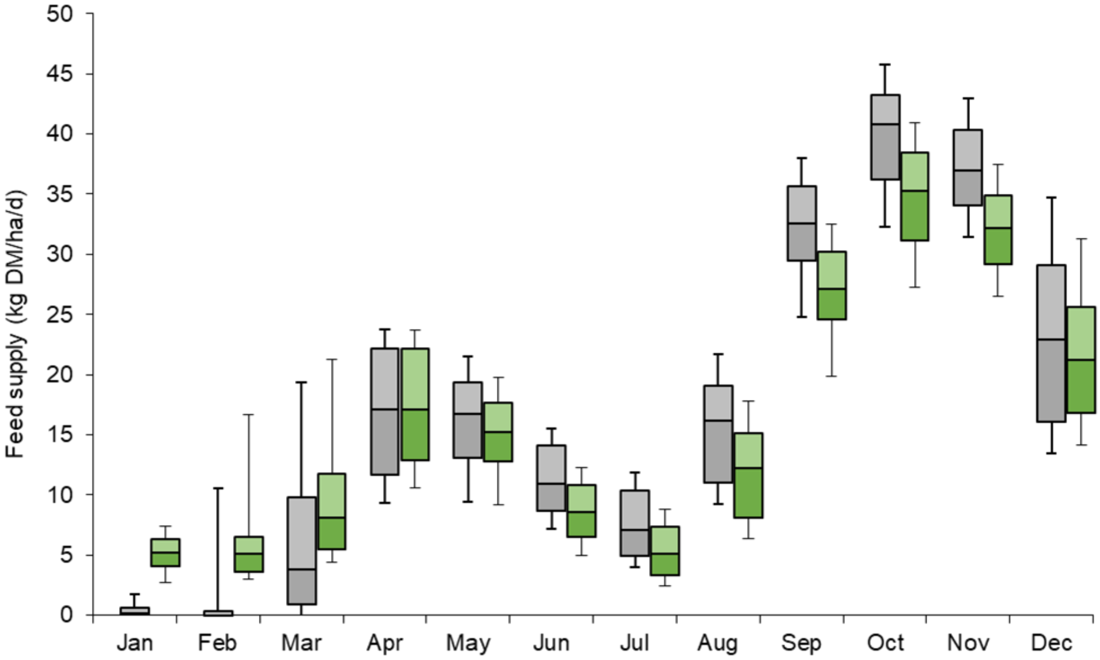


Fig. 4.33. Change in monthly feed supply and its variability for a feed-base relying on a summer-dormant grass (grey) and a feed-base incorporating 20% of lucerne (green) at Goulburn, NSW. Box represents upper and lower quartiles either side of the median, and bars decile 9 and 1 of monthly growth over 60 simulated years).

As a result of these changes in the farm feed supply there are significant reductions in the frequency and size of feed deficits possible at both study locations (Table 2). The frequency of months when fresh forage production was insufficient to meet livestock demand did not change dramatically amongst feed systems (still occurred in Jan-March in most years), however the size of these deficits did reduce (Table 4.30). For example, across both sites incorporating lucerne or chicory reduced the fresh feed deficit in the worst years by about 30% when a tenth of the farm was converted, and by about 50% when one fifth of the farm was converted.

The frequency with which total forage availability (including carry over) was insufficient to meet livestock demand was reduced compared with the base summer-dormant pasture through the addition of most forages, even when they produced less total dry matter. The analysis suggested that it was possible to reduce the frequency that farm feed deficits occurred to almost zero (i.e. <0.5% of the time) and effectively reduce the risk of feed gaps in late summer and early autumn (Fig. 4.34). The size of these deficits was also dramatically reduced. The best forage feedbase achieved reductions of up to 85% in the amount of metabolizable energy needed to fill these forage deficits when they occurred (Fig. 4.35).

The benefits of the addition of each of the forages generally increased as the proportion of land allocated to them increased from 10% to 20%. The summer activity of lucerne and chicory produced the most complementary growth patterns and the biggest reductions in the frequency and size of feed deficits (Fig. 4.34 and Fig. 4.35). The autumn sown brassicas were the least beneficial because they did not provide forage during the critical summer period in these systems, though they did provide some mitigation for the size of the feed deficit that might occur. The spring-sown brassicas were intermediate, reducing the size and frequency of feed deficits at both sites. But the analysis here may have underestimated their potential to accumulate and maintain a high-quality standing forage source that could be utilised at critical times.

Table 4.30. Changing frequency of months with feed deficits and size of annual feed deficits in the worst 20% of years incurred by a fat lamb enterprise (lambs sold in April @ 55 kg/hd LW) at two locations on the Southern Tablelands of NSW. Livestock revenue estimated at $2.75/kg LW for store lambs, $2.50/kg LW for fat lambs and $2.00/kg LW for cull ewes.

Forage scenario		Fresh feed deficit				Whole-farm forage deficit			
Area %	Forage type	Frequency (% months)		Size in worst 20% years ('000 GJ ME/ha)		Frequency (% months)		Size in worst 20% years ('000 GJ ME/ha)	
		Goulburn	Bombala	Goulburn	Bombala	Goulburn	Bombala	Goulburn	Bombala
Baseline		**29**	**34**	**10.1**	**12.4**	**7.0**	**14.4**	**5.4**	**9.2**
10%	Lucerne	29	33	7.4	8.1	2.6	5.3	1.9	3.1
	Chicory	29	33	7.2	7.8	2.4	4.9	1.7	2.6
	Spring Brassica	29	34	7.5	9.5	3.4	8.7	2.5	5.1
	Autumn Brassica	28	33	9.2	11.8	7.0	14.0	4.2	8.7
20%	Lucerne	29	33	5.3	5.2	0.2	0.5	1.0	3.0
	Chicory	29	31	5.0	4.8	0.2	0.5	0.7	2.4
	Spring Brassica	28	31	6.2	8.4	1.7	4.0	1.4	3.1
	Autumn Brassica	27	32	8.8	11.5	7.5	14.2	3.7	9.6
	Lucerne/Spring Brass	29	29	5.2	6.1	0.3	0.9	1.0	1.5

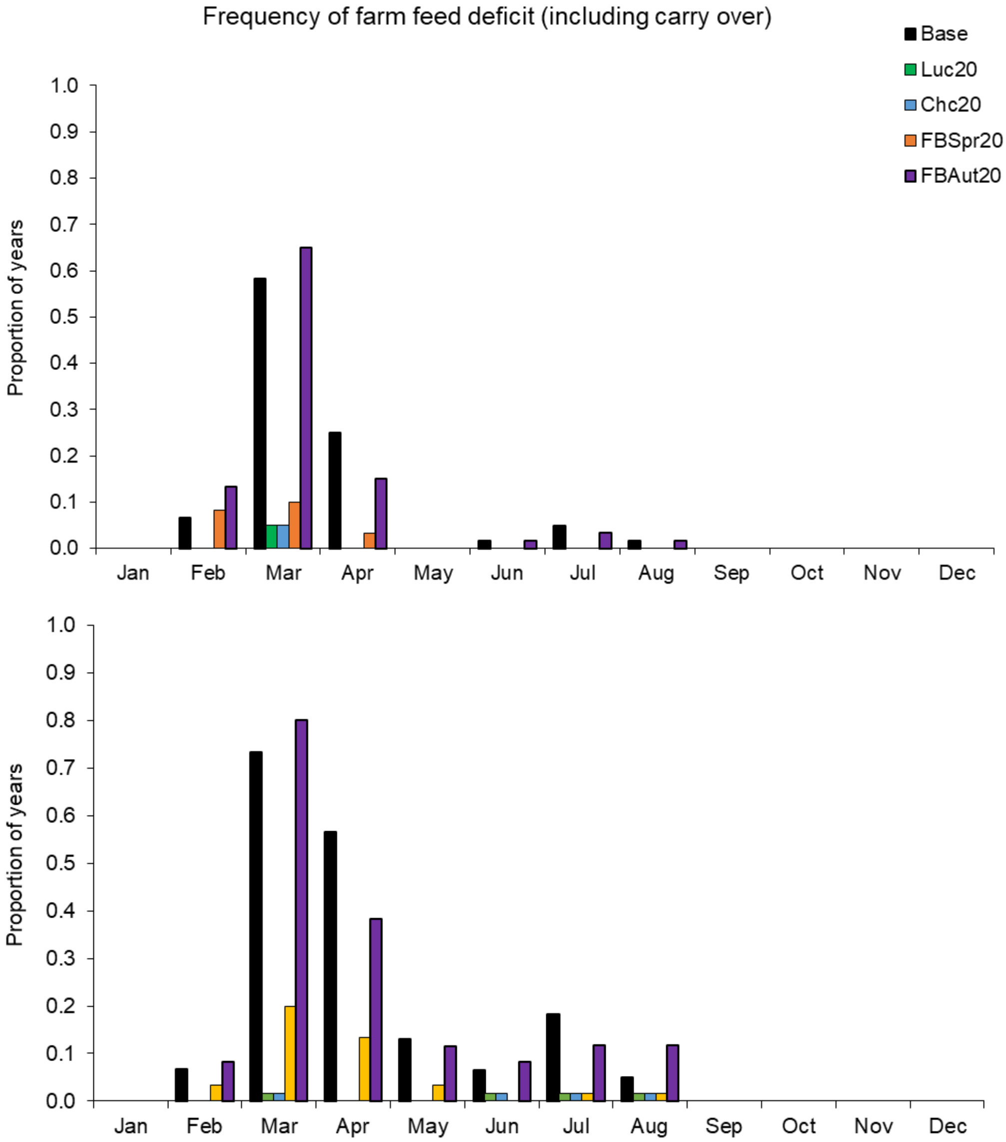


Figure 4.34. Frequency of a monthly forage deficit (including carry over) for a feedbase relying on summer-dormant grasses only (black) compared to incorporating 20% of higher fertility land to alternative forage options (Lucerne – green, Chicory – blue, Spring-sown forage brassica – orange, autumn-sown forage brassica – purple) at Goulburn (top) and Bombala (bottom).

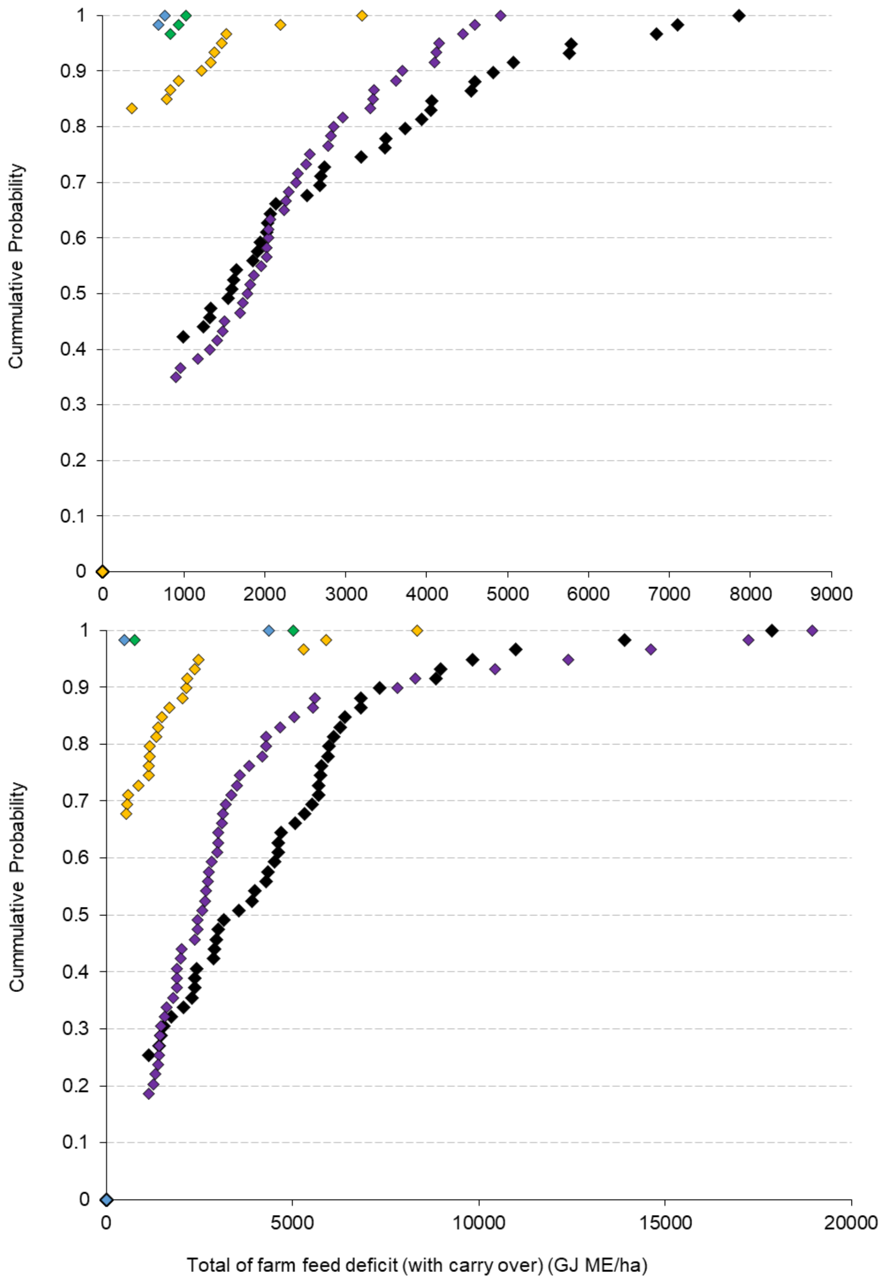


Figure 4.35. Magnitude of annual forage deficit (including carry over) for a feedbase relying on summer-dormant grasses only (black) compared to incorporating 20% of higher fertility land to alternative forage options (Lucerne – green, Chicory – blue, Spring-sown forage brassica – yellow, autumn-sown forage brassica – purple) at Goulburn (top) and Bombala (bottom).

5. Conclusion

5.1 Key findings

5.1.1 On-farm species evaluation component

Evaluation sites and conditions
A range of temperate perennial grasses, herbs and legumes and one tropical grass were evaluated for their potential to support meat production enterprises during the summer-autumn period in the Southern Tablelands/Monaro region of southern NSW. Although the focus of the study was on summer and autumn, production was measured in all seasons since a decision to use a perennial species, in contrast to a forage crop, depends partly on the pattern of production throughout the year.

Core site experiments were in areas and paddocks considered capable of supporting high-production activities such as finishing lambs. Soil fertility was maintained at levels required to achieve this. They were not aimed at areas with predictably high moisture constraints (low average rainfall, shallow soil) or low soil fertility unlikely to support meat production (e.g. driest parts of Monaro on low fertility soils; Hackney et al. 2019). Supplementary site experiments extended coverage of the target environment to more acidic soils and less favourable locations in the landscape (Gunning), cooler areas at higher altitude (Dry Plain) and warmer areas further from the coast (Canberra).

All sites experienced drought conditions during the study which delayed sowing (Bombala), affected establishment (Goulburn, Gunning) and growth and persistence (all sites). While Goulburn experienced reasonable rainfall in the first summer (2018/19), this summer was also one of the hottest on record. Of the core sites, dry conditions were more prevalent at Bombala. The Canberra site was lowest in altitude of all the sites and probably experienced the most severe combination of drought and high summer temperatures.

All experiments were managed by a regime of mowing to around 5 cm. Results are therefore more relevant to pastures subjected to careful grazing management, typically rotational grazing, expected for productive, high-input pastures.

Persistence – general observations
Drought was the most pervasive stress that affected all sites. Largest differences in persistence in terms of frequency of live base occurred in the Canberra pilot evaluation experiment where drought steadily increased in intensity on established plots over two years. Persistence in that experiment was ranked in the order of lucerne > phalaris ≥ Porto cocksfoot > Savvy cocksfoot, tall fescue, chicory > plantain, red clover. By contrast, while the high-altitude Dry Plain site was affected by drought in the establishment year and first summer, there was little decline observed in any species during the drought despite competition from annual grasses in spring. We hypothesise that this was because of the considerably lower mean temperature at the Dry Plain site and therefore suggest that species of lower drought tolerance, such as perennial ryegrass, may persist adequately in cooler, higher altitude areas.

Non-legume species at core sites could be grouped into those which relied on longevity of established plants for persistence and those for which persistence relied on a combination of seedling recruitment and survival of established plants. Among the former group, phalaris, perennial veldt grass and Puna chicory were most persistent through the severe 2019-20 drought period. Digit grass was also very persistent at the single site where it established (Goulburn). Tall fescue and cocksfoot declined at both core sites by around 20-30 % but made partial recovery under high rainfall once the drought broke and remained productive. Tall fescue was much less persistent than phalaris through the drought in limed acid soil site at Gunning. Chicory also declined through the drought period at Gunning, but this appeared to be due to severe overgrazing by rabbits and kangaroos rather than moisture stress. Perennial ryegrass declined the most of all non-legume species during drought at Goulburn but declined less than cocksfoot and tall fescue under a longer drought period at Bombala. Possible reasons for better survival at Bombala include the fertile soil type at Bombala combined with lower temperature compared with Goulburn.

All *Bromus* species and plantain relied on seedling recruitment for stand survival at the Goulburn core site. While the contribution of recruitment versus survival of existing plants for *Bromus* species was not measured, casual observation suggested that survival of existing plants through the 2019-20 drought period was low for grazing, pasture and coloured bromes. All had abundant seedlings the following season. Existing plants of prairie grass appeared to have higher survival but further work in this area is required. Much less recruitment was observed at the Bombala core site and only prairie grass remained at high frequency among *Bromus* species there. Recruitment among *Bromus* species also appeared to be lower at Dry Plain but survival of existing plants was higher than at the core sites under cooler conditions. Plantain also recruited strongly at Goulburn but less at Bombala and Dry Plain. Plantain declined slightly through drought at Bombala and in the final year at Dry Plain. A strong annual grass component at Dry Plain may have been responsible for low recruitment by plantain. However, established plants grew well there.

Lucerne was highly persistent through drought at both core sites and in the Canberra experiment but its susceptibility to other common stresses was revealed under waterlogging at Goulburn and soil acidity despite lime application at Gunning where lucerne failed completely. Observations at Goulburn after the experimental period (November 2021) suggested that lucerne had declined further under continuing high rainfall and wet soil conditions. Caucasian clover was also highly persistent through drought at the core sites. Talish and strawberry clovers were more persistent through drought than white and red clover. The high capacity for stoloniferous spread allowed strong recovery by white clover but the much lesser capacity of the red clover varieties allowed only limited recovery.

Nutritive value – general observations

Nutritive value was measured only at the core sites and only during the summer-autumn period. At a general level, nutritive quality values for species in the non-legume experiments in summer were often lower than preferred for rapid lamb growth, particularly in the much above average temperature summer in 2018/19 at Goulburn. Clark et al. (2013) reported ME values in the range of 10-12 MJ/kg for a range of temperate perennials in January at Hamilton, Victoria, and Cave et al. (2015) reported values for herb-clover mixes of 11.4-11.8 MJ/kg at Palmerston North New Zealand in the summer-autumn period. These values are higher than we observed in summer although whether swards were in comparable condition is unknown. Conversely, our values in summer are only slightly less than those observed for pasture and herb mixes in summer at Palmerston North in another study (Somasiri et al. 2015) and those for chicory, plantain and lucerne at Hamilton by Raeside et al. (2020), and similar to values for plantain in summer in another New Zealand study (Kemp et al. 2014). Very low ME values were observed for lucerne in hot, dry conditions at Hamilton, Victoria (Nie et al. 2020).

High temperatures have been observed to reduce nutritive quality in grazed perennial ryegrass, tall fescue and lucerne in northern Victoria (Rogers et al. 2022). It is likely that our summer nutritive values also were influenced by temperature and moisture conditions. Levels of stem content also had a major influence on nutritive quality parameters in this study. However, this was not always the case and tall fescue, for example, was usually vegetative during summer but not of markedly higher quality because of this. If correct, values for nutritive quality that we observed will set a limit on liveweight gain by lambs. We acknowledge that nutritive values are sensitive to sample processing (Dale et al. 2016) but that relative rankings are usually similar between methods (Dale et al. 2017). Our samples were kept cool using ice bricks until drying commenced from 3-6 hours after harvest, but time taken to oven dry may have reduced ME values.

Non-legume species
Chicory. Chicory was outstanding as a specialist summer species with reliable production of high-quality forage from late spring through summer at least into early autumn in both moister and drier periods and coming out of severe drought. Chicory:

- had the highest total summer production over the experimental period at Goulburn and was equal highest with lucerne at Bombala. It was more specialised towards summer growth than lucerne being less productive in the cooler months;
- was persistent over 3 years at Goulburn and 2 years at Bombala despite drought. Like phalaris, chicory is a deep-rooted species capable of taking up moisture relatively deep in the soil profile (Hayes et al. 2010b). Although low persistence by chicory has been partly related to moisture stress in drier environments (Hayes et al. 2010b, Li et a. 2010), in the milder environment of the Southern Tablelands its deep root system can be expected to confer good drought tolerance. Decline in chicory due to severe overgrazing by rabbits and kangaroos when it was the only green herbage available was an indirect consequence of drought and flags management problems that may occur during very dry periods;
- usually exceeded or equalled production and nutritive quality of Sardi Grazer lucerne at summer harvests under conditions where nitrogen levels were maintained through the application of urea. Chicory was always relatively high in ME content although not always at the level of 10.5 MJ/kg or greater preferred for rapid lamb growth. It was consistently much lower in crude protein content than lucerne and most of the grasses but the levels around 12-14 % DM typically observed were sufficient for growth of lambs above 20 kg liveweight (Abbott 2018). Timing of harvests meant that stems sometimes were developing in chicory, particularly in cv. Commander, and ME content was considerably higher when sampled between the main harvests before stems formed, indicating a role for management in achieving the highest nutritive quality;
- was clearly superior to lucerne in its acid soil tolerance at the Gunning site, supporting observations at another acid soil site elsewhere in southern NSW (Hayes et al. 2008) and general evidence from Tablelands sites (Upjohn et al. 2005). While chicory did not perform as well at Gunning as at the core sites, good drought tolerance and superior acid soil tolerance supports its use as an alternative high-quality summer-active species to lucerne in acid soil environments.

Excellent warm season performance of chicory must be balanced against low productivity in winter on the Southern Tablelands. Total sward yield of chicory plots during winter-spring in the Gunning mixtures experiment did not suffer because of rapid ingress of volunteer winter-growing species from the seedbank. Sowing chicory with grasses, legumes and herbs that grow more actively in winter should improve cool season production and reduce ingress of unwanted species. Excluding grasses from a mix would allow good grass control for the following pasture or crop.

Sensitivity of chicory growth to low temperature indicates a need to avoid sowing at times when temperatures remain low, e.g. late autumn sowing as in the Gunning mixtures experiment which probably resulted in relatively low starting frequency despite adequate seedling numbers at emergence. Lack of growth under cold winter conditions followed by competition from annual grasses in spring may have resulted in death of some chicory seedings and low initial frequency at Dry Plain.

The potential of chicory as a high-quality warm-season forage species suited to activities such as lamb finishing has been recognised previously in south-eastern Australia (Kemp and Michalk 1998; Kemp et al. 2002; Li et al. 2010). Concerns over persistence (Alemseged et al. 2003; Li et al. 2010) appear to have retarded adoption but Li et al. (2020), for example, observed good persistence for at least 4 years under a cutting regime at a site (Hamilton, Victoria) similarly suited to temperate species as the Southern Tablelands. The importance of a companion legume and suitable grazing management for persistence has been noted (Kemp and Michalk 2002; Alemseged et al. 2003; Li et al. 2012). In this study, Puna chicory persisted without decline at both sites whereas the more winter-active Commander declined by 33% at Goulburn and 17% at Bombala although stands were still productive. Observations at Goulburn after the experimental period (November 2021) indicated excellent density in Puna but low density in Commander. Higher persistence by the Puna compared with Commander was also observed by Li et al. (2012).

Herb mixes containing chicory were shown to give increased lamb liveweight gain compared with grass-based pastures during summer in New Zealand (Golding et al. 2011, Somasiri et al. 2015a) and chicory was effective in supporting lamb growth over summer on the Central Tablelands of NSW (Holst *et al.* 2006). The value of chicory for lamb fattening over summer has also been observed at sites in south-eastern Australia in farmer demonstration projects, e.g. PIRD.99.v02 (2005), PIRD 96.n04 (2006), PIRD 98.n13 (2006). We conclude that a limited area devoted to chicory could make a very significant contribution to the ability to finish lambs on the Southern Tablelands.

Cocksfoot. Cocksfoot is already widely sown in the Southern Tablelands region where it is adapted to a wide range of soil types including lighter-textured, acidic and lower fertility soils. This includes intermediate and higher summer dormancy types more persistent through dry summers than the summer-active (subsp. *glomerata* type) cultivars sown in this study.

Summer-active cocksfoot demonstrated a potential similar to tall fescue for substantially higher production than phalaris from late spring to autumn at the core sites (except for the drought summer) and at Dry Plain. Like tall fescue, cocksfoot declined by around 20-30 % during the drought period at the core sites but recovered partially under high rainfall to remain productive post-drought. Cv. Porto was more persistent than cv. Savvy during drought at Goulburn and Canberra.

Cocksfoot was more productive than tall fescue in the late spring to autumn period at core sites in the final year following the drought. It was equally as productive as chicory in late spring and autumn of the final year at Bombala and nearly as productive as chicory in the final summer at Goulburn. High summer-autumn productivity by cocksfoot in the favourable 2020-21 summer at Dry Plain supports similar observations at the core sites. In the Canberra pilot experiment, Porto cocksfoot was highly ranked for production in all seasons and was the most productive grass species in the first summer. It was more persistent than either of the tall fescue cultivars under drought at this site. Cocksfoot was not grown on the acid soil at Gunning. However, cocksfoot is more tolerant of acid soils high in Al than phalaris and tall fescue (Hayes et al. 2012; Song et al. 2015) and would be expected to perform well in the acid soil at Gunning.

Cocksfoot was broadly similar in ME content to tall fescue and phalaris but slightly higher on average in NDF. Its tendency for stem development during summer was only slightly greater than that of tall fescue and much less than phalaris. Like all the grasses, ME content of cocksfoot during summer at the core sites was usually well below 10.5 MJ/kg ideal for rapid growth of lambs, only achieving this level once with other species in February 2021 at Bombala. In a Tasmanian study, Kara cocksfoot consistently exceeded 10.5 MJ/ha under field conditions and was considered sufficient to satisfy the requirements of a dairy cow (Turner et al. 2006). However perennial ryegrass exceeded cocksfoot in ME content. Cocksfoot was consistently high in crude protein among the perennial grasses as has been observed elsewhere (Turner et al. 2006; Hayes et al. 2010).

Our results suggest that summer-active cocksfoot has a definite role in warm season pasture for meat production on the Southern Tablelands, particularly on lighter-textured soils. Combined with its tolerance of low fertility and acid soils, summer-active cocksfoot of the cv. Porto type is recommended over tall fescue for pasture with higher summer growth potential than phalaris. Summer-active cocksfoot may not persist well during occasional severe droughts as in the Canberra experiment and under close grazing at an acid soil site north of Canberra (Culvenor et al. 2004). A decision to sow may therefore depend on perceived risk of major drought but less so than tall fescue. Avoidance of grazing below about 1600 kg/ha has been recommended to improve persistence of summer-active cocksfoot during dry summers (Hackney and Dear 2007). Summer-active cocksfoot should survive well during normal summers on the Southern Tablelands.

Tall fescue. Summer-active (continental) tall fescue is less widely used on the Southern Tablelands than cocksfoot but its potential as a high-quality species for grazing enterprises has been demonstrated in areas of south-eastern Australia with rainfall >600 mm, particularly on heavier soils which retain moisture (Reed et al. 2008; Raeside et al. 2012).

Summer productivity of tall fescue substantially exceeded that of phalaris in moist summers at Goulburn. Productivity was generally similar to cocksfoot being slightly greater in the first summer but less in the third summer after the drought. Persistence was like that of Savvy cocksfoot and slightly less than Porto at Goulburn and similar to both cocksfoot cultivars at Bombala (except for Finesse Q which was less persistent). Porto cocksfoot was more persistent than either tall fescue cultivar in the Canberra experiment.

Tall fescue also demonstrated its significantly higher potential for summer production compared with phalaris in the Gunning mixtures experiment before declining during the 2019/20 drought period. It survived the first summer at Gunning as well as phalaris and made a partial but gradual recovery in the high rainfall period after the drought. Average decline in frequency of Quantum II MaxP at Gunning was 85 % immediately post-drought (recovering to 74 % less a year later) compared with 30% at Goulburn and 21 % at Bombala core sites. In comparison, phalaris declined by 13 % at Gunning and was stable at the core sites. In other studies, Demeter summer-active tall fescue declined more than phalaris under grazing during a drought year at Canberra (Axelsen and Morley 1968). Quantum II tall fescue declined by 48 % during drought at a short season site in western Victoria although it was also highly productive over a three-year period (Reed et al. 2008). In another study, Quantum II tall fescue persisted similarly to Landmaster phalaris at sites in western Victoria but not in the southern NSW cropping zone (Culvenor et al. 2015). AU Triumph summer-active tall fescue declined more than phalaris across sites in southern Australia but only by 10-20% despite low rainfall years (Nie et al. 2008).

The larger decline in Quantum II tall fescue during drought at Gunning compared with the core sites may be partly related to high acidity and exchangeable Al in the soil profile restricting root growth. Landmaster phalaris and Demeter summer-active tall fescue are very similar in their Al tolerance (Song et al. 2015) but the Al tolerance ranking of Quantum II tall fescue is unknown. With lime application it was sufficient to establish well at Gunning and provide a dense, productive stand in the second spring after sowing.

Nutritive value of tall fescue was broadly similar to that of cocksfoot and phalaris. Tall fescue was marginally higher in ME at some sampling dates and lower on average in NDF facilitated by less stem development. Its low aftermath heading and resulting low stem content in summer did not appear to substantially benefit its nutritive value compared with cocksfoot and phalaris even when phalaris had stems present. Tall fescue ran to head much earlier in spring than other grasses which would reduce nutritive value at that time. Because of this, heavy grazing of tall fescue through spring is recommended (Raeside et al. 2016) but this may be difficult to achieve.

We conclude that summer-active tall fescue can be a highly productive grass and will likely survive normal dry periods on the Southern Tablelands. A decision to use it will depend on the perceived risk of major drought and preparedness to resow after such an event. Given its good productivity in the warmer months this may be warranted for a highly productive finishing paddock but probably not for long-term, general-purpose pasture. Avoidance of grazing below about 1000 kg/ha during dry summers is recommended for persistence (Raeside et al. 2016).

Perennial ryegrass. Despite being less drought tolerant than phalaris, cocksfoot and tall fescue, perennial ryegrass was included at core sites because of its potential to support high production grazing enterprises as demonstrated by its dominant role in dairy pastures (Neal et al. 2009) and its high seedling vigour which results in rapid grazing readiness, as observed at the Bombala core site, and ease of re-establishment compared with other perennial grasses.

If the experimental mountain rye entry is ignored, perennial ryegrass was the least persistent species through drought at Goulburn (46% decline in frequency on average) but surprisingly was not the least persistent at Bombala (14 % decline on average cf. 23 % on average for cocksfoot and 49% decline for Finesse Q tall fescue). Soil type and cooler average temperatures at Bombala may have been factors in this result. Persistence during drought by perennial ryegrass in the relatively cool environment of Dry Plain was also higher than at Goulburn and like that at Bombala.

Base AR37 tetraploid perennial ryegrass had the highest total summer production after chicory and lucerne at Bombala (although values were low), and ryegrass cultivars were similar to cocksfoot and exceeded tall fescue in total autumn production there. Despite loss of plants during drought, perennial ryegrass cultivars also remained reasonably productive at Goulburn in late spring and the first half of summer in 2020/21 under the cutting regime employed. Perennial ryegrass was the equal most productive species over the two summer seasons at the high-altitude Dry Plain site.

Perennial ryegrass had a clear advantage over other perennial grasses in nutritive quality and was only exceeded on average by chicory in ME content. This advantage in nutritive quality compared with the other perennial grasses was expressed mainly at Goulburn. At Bombala, nutritive quality of other perennial grasses was closer to that of perennial ryegrass probably because sampling was largely confined to late summer or autumn due to the dry summers.

Our results confirm recommendations that perennial ryegrass is more suited to cooler areas of the Southern and Central Tablelands of NSW (Clements et al. 2003). They indicate a possible role for perennial ryegrass in summer-autumn meat production in cooler districts or where growers are prepared to re-seed if stands do not persist.

Prairie grass. Prairie grass is a vigorous, usually short-lived perennial grass with potentially high nutritive quality and heat tolerance suited to fertile, well drained soils (Stewart 1996). Research has shown it is a suitable alternative to perennial ryegrass in subtropical dairy pastures in Australia so long as it is managed to allow seedling recruitment (Fulkerson et al 2000; Neal et al. 2009). Stands at least 4 years old at free-draining sites on the Southern Tablelands have been achieved by allowing seedling recruitment (T. Winters, Cleanseeds Pty Ltd, pers. comm.).

Consistent with its reputation for rapid early growth, prairie grass was the highest-yielding species at Goulburn in the first summer but ranked much lower for summer production in the third summer. Prairie grass was outstanding for autumn production in all 3 years at Goulburn. Abundant seedling recruitment was observed in all years at Goulburn. Reliance on seedling growth after seeding in late spring/early summer probably explains the lower summer production after the first year but then high autumn growth once seedlings had grown larger. Prairie grass was less productive compared with other species at Bombala although it produced well in winter/early spring of 2020. These results can be explained by the much lower level of seedling recruitment observed at Bombala, possibly a chance result due to timing of late spring/early summer removal of heads but also to the drier summers. Unlike reports that prairie grass retains high nutritive quality even when reproductive (Turner et al. 2007), we consistently found lower nutritive quality (lower ME and crude protein, higher NDF) relative to non-brome grasses in samples of bulk herbage collected by forage harvester. This was observed mainly in summer harvests and less so in autumn harvests and was at least partly due to reproductive stem content. Lower ME content associated with higher fibre content was also observed for prairie grass compared with perennial ryegrass and cocksfoot in bulk samples from a Tasmanian field experiment (Turner et al. 2006). Grazing stock could avoid stem material to some extent and select a higher quality diet than we observed.

On balance, prairie grass has potential as a useful addition to warm-season (particularly autumn) pasture for meat production so long as it is managed for seedling recruitment which should not be difficult in grazed rather than mown situations. Ease of establishment because of high seedling vigour is another advantage of prairie grass for shorter term pastures.

Other perennial bromes. Like prairie grass, grazing, pasture and coloured bromes do not tolerate waterlogging but have a more densely tillered and prostrate growth habit better suited to close grazing (Hackney et al. 2007). Gala grazing brome potentially has good winter production (Stewart 1992) and pasture and coloured bromes better summer production (Hackney et al. 2007). Coloured brome had higher early summer production and persistence than perennial ryegrass in dry summers at a 620 mm average rainfall site (Hall and Hurst 2012) and was exceeded only by perennial ryegrass for summer production under irrigation in northern Tasmania (Smith et al. 2015).

All three species yielded reasonably well at Goulburn, with grazing brome better for autumn and winter growth as expected, and pasture and grazing bromes were quite productive earlier in the first and third summers. Coloured brome yielded well in the late spring and first half of the final summer. Like prairie grass, all three perennial bromes depended on seedling recruitment for persistence at Goulburn. There was less recruitment at Bombala due to dry summers and all three species were among the lower-yielding entries except for grazing brome in winter/early spring 2020.

Like the core sites, grazing and coloured brome were not quite as productive in summer at Dry Plain as cocksfoot and tall fescue but more so than phalaris. Grazing brome ranked highly for growth in winter/early spring of year 2 (2020). All the brome species persisted well there with seedling recruitment. Coloured, pasture and grazing bromes were disappointing for low persistence of established plants and lower productivity than phalaris, cocksfoot and tall fescue in the Canberra experiment. Competition in dense clumps of seedlings may have retarded growth Reasonable production by grazing brome in the final autumn after the drought broke at Canberra was an exception.

Nutritive quality of bulk shoots of the three species was on average the lowest of the temperate grasses and largely associated with high stem content. Nutritive quality approached that of other temperate species when stem content was low, and we assume that grazing stock could select a higher quality herbage.

Overall, grazing, pasture and coloured bromes did not rank highly for summer or year-round production or nutritive quality of bulk shoots compared with other grasses. No compelling evidence was gained to suggest they should be used over alternative species.

Plantain. Plantain was reasonably productive in summer and autumn at Goulburn. It was not highly ranked for production under drier conditions at Bombala but was quite productive in the final autumn (April 2021). In the cooler environment of Dry Plain, plantain was much more productive relative to other species than at the core sites, being equally productive as cocksfoot over two summers and not significantly less productive than the highest-yielding species, perennial ryegrass. Presumably this was due to reduced moisture stress under lower temperatures. Productivity under much warmer conditions in the Canberra experiment was low, accompanied by poor persistence.

Plantain tended to wilt during dry periods at all sites but recovered well after rain including the rains in early February at Goulburn which ended the severe drought period there. In a glasshouse experiment, Langworthy et al. (2018) found that plantain was relatively tolerant of combined heat and moisture stress, although not as tolerant as chicory. Plantain readily became reproductive at Goulburn during summer which reduced quality but resulted in plentiful seed production. This allowed seedling recruitment to maintain stand persistence. Lower recruitment at Bombala and Dry Plain resulted in lower frequency by the end of the study although levels remained in the 50-60 % range after two years. Recruitment was not observed to any extent at Canberra on a hard setting soil with a high density of weeds.

Overall, plantain was relatively high in ME content but lower than chicory and perennial ryegrass. It was low in NDF when stem content was low later in summer and in autumn. Plantain was usually lower in crude protein than other species, but levels were mostly adequate for lamb growth.

The potential of plantain as a superior finishing feed for lambs in the warmer months compared with grass-based pastures has been demonstrated under New Zealand conditions (Golding et al. 2011; Somasiri et al. 2015a, b). However, working in western Victoria, Raeside et al. (2016b) found that liveweight gain by lambs grazing plantain during autumn may be lower than expected due to low dietary preference although herbage mass in their study was considered too high for best quality. Lamb growth was also lower in plantain than in chicory and perennial legumes under moisture stress conditions in summer at Palmerston North, New Zealand (Kemp et al. (2021).

On balance, we suggest that the relatively high nutritive quality of plantain combined with reasonable potential for productivity warrants a possible role for plantain in meat production pastures on the Southern Tablelands particularly if these pastures are short term or in cooler areas.

Other grasses. Perennial veldt grass, digit grass and mountain rye formed a group of "experimental" species in this study. Perennial veldt grass was highly persistent at both core sites and of intermediate productivity. Growth relative to other species was higher in autumn-winter-spring than in summer but it exceeded phalaris in summer and autumn production in the third year at Goulburn. It was of generally similar nutritive quality to most of the perennial grasses except for perennial ryegrass and was the highest species in crude protein of the grasses.

Mountain rye is a short-lived perennial that has shown promise on acidic, well-drained soils at high altitude in Australia (Oram 1996). The breeding line, Family 10, was highly productive in the first summer at Goulburn and second only to chicory in the following spring. Seedling vigour was high and spring growth relatively high at Bombala. It did not survive the drought period at Goulburn and declined severely at Bombala. Family 10 requires an opportunity for seeding and recruitment to persist (Oram 1996) and the harvesting schedule employed prevented this. Hackney et al. (2006) observed very high production by mountain rye like that of Italian ryegrass in the first year at another Monaro site. If mountain rye had been managed to allow seed to set and disperse, it likely would have been more persistent and rated more highly as part of a mixed species pasture.

Digit grass was included in the core site study because of perceptions that tropical grasses may be suited to southern as well as northern and central inland NSW where they have proven highly persistent and respond rapidly to summer rainfall (Boschma et al. 2010), and as an initial guide to possible utility under a predicted warmer climate. Digit grass established at Goulburn aided by good rainfall in the first summer but failed to establish under dry conditions at Bombala a year later. It persisted well at Goulburn through two winters and without loss during the 2019/20 drought period. It responded to drought-breaking rains in February 2020 the most rapidly of all species and during this time displayed the very high growth rates that are characteristic of tropical grasses in inland northern NSW (Boschma et al. 2016). Its growing season was confined very largely to summer-early autumn, and it made virtually no growth in the cooler months, making it a highly specialised summer forage. The main disadvantage of digit grass for lamb finishing was its low nutritive quality compared with the temperate species, which was exacerbated by a strong tendency to run to head. Boschma et al. (2016) found that leaf-stem ratio and nutritive quality of digit grass were increased by defoliation fortnightly compared with 6-weekly, together with high rates of nitrogen fertilisation, during summer near Tamworth. However highest levels of metabolisable energy recorded were still only 9.5 MJ/kg DM in green leaf. We measured a highest ME content of 9.9 MJ/kg DM at Goulburn when digit grass was sampled after 2 weeks of growth in February 2020. ME after the following growth period of 3 weeks duration was only 8.8 MJ/kg with a high stem content. Typically, it was 1-2 MJ/kg DM lower than the temperate grasses although diet selection by stock may reduce this gap.

We suggest that tropical grasses such as digit grass do have a future role on the Southern Tablelands but not for applications such as lamb finishing requiring high nutritive quality. Research is required on establishment and management in this environment.

Standard species. Phalaris and lucerne were the standard species in these experiments, phalaris because it is the standard species for sown pastures in the Southern Tablelands/Monaro region, lucerne because it is the standard summer forage species. See the following section on legumes for discussion of lucerne.

Phalaris was highly persistent through drought at the core sites and in the Gunning mixtures experiment and was the most persistent grass species at Canberra. It was clearly superior to the more summer-active species in production during winter which is a time when feed is typically of high value in sheep and beef farms in south-eastern Australia (Ludemann and Smith 2015). The period when other species most reliably expressed their potential for higher production than phalaris occurred in late spring/early summer when decisions must be made on whether to sell lambs or retain them for finishing. Otherwise phalaris performed quite well for biomass and quality later in summer and in autumn.

Good establishment and persistence by Landmaster in the limed but deep acid soil at Gunning supports the revised recommendations concerning the use of phalaris on acid soils which noted that phalaris “should be considered for inclusion in new plantings on acid soils not only for its acid tolerance, but also for its drought tolerance which increases the resilience of pasture swards” (Hayes et al. 2015). The soil profile at Gunning had no physical limitation to root growth to more than 1 m depth (R. Hayes, pers. comm.) which is an important requirement for phalaris to persist well.

With its combination of high persistence, cool season growth and annual production, phalaris remains a natural choice for long-term, general-purpose pastures. A mix of phalaris, lucerne and subterranean clover used on the Bombala host property (J. Jeffreys, pers. comm.) appears highly suitable for that soil type and environment and could respond to cool and warm season rainfall. The Gunning mixtures experiment confirmed the suitability of phalaris and subterranean clover for the general-purpose sown pasture base in that environment.

Legume species

Legumes are a vital component of southern Australian pastures because of their DM production, high nutritive quality and symbiotic nitrogen fixation which underpins the nitrogen economy of productive pastures. The focus of this study was on herbage production and nutritive quality of perennial legumes for animal production during the summer-autumn period. Core site legume experiments were conducted in the absence of a companion grass or herb which would be expected to enhance persistence and productivity during periods of moisture stress. Perennial grasses have been shown to dry the soil and reduce regeneration of subterranean clover during late summer (Dear et al. 1998). This ability increased with the summer growth activity of the companion perennial (Dear and Cocks 1997). At least parallel effects if not of the same magnitude can be expected on some perennial legumes such as the shallow-rooted white clover. Our legume evaluation experiments therefore provided a guide to the potential of a range of perennial *Trifolium* legume species compared with lucerne, the standard summer-growing perennial legume for meat production in south-eastern Australia.

Lucerne. Lucerne was clearly the most productive species during summer in the core site legume experiments. 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. In the non-legume experiments, lucerne was the most productive species during summer except for chicory at Bombala but was exceeded by chicory and equalled by several grass cultivars at Goulburn. However, lucerne gave more reliable summer production than the grasses at Goulburn. Factors possibly reducing relative performance of lucerne at Goulburn included soil conditions and insufficient time between harvests in summer since flowering percentage was very low at most harvests (see Table 4.8).

Total summer DM production of lucerne in the legume experiment at Goulburn was at least 3 times that of the clover species and at Bombala was at least twice that of the most summer-productive clover cultivar, Astred red clover. This continued into autumn 2020 during drought at Bombala and immediately post-drought at Goulburn. Only under high March rainfall in 2021 did the clover species yield similarly to or outyield lucerne in autumn

Lucerne was reliably higher in crude protein than the grasses and herbs and, like chicory and plantain, was relatively low in NDF. ME content of lucerne was about 0.5 MJ/kg higher on average than most of the grasses (except perennial ryegrass) at Goulburn but only equal to the highest grasses at Bombala. At Goulburn, lucerne tended to be higher than the grasses at the late spring/early summer sampling time. It is noted that nutritive quality can decline substantially in mature lucerne under dry summer-autumn conditions (Nie et al. 2021).

Lucerne was highly persistent through drought at both core trial sites and in the Canberra experiment. However, complete loss of lucerne in the deep acid soil at Gunning is illustrative of the limitations of lucerne in some Tablelands soils. Despite a high rate of lime application, highly acidic soil beneath the ameliorated layer would have inhibited growth of deep roots needed for survival of lucerne. Waterlogging is another common limitation on the Tablelands. Very wet conditions in winter 2020 and autumn 2021 at Goulburn appeared to adversely affect lucerne. Observations after the experimental period (November 2021) suggested that lucerne had declined further under continuing high rainfall and wet soil conditions.

Combined with observations of high nutritive quality in summer and good productivity during winter and spring in this study, we conclude that lucerne remains the most productive summer-autumn perennial legume in areas with suitable soil pH and depth and freedom from waterlogging. Unlike most commercial clover species, lucerne has a strict requirement for rotational grazing management (Lodge 1991). Cv. Sardi Grazer used in this study has improved tolerance of extended grazing (Barenbrug 2021) but was no more persistent than cv. Titan 9 under our mowing regime and was usually less productive (10-20 % lower at Goulburn except on two dates and 10-14% lower at Bombala) as has been observed under mowing elsewhere (Nan et al. 2019).

White clover. Summer herbage production of white clover was generally low at core sites with a highest DM recorded of 1.3 t/ha for cv. Haifa in summer 2020-21 at Goulburn. Periods of low rainfall or high temperature at both sites appeared to prevent white clover, and indeed all other clover species, from being very productive during summer and we conclude that an exceptionally wet and cool summer would be required for good summer production from white clover on the Southern Tablelands. This conclusion extends also to the first half of autumn. High early autumn rainfall in the absence of hot weather was experienced in the final year at both sites. This resulted in excellent growth by all perennial clovers at Bombala including white clover (3.3 t/ha on 19 April after 2.3 months growth). In contrast much less growth occurred at Goulburn (0.7-0.8 t/ha) for unknown reasons. White clover showed relatively good productivity in winter and spring at both sites and as expected, its nutritive quality was high except when heavily in flower.

Three cultivars of white clover were included in the study: Haifa, a large-leaved cultivar used widely for many years in Australia; Trophy, a medium to large-leaved cultivar bred for persistence in Australia with demonstrated superior survival of summer moisture stress (Ayre et al. 2007); and Nomad, a small to medium-leaved cultivar selected for increased persistence and drought tolerance in drier environments of New Zealand (Agricom 2021). Haifa and Trophy were of similar productivity in summer at both sites and in all seasons at Bombala. At Goulburn, Haifa was more productive than

Trophy in winter and spring, particularly in the very wet winter of 2020. Both cultivars were considerably more productive than cv. Nomad. For example, Haifa yielded 33 % higher than Nomad in summer and over all seasons at Goulburn and 50% higher in summer and 20 % higher over all seasons at Bombala. Little variation in nutritive quality was observed among cultivars.

Survival of white clover in NSW Tablelands environments relies both on survival and growth of stolons, which is most dependent on warm-season rainfall, and annual regeneration from seedlings, which is dependent on cool-season rainfall (Hutchinson et al. 1995). Grazing intensity and competition from cool-season annuals further influence these processes (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 core 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 since considerable flowering was observed in the previous spring.

White clover did not establish particularly well at Gunning probably due to the late sowing and much below average rainfall in the 5 months after sowing. Growth of established plants was observed in legume-only plots in the first summer which was above average in rainfall but also well above average in temperature. Emergence of seedlings was observed each autumn, but their development was hindered in 2019 by drought and the ingress of cool-season annuals.

A strong effect of companion non-legume species on the legume species including white clover was evident from early on in the Gunning mixtures experiment. Thus, clovers grown alone grew much better than in mixture with the non-legume presumably because the non-legumes reduced availability of moisture and light to the clover (Dear et al. 1998). More frequent defoliation of the swards may have reduced competition for resources from the non-legumes. Set stocking, for example, is known to favour clover composition in pastures compared with rotational grazing (e.g. Chapman et al. 2003). Chicory appeared to suppress clover less than the perennial grasses although its initial frequency was also lower than the grasses. The perennial grasses were dense and their suppressive effect on legume content suggest that lower sowing rates may be warranted. That white clover was relatively more affected than subterranean clover suggests a higher susceptibility probably to moisture stress enhanced by growing in summer when competition for moisture is high. Competition from a perennial grass may also have been a factor in the relatively poor growth by clovers during the final summer and autumn at Goulburn when goosegrass (*Eleusine tristachya)* invaded plots heavily.

Despite these constraints, white clover in the Gunning experiment remained with sufficient frequency that stoloniferous spread under good spring and summer rainfall allowed some production except where competition from perennial grass was high. However, it appears that white clover is near its threshold for survival at this location unless seasons are very favourable. This seems certainly the case in competition with dense perennial grass. Soil nitrogen levels may alter the competitive balance between grass and legume. We conclude that white clover remains worth adding to a pasture mix in more productive paddocks suited to lamb finishing pastures where it can contribute production and substantially improve quality in wet periods.

Caucasian clover and Caucasian × white clover. Caucasian clover and talish clover are deep-rooted perennial clover species suggested as possible options to improve drought tolerance and persistence of the legume component in Tablelands pastures (Hayes et al. 2019). Both currently experience seed supply problems in Australia.

Caucasian clover was highly persistent in the core site legume experiments. It retained a high frequency of live base during drought at Goulburn which assisted productivity in the immediate post-drought period compared with more slowly regenerating species. Caucasian clover was similar in nutritive quality to white clover at all sampling times. Norman et al. (2021) also found that digestibility (and therefore ME content) of caucasian clover was like that of white clover. Summer DM yield was 11 % lower than Haifa white clover on average at Goulburn and 19% lower at Bombala. Total autumn yield during the study was equal highest with talish clover, Haifa white clover and subterranean clover at Goulburn, but was considerably lower than white and red clover at Bombala due to lower growth response to high rainfall in March 2021. Its productivity in other seasons was often considerably lower than white clover, most notably in winter at Goulburn when it yielded 60% less on average than Haifa white clover. During the favourable spring of 2020, caucasian clover yielded 19 % less than Haifa at Goulburn but was equally as productive at Bombala.

Given its superior persistence compared with white clover 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 cv. Monaro caucasian clover 11 years after sowing compared with Haifa white clover, viz. 1475 kg/ha compared with 590 kg/ha in P-fertilised plots averaged over 7 harvests at a 1000 m altitude site in the Monaro region. These observations combined with slow establishment (Black et al. 2006) means that caucasian clover is probably best suited to truly permanent pasture situations but not to short-term pastures. 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).

Caucasian × white clover was developed to improve grazing and drought tolerance of white clover by transferring the deep-rooted rhizomatous growth habit of caucasian clover (Marshall 2001; Lloyd et al. 2017). The response of Aberlasting caucasian × white clover to the 2019-20 drought period was more like that of white clover in this study. It showed similarly low winter productivity as caucasian clover and was the least productive perennial species in all seasons. Nutritive quality was high.

Talish clover. Talish clover retained a higher frequency of live base through the 2019-20 drought and made more rapid recovery than white clover and red clover but was more adversely affected than caucasian clover. It therefore appears to have higher drought survival potential than white clover and red clover but less than that of caucasian clover. At Bombala it was grouped with Haifa and Trophy white clover, red clover and strawberry clover for total herbage DM over two years. It was less productive in the final autumn at Bombala than Haifa and Trophy white clover and red clover but was equally as productive as these species in winter 2020 and was the most productive of all species in spring 2020. At Goulburn, it was like other perennial clovers in summer growth and with caucasian clover was more productive on average in autumn than red clover and white clover except for Haifa but was less productive in winter. Spring productivity was generally like other clover cultivars except for Haifa white clover which was higher. Nutritive quality was either like white clover or sometimes lower in ME associated with higher NDF but nevertheless was high enough for rapid growth of lambs.

Norman et al. (2021) found that vegetative herbage of talish clover was substantially lower in digestibility than white clover associated with higher acid detergent fibre content. They also found that talish clover was of similar productivity over a year to caucasian clover and less than that of white clover. In the milder environment of the Southern Tablelands, productivity and nutritive quality of talish clover appeared closer to white clover than in the study of Norman et al. (2021). Talish clover is likely to be suited to at least some areas with acidic soils since it exhibited relatively high tolerance of Al in solution culture although it was relatively sensitive to Mn (McVittie et al. 2012). With better drought tolerance than white and red clover and good productivity, our evidence suggests that talish clover is well worth considering for sites in the Southern Tablelands environment if seed becomes available.

Red clover. The two cultivars tested in this study, Astred and Rubitas, are a more prostrate type of red clover with some capacity for vegetative spread. They have proven to be more persistent under grazing than traditional erect "crown" types (Smith and Bishop 1998; Hyslop et al. 1996, 1999). Both bred in Tasmania, Rubitas was more persistent than Astred under close sheep grazing at a 678 mm average annual rainfall location in Tasmania (Hall and Hurst undated). Astred is recommended as a long-lived perennial for medium rainfall areas of Tasmania (Knox et al. 2006).

Both cultivars of red clover established well in the core site legume experiments. Frequency of live base was very low immediately after drought at Goulburn, similar to white clover. However, ability to recover via stoloniferous spread was much less than that of white clover and both cultivars finished the experiment with the lowest frequency of any species, around 30-35 %. This lower ability to recover frequency after drought was also displayed at Bombala but frequency declined less during drought to remain at reasonable levels possibly due to cooler temperatures and soil type. Dry summer conditions probably inhibited the development of new plants at stem nodes, a process which occurs mainly post-flowering (Hall and Hurst undated). Red clover survived poorly under increasing drought intensity over two years in the Canberra experiment.

Summer production of red clover was like that of white clover at both sites and much less than that of lucerne. Autumn production was also similar to white clover. Astred had higher summer herbage DM than Rubitas at Bombala but not at Goulburn. During more favourable seasons, e.g. spring 2020 and autumn 2021 at Bombala, red clover and white clover were similar in productivity. White clover exceeded red clover in these seasons at Goulburn due to higher recovery after drought. Haifa white clover was more productive than either red clover cultivar during both winters at Goulburn but was similar to Astred in the single winter at Bombala. Red clover was lower in ME content than white clover on several dates, sometimes by a considerable margin. This was associated with higher NDF and slightly lower crude protein. Norman et al. (2021) found that Rubitas red clover was at least as productive as white clover in warmer and cooler periods of the year at Adelaide. It was lower in digestibility than white clover when vegetative but similar when flowering and when mature.

We conclude that red clover is a rapidly establishing species with potentially good productivity in the Tablelands environment. However, it will be suited to moister paddocks and to moister and cooler districts than Canberra. Like white clover the potential of red clover will only be fulfilled in moist, cool periods and while density remains sufficient. Major drought is likely to see a marked decline in persistence with less ability to recover than white clover displays. Like white clover, it is probably worth adding to a pasture mix in more productive paddocks suited to lamb finishing pastures but would not be suited to long-term general-purpose pastures and in less favourable paddocks.

Strawberry clover. Strawberry clover is a summer-active species usually recommended for areas prone to waterlogging and salinity. It has a reputation for good persistence but questionable productivity in Tasmania (Knox et al. 2003). A New Zealand study reported low productivity by cv. Palestine, but an Australian study reported similar productivity to white clover and red clover at Adelaide (Norman et al. 2021). It is regarded as being 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).

Higher drought tolerance of strawberry clover compared with white clover was amply displayed at Goulburn where frequency of live base of strawberry clover remained relatively high during the 2019-20 drought period and declined less than talish clover but more than caucasian clover. Vigorous spread from stolons then allowed it to recover to have the highest frequency of all species in 2020. Drought survival and recovery were also good at Bombala. Strawberry clover showed its expected good performance under wet conditions at Goulburn, being the highest-yielding species in the very wet winter-early spring period in 2020. Productivity in summer was similar to white clover and red clover and much less than lucerne, higher than white clover and red clover in autumn in two years at Goulburn but around 15 % lower in the favourable autumn of 2021 at Bombala. Winter and spring production was generally good. ME content of strawberry clover was sometimes slightly lower and NDF higher than white clover, but nutritive quality was always high enough for rapid lamb growth. Norman et al. (2021) reported similar nutritive quality to white clover.

Strawberry clover has been included in pasture mixes in Australia for many years without attracting particular attention for productivity except in wet soils. Its high drought tolerance combined with good productivity under non-waterlogged dryland conditions was not anticipated. Lack of competition from a perennial grass may have enhanced its performance since strawberry clover is said to be favoured by hard grazing to control the grass component (Knox et al. 2006). Strawberry clover is also said to be highly sensitive to acid soils (Duncan 1999). However, the registration description of cv. Palestine states that it tolerates a wide range of soil acidity but that it has a high P and K requirement (Oram 1990). Li et al (2008) found that productivity of strawberry clover was like that of lucerne at waterlogging-prone sites with heavier soils even though significant waterlogging did not occur during the period of study.

Our study suggests that strawberry clover could have wider application in general pasture on the Southern Tablelands than at present. Susceptibility to grass competition may make it unsuited to pastures managed to accumulate high levels of biomass, e.g. for finishing lambs. More research is required on the productivity, soil tolerances and grazing management of strawberry clover under normal dryland conditions.

Subterranean clover. The cool-season annual subterranean clover was included in the present 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. Use of an earlier-maturing cultivar was indicated. Leura was able to set seed despite dry conditions at Goulburn in 2019 and strongly regenerated the following year under high rainfall to be highly productive in winter and early spring. It was also the equal-highest producing species with strawberry clover in the final autumn at Goulburn. Subterranean clover, whether originating from sown seed or the existing seedbank, proved better adapted and more productive than white clover in the Gunning mixtures experiment.

Although subterranean clover will contribute little to green forage consumed in summer, e.g. for lamb finishing, it nevertheless grows strongly in other seasons when it can build the soil N levels needed for growth by other species in summer. It therefore remains an important species even for summer-growing pastures.

Summary

(i) Lucerne was the most reliably productive species during summer and should remain a species of choice for the legume component of summer-autumn finishing pastures on the Southern Tablelands/Monaro where it can be grown.

(ii) Chicory was outstanding as a specialist summer species with reliable production of high-quality forage from late spring through summer at least into early autumn. Good drought tolerance and superior acid soil tolerance supports its use as an alternative high-quality summer-active species to lucerne in non-acid and acid soil environments. Like lucerne, a limited area devoted to chicory could potentially make a significant contribution to the ability to finish lambs on the Southern Tablelands.

(iii) Summer-active cocksfoot and summer-active tall fescue can be highly productive grasses which will likely survive normal dry periods on the Southern Tablelands. Both displayed a similar potential for superior summer growth compared with phalaris, typically 50-100 % or 1-1.5 t/ha more DM in moist summers. The two species were generally similar in ME, but cocksfoot was higher in crude protein on average. Combined with its tolerance of low fertility and acid soils, we would recommend summer-active cocksfoot over tall fescue for pasture with higher summer growth potential than phalaris. However, both have a role in warm season pasture for meat production on the Southern Tablelands depending on soil type. Since cocksfoot and tall fescue both declined more under drought than phalaris, a decision to use either species may depend on the perceived risk of major drought and preparedness to resow after such an event. This may be warranted for a highly productive finishing paddock but probably less so for long-term, general-purpose pasture. Careful grazing management can reduce decline in dry summers. Cv. Porto cocksfoot was more persistent than cv. Savvy and tall fescue.

(iv) Perennial ryegrass declined the most of any commercial species during drought at Goulburn but not in the cooler Monaro environment. Perennial ryegrass had a clear advantage over other perennial grasses in nutritive quality and was only exceeded on average by chicory in ME content. We suggest a possible role for perennial ryegrass in summer-autumn meat production in cooler districts or where growers are prepared to re-seed if stands do not persist.

(v) Prairie grass was considered to have potential as a useful addition to warm-season (particularly autumn) pasture for meat production so long as it is managed for seedling recruitment which should be easy to achieve under grazing compared with mowing. Ease of establishment because of high seedling vigour is an advantage of prairie grass for shorter term pastures.

(vi) Grazing, pasture and coloured bromes did not rank highly for productivity compared with other grasses. All three relied at least partly on seedling recruitment for stand persistence. Nutritive quality of bulk shoots of the three species was on average the lowest of the temperate grasses and largely associated with high stem content. Quality approached that of other temperate species when stem content was low. Grazing stock should be able to select a higher quality herbage. No compelling evidence was gained to suggest these species should be used over alternative species.

(vii) Plantain was reasonably productive at the core sites but was more productive, relatively, at the cooler Dry Plain site. It relied partly on seedling recruitment for stand persistence. It was high in nutritive quality when stem content was low and grazing stock should be able to select a higher quality diet when stems are present. We suggest that the relatively high nutritive quality of plantain combined with reasonable potential for productivity warrants a role for plantain in meat production pastures on the Southern Tablelands, particularly if these pastures are short term or in cooler areas.

(viii) Tropical grasses such as digit grass are likely to have a future role on the Southern Tablelands but not for applications such as lamb finishing requiring high nutritive quality unless grazing is restricted to early regrowth with high nitrogen application.

(ix) Perennial veldt grass was highly persistent with good productivity not markedly different from more commonly used species. It displayed good winter growth and exceeded phalaris for summer growth on occasions. On average, it had the highest protein content of the grasses and herbs.

(x) Phalaris combined high persistence, winter growth and annual production. Productivity relative to other species was lowest when partially dormant in late spring/early summer but performed quite well for biomass and quality later in summer and in autumn. Remains a good choice for long-term, general-purpose pastures.

(xi) White clover and red clover were considered worth including in mixes for high production paddocks because of their ability to respond with high quality feed in wet periods. They cannot be relied upon during normal summer conditions on the Southern Tablelands and will decline severely during drought. Red clover will not be able to recover significantly once it declines but the higher capacity for stoloniferous spread of white clover can allow good recovery during sustained wet periods if competition from a perennial grass is not too high. Cv. Haifa was the most productive cultivar of white clover. Red clover has an advantage in rapid establishment and would be suited to shorter-term pastures.

(xii) The superior drought survival ability of caucasian clover compared with other clovers was confirmed. Caucasian was of similar high quality to white clover but was less productive in the short time frame of this study. It is probably suited to long-term, general-purpose pastures in the Southern Tablelands/Monaro.

(xiii) Caucasian × white clover behaved more like white clover in terms of drought response and was the least productive legume cultivar.

(xiv) Talish clover was similar in production to white and red clover in this study and was less affected by drought. Quality was slightly lower but talish clover would be well worth trying in high production pastures when seed is available.

(xv) Strawberry clover showed unexpectedly good drought survival as well as expected tolerance of wet conditions and was one of the most productive cultivars when grown alone without a companion grass. It could have wider application in general pasture on the Southern Tablelands than at present. More research on this possibility is required.

(xvi) Although the late maturing subterranean clover cultivar, Leura, was not well suited to the dry spring in 2019 at Bombala, it did set seed at Goulburn and recovered strongly after drought. Its good production from autumn to spring should allow it to contribute to the nitrogen economy of summer pastures. Excellent adaptation to the Southern Tablelands environment means subterranean clover of appropriate maturity type should be included in mixes even for summer-active perennial pasture.

5.1.2 Grazing study component

The grazing study was consistent with the on-farm species evaluations in suggesting that herb-based pasture, particularly chicory, is a good summer-active option that supports lamb finishing over the summer-autumn period on the NSW Southern Tablelands.

The herb-legume treatment produced the highest rates of lamb liveweight gain in both years of the study. Several studies in New Zealand have illustrated the ability of herb-based pastures to produce high rates of liveweight gain in lambs. Greater rates of liveweight gain in ewes and lambs (both pre- and post-weaning) were recorded on a mix of chicory, plantain, white and red clover than on a ryegrass dominant sward (Golding et al. 2011; Hutton et al. 2011). Somasiri et al. (2015a) showed that herb-clover mixes comprising plantain and/or chicory outperformed perennial ryegrass- clover mixes over summer in terms of lamb liveweight gain, weight at slaughter, carcass weights and dressing out percentages. In an autumn trial, lamb liveweight gain was also greater on the herb-clover mixes than perennial ryegrass (Somasiri et al. 2015a) but the herb-mix comprising plantain and clover did not perform as well as the chicory-plantain-clover mix in a dry autumn, highlighting the superior ability of chicory to persist through dry spells. Fraser and Rowarth (1996) also showed that rates of liveweight gain and fasted weights at slaughter were greater for lambs grazed on white clover or chicory than on plantain or ryegrass over summer-early autumn. However, they noted that CP was the most important driver of lamb productivity, and this was much greater than in the herb-legume treatment in our trials. We found that the CP content of chicory and plantain was marginal for finishing lambs, so growing these in combination with a legume is critical for increasing the sward CP content.

5.1.3 Modelling component

The modelling analysis clearly shows that summer and early autumn feed gaps are likely to be a critical constraint for the adoption of fat lamb systems in many regions of the Southern Tablelands of NSW. It shows that identifying summer-active forages that can augment the existing feedbase to provide high quality feed during summer can have large benefits for mitigating the risks associated with moving to such a system. While this analysis supports the application of lucerne or chicory for such a purpose, this does not exclude a diversity of other forages that may also provide summer growth that may be better suited to specific soils, grazing management or agronomic needs for a particular farm.

While it was not the explicit purpose of this analysis to arrive at an economic assessment of the value that the summer-forages could provide to the system, some simple estimations of this can be made based on this analysis. The expected increases in lamb production from changing to a fat lamb system would generate conservatively about $40-45/ha extra revenue from the livestock system, but this came at significantly higher risk using the existing feedbase (Table 4.29). The analysis here suggests that a fat lamb system could be supported via alternative feed systems to achieve a similar level of risk as the current store lamb system. That is, farmers would experience a similar frequency of farm feed deficits. This would be achieved via replacing 20% of the more fertile or productive soil types on the farm with a summer-active forage. Hence, these forages in combination with the fat lamb system are effectively generating an estimated increase in revenue of around $200 per year per ha sown. This could provide a guideline for the extra cost that could be accommodated for implementing these alternative forages in these systems.

This analysis considered only a limited range of potential forage options that might be utilised in the feedbase in these regions. This was limited by the lack or effective models for many forages, and hence we chose a selection of options for which we had some expectation that the model would perform well. Despite this, the analysis clearly demonstrates the value of extra forage production in summer, as represented by lucerne in this analysis. It would be expected that several other options, such as summer active grasses or cultivars would achieve similar benefits to the resilience of the farm feedbase even though they were not explicitly analysed here. Further, it was clear that further evaluation and refinement of the chicory model available in APSIM may be needed to represent the production levels achieved experimentally. We assumed that chicory would achieve similar production levels and growth patterns to lucerne but may offer benefits of maintaining higher quality. This assumption requires further validation to distinguish between the relative benefits that lucerne or chicory may provide to the system. The field trials conducted as part of this project suggest that chicory is generally more productive than lucerne over the summer-autumn period on the Southern Tablelands, with similar levels of ME (tending to be slightly higher in chicory). However, lucerne has the advantage of fixing its own N for use at the time of growth and for building soil N levels, and it had significantly greater levels of CP compared to chicory.

Finally, as we pointed out earlier in the report, this analysis uses a static approach of comparing the livestock demand for a specified system and target productivity with the potential forage productivity that could be achieved. Hence, this ignores some of the interactions and feedbacks that are likely to occur over time, or the impacts of different forage availabilities on livestock productivity. We did also not investigate or account for how tactical or static adjustments in stocking rates or livestock enterprise management (e.g. lambing time, early weaning, etc), might interact with the alterations to the feed system or could help to mitigate risk. To capture these more complex interactions a more sophisticated modelling approach would be required, but this is likely to require a significant investment of time and resources to further investigate. The current analysis provides some useful insights that could inform such future analysis should that be required.

5.2 Benefits to industry

This project aimed to specifically address the problem of low quantity and quality of pasture over the summer-autumn period on the NSW Southern Tablelands, which limits the ability to finish lambs on pasture. The results of the on-farm species evaluation, grazing study and modelling components consistently pointed to **three major recommendations** for lamb producers in this region:

1. **Convert a limited area of high-fertility land to a specialist summer-active finishing pasture.** Our modelling suggests that conversion to a fat lamb system (c.f. selling lambs as stores) would generate additional revenue of at least $40/ha. By replacing 20 % of the more fertile soils on a farm with summer-active forages to support lamb finishing, the producer could generate an additional $200/year/ha sown.

2. **Use chicory alone or in combination as the non-legume component of a mixed pasture.** Chicory was the stand-out performer in both the species evaluation and grazing experiments, providing forage of high quality and quantity from late spring through at least early autumn, and producing the highest lamb growth rates. It showed good tolerance to

drought and acid soil conditions. Other good non-legume options for the summer-autumn period included summer-active cocksfoot, perennial ryegrass, prairie grass and plantain.

3. **Use lucerne where possible, alone or in combination as the legume component of a mixed pasture.** Lucerne was the most reliably productive legume and should remain the legume of choice in pastures grazed over the summer-autumn on soils that can support it (i.e. not in areas with acidity at depth or prone to waterlogging). The inclusion of red, white and subterranean clovers in summer-specialist mixed pastures is also recommended for their ability to respond to moisture (red and white) and for building N from autumn to spring (subterranean).

These recommendations could be extended to other livestock operations in southern NSW and in areas of Victoria and Tasmania where a summer-autumn feed gap limits animal production. Adoption of these recommendations could also aid in reducing risk within livestock enterprises carrying animals over the warm season by increasing drought resilience.

6. Future research and recommendations

In completing the modelling component of this project, we became aware that existing pasture and forage parameterizations in agricultural models are very limited. This includes chicory despite the existence of a New Zealand model which was used here. In addition, very few summer-active pasture cultivars have been validated. This means that users of these models are either limited to the parameterized species and cultivars or have to adjust species' attributes without proper validation. With the growing emphasis on systems modelling, and the usefulness of modelling pasture behaviour over a greater run of years than field trials can be conducted, we feel this is an unsatisfactory situation. Validating further crop and pasture models should be a priority for future research.

The results of this project suggest that lamb producers on the NSW Southern Tablelands could reduce their risk of feed deficits and improve their ability to finish lambs over the summer-autumn period by converting a portion of high-fertility land to a high-quality summer active pasture. The best performers in our trials, chicory and lucerne, are commercially available and ready for adoption, alone or in combination. This could likely be extended to cattle operations and be applicable in Victoria and Tasmania; validation in these enterprises and areas would be beneficial.

A pathway to adoption for specialist summer-autumn forage would need to include an agronomic package for chicory describing its environmental and overall systems fit, and management recommendations to optimize quality and persistence. This may also include advice for practice changes in converting an enterprise from store to prime lambs, including animal health issues specific to carrying animals through summer. Distribution of this information could be through farming systems groups as well as seed companies. On-farm demonstrations of animal performance and grazing management on a chicory-legume pasture would also be beneficial for engaging farmers and demonstrating that chicory can persist well for several years when grazed carefully. These demonstrations could also include mixtures with other promising species for warm-season production such as summer-active cocksfoot, perennial ryegrass, prairie grass and plantain. Further research is also warranted to test mountain rye under grazing regimes that allow it to set seed, and to investigate the performance of strawberry clover in mixed pastures.

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8. Appendix

8.1. Acid detergent fibre (% DM) over 3 summer-autumn seasons at the Goulburn core site.

Harvest dates were 12-Dec-18, 15-Jan 19, 13-Mar-19, 15-May-19 (Season 2018-19), 18-Nov-19, 11 Mar-20, 22 Apr-20 (Season 2019-20), 30-Nov-20, 13-Jan-21, 24-Feb-21, 8-Apr-21 (Season 2020-21). Means ignore intermediate harvests of some species on 21-or 25-Feb-20 (Season 2019-20) and 21-Dec-21 (Season 2020-21).

Species	**Cultivar**	**Season 2018-19**					**Season 2019-20**					**Season 2020-21**					
		Dec	**Jan**	**Mar**	**May**	**Mean**	**Nov**	**Feb**	**Mar**	**Apr**	**Mean**	**Nov**	**Dec**	**Jan**	**Feb**	**Apr**	**Mean**
Tall fescue	Quantum II MaxP	32.3	26.8	26.6	21.2	26.7	32.5		22.4	23.5	26.1	27.3		24.0	23.8	22.4	24.4
Tall fescue	Hummer MaxP	36.0	26.7	25.8	20.6	27.3	31.7		22.6	23.8	26.0	26.8		24.6	23.4	22.7	24.4
Tall fescue	Finesse Q	32.6	25.8	25.2	20.2	26.0	28.2		21.7	23.1	24.3	27.9		23.5	23.7	22.9	24.8
Cocksfoot	Savvy	32.0	28.2	27.2	22.9	27.6	28.0		24.5	24.2	25.5	31.8		25.7	27.3	25.4	27.5
Cocksfoot	Porto	32.6	27.6	27.3	21.3	27.2	28.3		24.7	26.0	26.4	34.2		24.9	27.3	24.0	27.6
Per. ryegrass	Base AR37	30.6	26.5	24.5	18.3	24.9	23.0		20.8	20.0	21.3	24.2		24.0	19.3	19.5	21.8
Per. ryegrass	Excess AR37	32.5	24.5	25.6	17.2	24.9	25.6		19.8	20.5	22.0	24.8		23.7	19.6	18.1	21.5
Per. ryegrass	Kidman	34.8	26.2	24.8	18.9	26.2	29.6		21.4	21.1	24.1	26.4		23.3	20.7	21.3	22.9
Prairie grass	Atom	31.7	29.6	32.4	26.0	29.9	35.5		24.5	24.2	28.1	27.1		24.3	20.5	22.5	23.6
Grazing brome	Gala	30.6	27.8	32.3	24.8	30.1	36.9		23.2	26.2	28.7	28.5		26.6	22.6	23.0	25.2
Pasture brome	Bareno	32.4	27.2	28.6	23.0	27.8	27.9		19.4	21.4	22.9	30.4		26.4	23.5	22.6	25.7
Coloured brome	Exceltas	34.2	27.8	29.9	24.7	29.2	29.8		19.3	22.9	24.0	31.1		28.4	24.5	22.6	26.6
Mountain rye	Family 10	31.8	29.7	26.7	19.8	27.0	29.7		21.2	20.5	23.8						
Per. veldt grass	Mission	37.0	25.2	23.2	21.8	26.6	31.6		24.2	21.5	25.8	31.7		27.7	22.9	23.5	26.4
Digit grass	Premier	nd	26.2	31.4	33.6		33.4	26.9	31.0	29.9	31.4	28.4	25.4	28.9	32.3	29.5	29.8
Chicory	Puna	30.4	25.9	23.3	20.0	24.9	24.7	21.5	26.9	20.3	24.0	23.1	19.8	22.2	20.3	18.7	21.1
Chicory	Commander	34.0	32.3	26.7	19.6	28.1	24.3	23.6	26.2	21.0	23.8	25.4	19.2	23.7	21.0	18.1	22.1
Plantain	Tonic	29.3	27.7	23.3	19.0	24.8	36.9		29.1	18.7	28.3	25.9		21.1	18.3	18.0	20.8
Phalaris	Holdfast	36.7	28.7	25.8	20.8	28.0	31.3		22.9	23.1	25.7	28.9		26.3	24.1	22.8	25.5
Lucerne	Sardi Grazer	27.3	30.2	26.4	21.5	26.4	30.7		27.7	22.0	26.8	27.1		23.8	23.7	19.4	23.5
	s.e.d. × 2		*2.9*			*1.8*		*2.4*			*1.4*			*2.0*			*1.1*

8.2. Digestibility (% DM) over 3 summer-autumn seasons at the Goulburn core site.

Harvest dates were 12-Dec-18, 15-Jan 19, 13-Mar-19, 15-May-19 (Season 2018-19), 18-Nov-19, 11 Mar-20, 22 Apr-20 (Season 2019-20), 30-Nov-20, 13 Jan 21, 24-Feb-21, 8-Apr-21 (Season 2020-21). Means ignore intermediate harvests of some species on 21-or 25-Feb-20 (Season 2019-20) and 21-Dec-21 (Season 2020-21).

Species	**Cultivar**	**Season 2018-19**					**Season 2019-20**					**Season 2020-21**					
		Dec	**Jan**	**Mar**	**May**	**Mean**	**Nov**	**Feb**	**Mar**	**Apr**	**Mean**	**Nov**	**Dec**	**Jan**	**Feb**	**Apr**	**Mean**
Tall fescue	Quantum II MaxP	51.4	62.6	62.9	67.8	61.2	54.6		67.0	69.4	63.7	62.3		64.5	66.4	67.2	65.1
Tall fescue	Hummer MaxP	47.9	62.6	64.1	67.6	60.5	55.3		67.3	70.4	64.3	63.0		63.7	66.5	68.1	65.3
Tall fescue	Finesse Q	50.2	62.5	63.7	68.2	61.2	60.3		67.5	69.7	65.8	61.8		64.7	66.3	67.6	65.1
Cocksfoot	Savvy	53.8	62.3	60.6	64.0	60.2	59.3		65.7	69.0	64.7	59.8		64.8	64.1	67.5	64.1
Cocksfoot	Porto	52.0	62.1	60.6	65.2	60.0	57.8		65.8	67.0	63.5	56.3		64.8	63.4	68.4	63.2
Per. ryegrass	Base AR37	53.7	64.1	64.4	72.6	63.7	65.1		67.5	73.6	68.7	67.1		65.2	73.1	74.2	69.9
Per. ryegrass	Excess AR37	52.0	65.2	64.0	72.0	63.3	62.4		69.1	74.5	68.7	66.5		65.6	72.2	74.5	69.7
Per. ryegrass	Kidman	50.6	63.8	64.6	71.9	62.7	58.3		67.3	73.5	66.4	64.7		65.8	71.3	71.4	68.3
Prairie grass	Atom	53.5	59.0	55.1	60.7	57.1	49.1		65.7	68.8	61.2	62.9		63.3	69.9	69.8	66.5
Grazing brome	Gala	50.0	63.6	57.0	62.1	58.2	49.9		66.4	68.7	61.6	62.1		62.5	67.5	69.3	65.4
Pasture brome	Bareno	51.1	62.4	58.1	62.4	58.5	57.5		68.1	72.6	66.1	58.2		61.1	66.8	67.9	63.5
Coloured brome	Exceltas	48.8	60.8	56.4	61.3	56.8	55.7		69.2	69.9	64.9	57.4		58.5	65.3	68.7	62.5
Mountain rye	Family 10	52.5	58.3	60.1	67.7	59.6	56.1		66.3	70.7	64.4						
Per. veldt grass	Mission	48.0	66.0	66.8	68.0	62.2	55.4		64.9	71.9	64.0	59.4		62.4	69.0	70.3	65.3
Digit grass	Premier	nd	62.8	56.9	56.5		51.7	67.7	61.4	59.8	57.6	63.1	63.4	60.3	60.2	63.0	61.7
Chicory	Puna	60.7	66.8	68.7	69.8	66.5	68.2	75.3	64.5	74.1	68.9	72.2	75.0	71.2	75.1	75.5	73.5
Chicory	Commander	56.1	59.9	64.8	70.4	62.8	68.4	73.4	63.5	74.7	68.9	69.5	74.8	68.8	73.3	75.5	71.8
Plantain	Tonic	57.0	61.9	66.8	69.6	63.8	50.0	71.3	60.4	76.2	62.2	63.8		67.4	72.8	71.6	68.9
Phalaris	Holdfast	45.8	60.5	62.1	66.3	58.7	56.0		68.5	70.2	64.9	61.5		62.3	67.2	69.2	65.0
Lucerne	Sardi Grazer	62.1	61.9	63.4	66.1	63.4	60.1		64.8	70.3	65.1	67.8		69.3	68.9	71.0	69.3
	s.e.d. × 2			*2.8*		*1.6*			*2.9*		*1.7*			*2.3*			*1.3*

8.3. Acid detergent fibre (% DM) over two summer-autumn seasons at the Bombala core non-legume site.

Species	Cultivar	Season 2019-20			Season 2020-21			
		Dec	Mar	Mean	Dec	Feb	Apr	Mean
Tall fescue	Quantum II MaxP	31.5	22.1	26.8	33.4	19.9	17.8	23.7
Tall fescue	Hummer MaxP	33.9	21.7	27.8	34.0	20.3	19.8	24.7
Tall fescue	Finesse Q	31.0	20.2	25.6	34.7	19.2	17.0	23.6
Cocksfoot	Savvy	31.7	20.8	26.3	34.2	21.8	21.7	25.9
Cocksfoot	Porto	33.0	19.5	26.2	32.8	20.8	22.5	25.4
Per. ryegrass	Base AR37	24.9	18.5	21.7	29.6	19.7	18.6	22.6
Per. ryegrass	Excess AR37	26.6	19.0	22.8	31.4	19.2	18.9	23.2
Per. ryegrass	Kidman	28.8	19.2	24.0	32.4	19.3	19.8	23.8
Prairie grass	Atom	33.6	20.1	26.8	33.4	20.6	21.6	25.2
Grazing brome	Gala	35.0	21.7	28.3	37.1	22.8	19.3	26.4
Pasture brome	Bareno	30.8	20.6	25.8	35.0	25.4	20.3	26.9
Coloured brome	Exceltas	34.2	24.1	29.1	36.4	26.9	19.2	27.5
Mountain rye	Family 10	30.1	24.9	27.5	30.4	26.3	18.7	25.1
Per. veldt grass	Mission	35.1	19.1	27.1	33.5	25.5	19.2	26.0
Digit grass	Premier							
Chicory	Puna	29.8	18.4	24.1	23.6	19.2	15.4	19.4
Chicory	Commander	31.9	18.7	25.4	21.7	21.0	21.0	21.2
Plantain	Tonic	35.1	17.4	26.2	30.4	20.8	15.8	22.3
Phalaris	Holdfast	31.0	17.8	24.4	33.5	19.6	21.2	24.8
Lucerne	Sardi Grazer	29.6	16.9	23.3	27.2	19.0	21.6	22.6
	s.e.d. × 2	*2.3*		*1.7*		*2.4*		*1.4*

8.4. Digestibility (% DM) over two summer-autumn seasons at the Bombala core non-legume site.

Species	**Cultivar**	**Season 2019-20**			**Season 2020-21**			
		Dec	**Mar**	**Mean**	**Dec**	**Feb**	**Apr**	**Mean**
Tall fescue	Quantum II MaxP	56.4	70.0	63.2	54.5	73.0	72.5	66.7
Tall fescue	Hummer MaxP	53.8	70.5	62.2	53.9	73.2	69.2	65.4
Tall fescue	Finesse Q	56.7	72.0	64.4	53.7	74.1	74.5	67.4
Cocksfoot	Savvy	57.3	70.7	64.0	53.6	72.3	69.4	65.1
Cocksfoot	Porto	57.0	73.2	65.1	56.3	72.6	67.8	65.5
Per. ryegrass	Base AR37	63.7	76.0	69.9	58.7	72.0	70.1	66.9
Per. ryegrass	Excess AR37	61.9	75.9	68.9	56.8	72.9	70.2	66.6
Per. ryegrass	Kidman	59.3	74.1	66.7	55.2	72.3	68.8	65.4
Prairie grass	Atom	50.8	70.4	60.6	55.4	73.4	68.9	65.9
Grazing brome	Gala	50.1	69.4	59.8	51.0	71.4	73.5	65.3
Pasture brome	Bareno	54.2	70.2	62.2	52.8	65.0	70.9	62.9
Coloured brome	Exceltas	50.2	67.1	58.7	51.3	62.6	72.7	62.2
Mountain rye	Family 10	55.4	67.3	61.4	59.5	67.5	73.9	67.0
Per. veldt grass	Mission	53.0	75.0	64.0	53.0	64.7	71.4	63.0
Digit grass	Premier							
Chicory	Puna	62.0	75.5	68.7	65.6	70.7	72.0	69.4
Chicory	Commander	60.7	76.0	68.4	68.4	69.0	67.7	68.4
Plantain	Tonic	53.7	77.5	65.6	57.7	69.9	71.5	66.4
Phalaris	Holdfast	58.1	74.8	66.4	55.4	74.6	70.9	67.0
Lucerne	Sardi Grazer	61.4	74.3	67.9	63.1	73.9	65.9	67.6
	s.e.d. × 2	*2.3*		*1.7*		*3.5*		*1.9*