Yield and botanical composition of four dryland pastures at Ashley Dene Research Farm over 8 years

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Abstract
Dry matter yield and botanical composition of four grazed dryland pasture types were compared over 8 years in summer-dry conditions at Ashley Dene, Canterbury, New Zealand. The experiment was sown in March 2013 to evaluate cocksfoot (CF)- or meadow fescue/ryegrass hybrid (RG)-based pastures established with either subterranean (Sub) or subterranean and balansa (S+B) clovers. Plantain was included in all pasture types. Perennial ryegrass established poorly on the low soil moisture holding capacity Lismore soil and in Year 2 was re-broadcast into the RG pastures. Despite this, plantain was the main sown species in RG pastures beyond Year 3. Total spring yield was greatest in Year 5 at 6720 kg DM/ha and varied with spring rainfall. Cocksfoot-based pastures had 60% of sown species present in the spring of Year 8, compared with 28% in RG-based pastures. Balansa clover was only present up to Year 5 after a managed seeding event in the first spring. White clover did not persist in the dryland environment past Year 2. Sub clover yield depended on the time and amount of autumn rainfall but contributed up to 45% of the spring yield. Cocksfoot-sub clover pastures appear to be most resilient in this summer-dry environment with variable spring rainfall.

Keywords: *Dactylis glomerata, Lolium perenne, Plantago lanceolata, Trifolium subterraneum, Trifolium michelianum*

Introduction
In New Zealand, dryland (rainfed) pastures rely on legumes to supply fixed nitrogen (N) and provide nutritious forage. Once soil nutrient deficiencies such as phosphorus, sulphur and molybdenum are corrected, soil moisture becomes the dominant influence on the choice of legume species for dryland pastures. These pastures can be characterised by the average length of the summer-dry period when growth is negligible due to low soil moisture. The duration of this dry period influences which legume species will thrive. In areas with reliable summer rainfall, where perennial white clover (*Trifolium repens* L.) is suitable, summer-dry periods are short and annual legumes are normally absent. Where the intensity and duration of summer moisture deficits increases, the contribution of annuals to total legume production increases and white clover declines from grazed pastures (Knowles et al. 2003). Annual species such as subterranean (sub) clover (*T. subterraneum* L.) dominate pastures in areas with an average of three to five months dry soil conditions each year (Olykan et al. 2019).

The productivity and persistence of temperate species in dryland environments is important for on-farm profitability, particularly for sheep and beef farmers. This was investigated previously in a 10-year (2002-2012) grazed 'MaxClover' experiment at Lincoln University. The control ryegrass (*Lolium perenne*)/white clover pasture was as productive as other grass-based pastures up to Year 5 (Mills et al. 2014). However, the contribution of sown species components to total yield on those pastures declined on average by 10% per year, compared with 4% per year for cocksfoot (*Dactylis glomerata* L.) based pastures. In that experiment both sub and balansa (*T. michelianum* Savi) annual clovers enhanced the total legume contribution in cocksfoot-based pastures. However, the impact of their combined contribution was not examined.

The Templeton silt loam soil on the 'MaxClover' site has a moderate soil moisture holding capacity of 140 mm/m (Mills et al. 2006). To expand the relevance of those results to drier conditions, indicative of north- and west-facing slopes on hill country, a second grazed experiment, 'MaxAnnuals', was established. This experiment was located at Ashley Dene farm ~10 km west of the initial site but on a shallower Lismore stony silt loam with only 70 mm/m soil moisture holding capacity. The 'MaxAnnuals' experiment aimed to determine whether a combination of annual clovers, white clover and plantain (*Plantago lanceolata* L.) sown with cocksfoot or perennial ryegrass could provide productive and persistent pastures. The experiment was stocked initially for 5 years and live-weight and pasture production were measured. The plots were then used as part of the commercial farm for 2 years, until winter/spring 2020, when the opportunity arose to measure spring production and botanical composition of these pastures in Year 8. These results are used in this paper to quantify observed differences in the persistence of the sown species and the subsequent invasion of annual and grass weeds as biological indicators of pasture persistence.

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Materials and Methods

Site history and soil

The experiment was established in autumn 2013 at Ashley Dene (43°38′ S, 172°19′ E, 39 m a.s.l.), the Lincoln University dryland farm (Lucas et al. 2015; Hannah 2018). This involved dividing two commercial sized paddocks into 16 experimental units, each 0.5 ha and arranged in four replicate blocks. Earlier, in January 2012, Replicates 3 and 4 were sown in forage rape (*Brassica napus* L.) following lucerne (*Medicago sativa* L.). This was break-fed by sheep over winter, before a cultivated summer fallow for soil moisture conservation and weed control prior to pasture establishment. Replicates 1 and 2 followed a ryegrass/sub clover permanent pasture. It was sprayed with glyphosate 360 at 3 L/ha on 4 April 2012, and cultivated conventionally before sowing. During the experiment plants of nodding thistle (*Carduus nutans* L.) were hand-grubbed, but no other weed control was practised. The soils are stony with variable depth to alluvial gravels, typical of the floodplain areas on the Canterbury Plains. The majority of the site is classified as a Lismore stony soil (~88%) with small areas of Lowcliffe stony (~9%) and Ashley Dene deep (~3%) soils in the SW corner of replicate 1 (Webb & Bennett 1986).

Experimental design and establishment

In autumn 2013, four annual clover-based pastures (Table 1), in four replicates were established in a randomised complete block design on 23 March 2013 and 16 April 2013. Pasture treatments were 'Ultra Enhanced' meadow fescue/perennial ryegrass hybrid cross sown with sub (RG/Sub) or sub plus balansa clovers (RG/S+B), or 'Greenly' cocksfoot sown with sub clover (CF/Sub) or sub and balansa clovers (CF/S+B). Sub clover was sown at a rate of 10 kg/ha and comprised 5 kg/ha each of 'Rosabrook' and 'Denmark' cultivars. Plantain cv. 'Tonic' and white clover cv. 'Grasslands Nomad' were also basal components included in all pasture mixes.

After the first year the hybrid meadow fescue/perennial ryegrass populations were sparse so 20 kg/ha of 'SFR31-033' perennial ryegrass seed infected with AR1 endophyte was broadcast over the eight ryegrass-based paddocks on 16 April 2015. Sheep mobs were used to trample in the seed and closed to allow seedlings to establish. The eight CF-based pastures had a "maintenance" grazing by hoggets from 30 June 2015 to 10 July 2015 to prevent suppression of the sub clover.

Soil fertility and fertiliser applications

Before establishment, no fertiliser was applied in 2011

Table 1 Sowing rates (kg/ha) of species and cultivars used in 'MaxAnnuals' experiment established at Ashley Dene, Canterbury, in autumn 2013 (Hannah 2018).

	Subterranean clover		White clover	Plantain	Balansa clover	MFxRG hybrid	Cocksfoot
Pasture	'Rosabrook'	'Denmark	'Nomad	'Tonic'	'Bolta'	'Ultra Enhanced'	'Greenly'
CF/Sub	5	5	0.5	0.5	0	0	2
CF/S+B	5	5	0.5	0.5	4	0	2
RG/Sub	5	5	0.5	0.5	0	10	0
RG/S+B	5	5	0.5	0.5	4	10	0

Table 2 Soil test results (0-7.5 cm) of soil cores bulked across replicate or pasture treatments over time for the dryland grazing experiment at Ashley Dene, Canterbury. Samples were collected in May or June.

Year	Area/Pasture	pH	Olsen P	K	Ca	Mg	Na	SO_4-S	Base saturation	Cation exchange capacity
		(H_2O)	µg/mL	Milliequivalents(me)/100g				µg/g	%	me/100g
2013	Reps 1 & 2	5.8	13	0.40	7.7	0.50	0.09	4	58	15
	Reps 3 & 4	5.9	20	0.59	7.0	0.50	0.08	6	55	15
2014		5.7	13	0.45	6.4	0.44	0.10	6	51	15
2015		5.6	20	0.53	7.2	0.59	0.15	36	58	15
2016		5.5	19	0.69	6.5	0.52	0.14	22	56	14
2017		5.8	32	0.71	7.5	0.68	0.14	11	62	15
2020		5.9	26	0.73	7.3	0.80	0.16	5	57	16

or 2012. In 2013 and 2014, following soil tests (Table 2), 350 kg/ha of Sulphur Super 20 (0% N, 8% P, 0% K, 20.6% S, 18% Ca) was applied to Replicates 1 and 2 and 180 kg/ha to Replicates 3 and 4. In 2015, 2016, 2019 and 2020 Sulphur Super 20 was applied to all replicates in early spring at 200 kg/ha. No fertiliser was applied in 2018.

Environmental

The long-term (1970-2012) mean annual rainfall at Burnham, ~3 km NE of the site, is 644 mm with monthly long-term mean rainfall ranging from 43 mm in February to 71 mm in August (Table 3). Rainfall measured on-site was highly variable with monthly totals ranging from 1 mm (January 2020) to 153 mm (July 2017). Mean monthly air temperatures followed expected seasonal patterns in this temperate environment but were consistently above average from July-December in Year 1 (2013/14; Table 4). In February 2016 the mean monthly air temperature was 18.8 °C, which was above the long-term mean of 16.2 °C while temperatures were ~10% below average in July 2017, August 2015 and August 2016.

Livestock and pasture management

Grazing management aimed to optimise the quantity

Table 3 Monthly rainfall (mm) from Ashley Dene, Canterbury from 2013/14 to 2019/20 (July-June) and July-October for the final season (2020/21). The long-term mean (LTM) for the period 1970-2012 is from the Burnham Sewage Plant located ~3km NE of Ashley Dene Farm.

	2013/14	2014/15	2015/16	2016/17	2017/18	2018/19	2019/20	2020/21	LTM
Jul	36	32	45	18	153	27	78	49	63
Aug	40	16	44	41	76	25	58	12	71
Sep	39	19	50	27	47	39	31	30	45
Oct	79	23	8	52	42	55	73	14	53
Nov	33	39	9	42	2	77	55		48
Dec	83	26	29	56	29	59	40		50
Jan	18	26	85	43	106	27	1		45
Feb	46	21	10	10	148	30	19		43
Mar	120	56	31	70	57	25	59		52
Apr	139	94	16	106	109	82	10		49
May	31	5	146	46	52	28	28		64
Jun	47	67	18	39	54	93	77		61
Total	711	422	491	550	875	566	528		644

Table 4 Mean air temperature (°C) from Ashley Dene, Canterbury from 2013/14 to 2019/20 (July-June) and July-October for the final season (2020/21). The long-term mean (LTM) for the period 1981-2010 is from the Broadfields meteorological station near Lincoln.

	2013/14	2014/15	2015/16	2016/17	2017/18	2018/19	2019/20	2020/21	LTM
Jul	8.2	6.7	6.4	6.7	5.5	7.3	7.9	6.2	16.9
Aug	9.4	7.3	6.7	6.5	8.2	7.6	7.0	8.1	16.6
Sep	9.5	9.2	8.1	9.9	10.0	8.6	8.8	9.6	14.9
Oct	12.4	11.2	12.0	11.5	11.5	10.7	10.1	11.7	12.2
Nov	13.7	13.5	13.1	13.4	13.8	12.7	15.0		9.3
Dec	16.1	15.6	14.5	15.2	17.3	15.2	15.2		6.7
Jan	15.9	17.8	15.6	16.7	18.5	17.8	16.1		6.1
Feb	16.4	16.2	18.9	16.8	16.0	16.8	16.9		7.6
Mar	13.8	15.3	15.8	14.5	15.0	16.3	13.5		9.6
Apr	12.2	12.9	12.8	12.1	11.2	10.8	11.9		11.5
May	9.8	9.4	11.8	8.1	9.2	10.3	9.5		13.3
Jun	8.0	6.7	8.5	6.6	6.6	5.9	7.5		15.4
Average	12.1	11.8	12.0	11.5	11.9	11.7	11.6		11.7

and quality of herbage produced for sheep "production" periods when live-weight (LWt) was measured, primarily in spring (Hannah 2018). It was endeavoured to match animal demand to feed supply. "Maintenance" grazing events, when LWt was not measured, occurred when pasture production was low. Grazing during these periods reduced dead material in pastures after summer and minimised competition from companion grasses, herbs and weeds for emerging annual clovers in autumn.

In Year 1 (2013/14), pastures were managed for establishment and seed set of the annual clovers. This involved one grazing by set-stocked hoggets from 17 September to 21 October 2013, before destocking for seed set with the aim to create a seed bank for regeneration in subsequent years. This initial seeding period was followed by set-stocked ewes from 14 January 2014 to 5 February 2014 and then hoggets set stocked from 6 May 2014 to 16 June 2014. From Years 2-5, ewes and their twin lambs were assigned to pasture treatments to measure animal production for the spring set-stocking phase. Ewes and lambs were set-stocked on their allocated pasture treatment for ~1 month and then mobs were combined into treatment groups and rotational grazing commenced. In most years, ewes were removed from treatments at weaning. Weaned lambs were returned to their allocated treatments to continue grazing, if sufficient feed was available. Pastures were destocked when feed supply was insufficient to support animal demand over summer. Hoggets typically grazed in the autumn and hoggets or dry ewes were used for most grazing events in summer and winter. For Years 6 and 7 the plots were grazed by the commercial flock as part of the total farm system, and no animal or herbage measurements were made. No provision was made for sub or balansa clover seed set after Year 1.

Pasture measurements

For Years 1-5, 50 rising plate meter readings (Jenquip EC09) were taken across each paddock before every grazing period. Total feed on offer was estimated by a calibration created from paired herbage yield and plate meter readings taken from a 0.2 m^2 quadrat cut to a residual height of 2.5 cm. One to five quadrats were cut from the plots sampled. Not all plots or treatments were sampled at every calibration event. Botanical composition was determined from subsamples (Cayley & Bird 1996) of the destructive cuts and, where necessary, averaged to get a plot specific value. The fractional composition from the destructive harvest closest to grazing was applied to paddock yields.

In Year 8, which is the focus of this study, yield and composition were determined from exclosure cages. All 16 paddocks (experimental units) were grazed hard by ewes to ~500 kg dry matter (DM)/ha residuals during May and early June 2020 and then plots were destocked. Cages were placed on 31 July 2020 and the first 0.2 m^2 quadrat and remaining cage area cut to a residual 2.5 cm. Cages were cut again on 8 September 2020 and 22 October 2020. One cage was placed per paddock in a representative area. Botanical composition was determined from subsamples of ~50 g fresh weight. Samples were dried at 65 ºC in a forced air oven for 48 hours. Spring pasture yield was defined as the period from 1 July until pastures were destocked as the soil dried out in spring.

Pasture quality for sown grass, sub clover and unsown grasses was determined by grinding dried samples in a Retsch ZM200 grinder with a 1 mm sieve. Near Infrared Reflectance Spectroscopy (NIRS; Floss NIR Systems 5000 Rapid Content Analyser) was used to analyse metabolisable energy (ME), crude protein, neutral detergent fibre (ADF) and acid detergent fibre (NDF).

Statistical analysis

Data were analysed by ANOVA (Genstat V.18, VSN International Ltd). Where the F-test was significant ($P<0.05$), means were separated by Fishers protected least significant difference (LSD) at $\alpha=0.05$. *A-priori* orthogonal contrasts were applied to yield and composition data to compare known groups of interest (CF vs RG-based pastures and Sub vs. S+B pastures). Years were analysed separately.

Results

Total spring yield

In spring of Year 1, pastures established with balansa clover produced 2157 kg DM/ha, which was 29% more ($P<0.05$) than those established without balansa (Figure 1). The following spring (2014), CF-based pastures produced 6175 kg DM/ha which was 5% more ($P<0.05$) than the 5895 kg DM/ha in the RG-based pastures. For the next 3 years there were no differences in total yield among the pastures, which averaged 3430 kg DM/ha in Year 3, 4145 kg DM/ha in Year 4 and 6720 kg DM/ha in Year 5. In contrast to those previous years, total herbage yield was greater ($P<0.010$) in the RG-based pastures in spring of Year 8, predominantly due to the unsown species. RG-based pastures produced 4190 kg DM/ha compared with 3250 kg DM/ha in the CF-based pastures.

Botanical composition

Sown grass yield

During the first year, the RG yields (374 kg DM/ha) were greater ($P<0.01$) than CF yields (173 kg DM/ha) and represented 21% of the total DM produced (Figure 1). The following year CF yield was more than double ($P<0.001$) that of RG at 2510 kg DM/ha or 41% of total

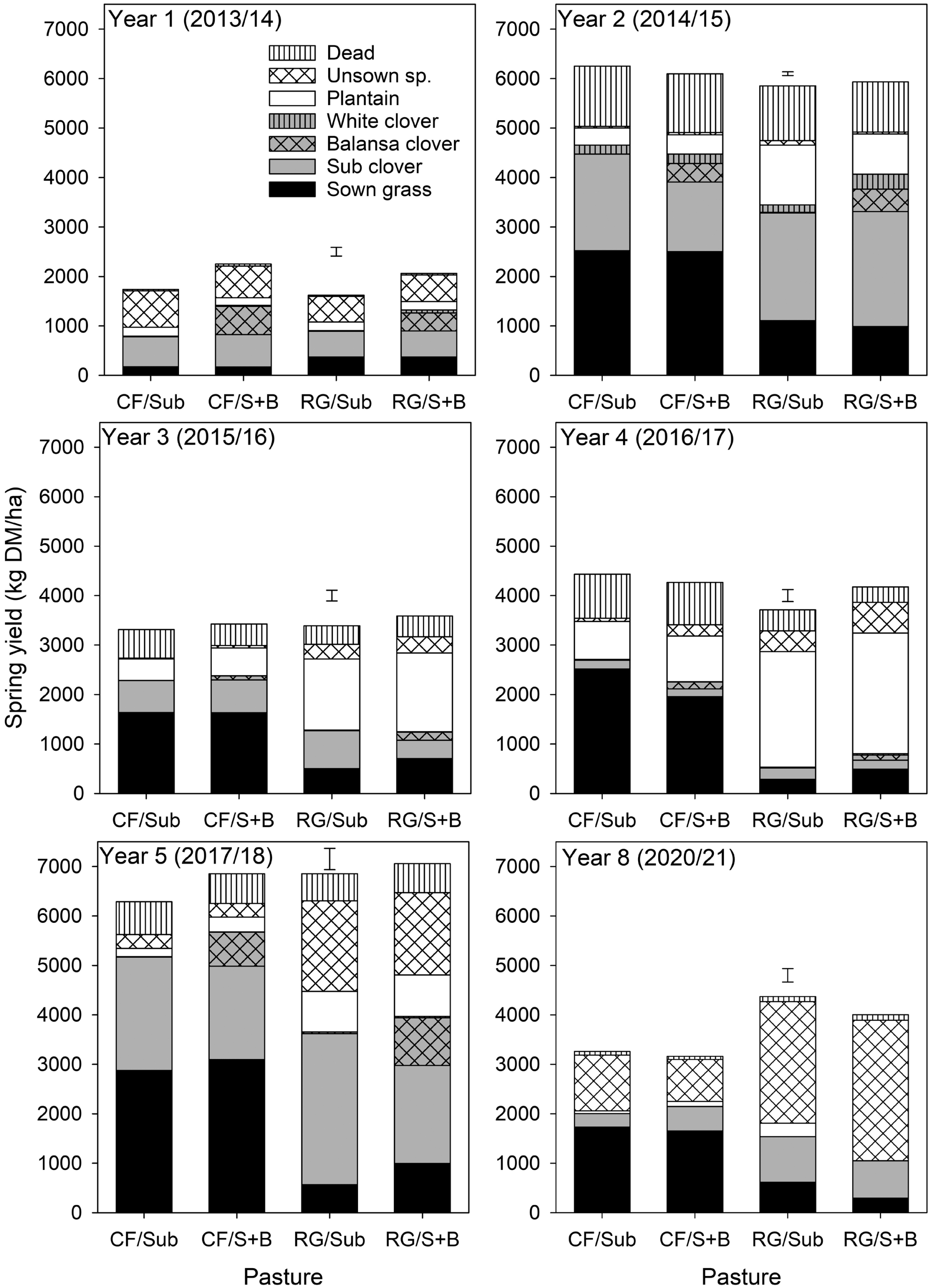

Figure 1 Yield and botanical composition of CF/Sub, CF/S+B, PL/Sub and PL/S+B dryland pastures in spring (July 1 until pastures dried off) over an 8-year period at Ashley Dene, Canterbury. The error bar is SEM for the sum of sown pasture components (grass+clovers+plantain).

yield compared with 1045 kg DM/ha or 18% of total yield. This trend of greater CF yields over RG yields continued through Years 3-5 and was observed in Year 8. In spring of Year 8 the CF yield was 1570 kg DM/ha compared with (P<0.05) 455 kg DM/ha for RG-based pastures. The CF yield represented 48% of the total yield during Year 8 spring compared with only 11% for RG.

Sown legume yields

Sub clover contributions to yield were similar in all pastures in Year 1 and averaged 576 kg DM/ha. The following year the sub clover yield was greater (P<0.05) in the RG-based pastures (2255 kg DM/ha) compared with the CF pastures (1680 kg DM/ha). In spring of Years 3 and 4 sub clover yields were much less and there was no difference among the pastures, averaging 615 kg DM/ha in Year 3 and 185 kg DM/ha in Year 4. In Year 5, sub clover contributed spring yields from 1935 kg DM/ha (S+B-based pastures) to a maximum of 3050 kg DM/ha in the RG/Sub pasture. The 40% sub clover in the Sub-based pastures was greater (P<0.05) than the 30% on offer in the S+B-based pastures. In Year 8 sub clover yield was not different among the pastures and averaged 610 kg DM/ha or 8-20% of the total yield.

Balansa clover yield was 57% more (P<0.001) in the CF/S+B pasture than the RG/S+B pasture (362 kg DM/ha) during Year 1. This was due to its greater stem component as a top-flowering species that was left ungrazed to set seed. In Year 2, balansa clover yield was reduced, averaging 210 kg DM/ha, which did not differ (P>0.05) among pastures. The RG/S+B pastures had double (P<0.01) the balansa yield at 163 kg DM/ha in Year 3 compared with the CF/S+B pastures (80 kg DM/ha). However, balansa clover contributed <3% of total yield in Year 4 and again this did not differ (P>0.05) among pastures. In Year 5, balansa clover yield was 830 kg DM/ha with no difference between the S+B pasture types. In Year 8 there was no balansa clover apparent in any of the treatments.

White clover yield was not significantly different between pasture types and absent from all pastures after Year 2.

Plantain yield

Plantain yield initially was not different among treatments (P≥0.05) and averaged 171 kg DM/ha in Year 1. In Years 2-5 plantain yield was less (P<0.05) in the CF-based pastures than the RG-based pastures. Plantain became the dominant species in the RG-based pastures in Years 3 and 4, contributing 44 and 60% of the total yield, in Sub and S+B pasture types, respectively. In Year 8 plantain yields were reduced and not significantly different across pasture types, with a mean of 108 kg DM/ha.

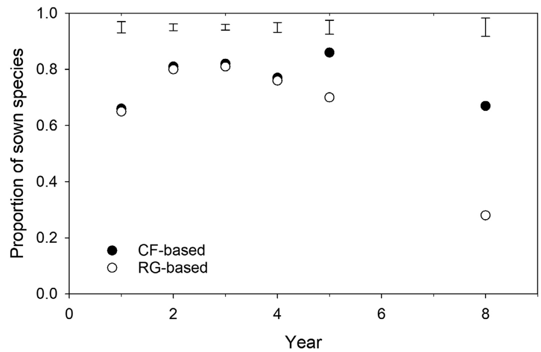

Figure 2 Proportion of all sown species (grass+clovers+plantain) in the yield of CF-based and RG-based dryland pastures in spring over an 8-year period at Ashley Dene, Canterbury. The error bars are the SEM.

Unsown species

In Years 1 and 2 annual dicotyledonous weeds, shepherd's purse (*Capsella bursa-pastoris* L.), chickweed (*Stellaria media* L.), storksbill (*Erodium cicutarium* L.) and fathen (*Chenopodium album* L.) were the main weed species. Subsequently, the main weeds were summer annual grasses, *Bromus mollis* L., *Vulpia* spp. and the winter annual barley grass (*Critesion murinum* L.). Unsown pasture components produced 610 kg DM/ha in Year 1 and accounted for 33% of total yield. In Year 2 unsown species comprised 19% of the total yield which did not differ among pasture types. From Years 3-5, and during Year 8, unsown species yield was greater in RG- than CF-based pastures, ranging from 315 kg DM/ha in Year 3 to 1770 kg DM/ha in Year 8.

Proportion of sown species

There was no difference in the proportion of yield attributable to all sown species (sown grass+clovers+plantain) among pasture types for the first 4 years. The proportion of sown species in the establishment year was 66% which then increased and stabilised at ~80% of the total yield for the following 3 years (Figure 2). In Year 5, the sown species component of RG-based pastures was mainly plantain and sub clover (Figure 1) but these had declined to 70% which was less (P<0.010) than the CF-based pastures at 86%. These components declined further to 28% in spring of Year 8, compared with (P<0.001) around 60% in the CF-based pastures.

Pasture Quality

Metabolisable energy was highest (P<0.001) for ryegrass at 12.1 MJ/kg DM compared with cocksfoot and sub clover at 11.6 MJ/kg DM (Table 5). The unsown grass species had the lowest ME of 11.0 MJ/kg DM.

Crude protein was highest (P<0.001) for sub clover at 26.9% followed by cocksfoot at 21.6%. Ryegrass had the lowest crude protein at 16.2%. ADF and NDF were highest (P<0.001) in the unsown grass at 27.0% and 51.2%, respectively.

Discussion

Cocksfoot was the most persistent grass in this dryland environment with its yield in Year 8 being comparable to earlier low-rainfall years (Figure 1). This is consistent with Mills et al. (2014) who found cocksfoot/sub clover pastures to be the most productive and persistent over 9 years of the 'MaxClover' experiment. Cocksfoot pastures also had a lower proportion of unsown weeds than ryegrass-based pastures. The meadow fescue/perennial ryegrass hybrid struggled to persist after Year 1 and broadcasting of ryegrass was only partially sucessful in Year 2. The lack of grass competition in these treatments enabled higher yields and a higher proportion of plantain (Figure 1). Over time plantain was seen to set seed, with a large number of seedlings germinating with sub clover in autumn. However, seedling establishment appeared limited and the original plants dominated the sown species component, until they declined in number and unsown weed grasses invaded, particularly in the former ryegrass plots.

Total spring yield was highly variable, ranging from 3540 kg DM/ha in Year 3 to 6720 kg DM/ha in Year 5 (excluding the establishing year, Figure 1). This is consistent with the relatively low water holding capacity of the Lismore soil and highly variable winter/spring rainfall that occurs in these dryland environments. This is shown by the highest total yield in Year 5, which coincided with the highest winter/spring rainfall of 320 mm. Years 3, 4 and 8 had similar winter/spring rainfalls of 182-223 mm, which was reflected in their low total yields. The exception was Year 2 when ~6000 kg DM/ha was produced despite low winter/spring rainfall of 176 mm. In this year, pastures contained the highest amount of dead material of any year (~1000 kg DM/ha, Figure 1), which was caused by leaving plots to set seed in Year 1. The dead material subsequently decayed or was eaten over the course of the second year.

Table 5 Quality of pasture components on 8 September 2020 at Ashley Dene, Canterbury. Within columns, different letters indicate differences between means at 5% significance level.

	ME (MJ/kg DM)	Crude protein (%)	ADF (%)	NDF (%)
Cocksfoot	11.6 b	21.6 b	25.3 b	51.7 a
Ryegrass	12.1 a	16.2 d	24.3 b	45.7 b
Sub clover	11.6 b	26.9 a	19.7 c	23.7 c
Unsown grass	11.0 c	19.2 c	27.0 a	51.2 a
P-value	<0.001	<0.001	<0.001	<0.001
SEM	0.099	0.551	1.607	2.704

Sub clover yield was also variable, ranging from 185 kg DM/ha in Year 4 to 3050 kg DM/ha in the plantain-dominant RG pastures of Year 5 (Figure 1). Sub clover yield was high in Year 2 due to a high autumn rainfall (336 mm, February-May) with early emergence occuring due to a 22 mm rainfall event on the 23 February 2014. The variable nature of autumn rainfall throughout the east coast of New Zealand means the contribution of sub clover to spring yields will also be variable and dependent on the timing of rainfall events of at least 20 mm (Lucas et al. 2015), and the cooling soil temperatures that sub clover requires to re-emerge (Teixeira et al. 2020). Sub clover yield in Year 2 also benefited from the grazing spell the previous spring which encouraged seed production. In spring of Year 3 the sub clover yield was low (615 kg DM/ha), due to low autumn rainfall (176 mm). The low yield (185 kg DM/ha) in the spring of Year 4 reflects a 'false strike' germination event that occurred at the end of January when 30 mm of rain fell. This was followed by 6 weeks of little rain (<10 mm) and seedlings were observed to die. A second flush of seedlings was observed in mid-March after 24 mm of rain. However, the seedling populations may have been reduced by the false strike. In spring of Year 5, there was both higher rainfall (232 mm) and an estimated ideal emergence in mid-March after 50 mm of rain fell over 4 days. This led to a higher sub clover yield than the previous years, particulary in the plantain-dominant treatments, where sub clover benefitted from less grass competition. The variable nature of autumn rainfall in this environment will affect the ability of sub clover to produce high quality pastures every spring. When a late break occurs, it would seem prudent to consider the use of N fertilizer in spring to lift pasture covers across the farm (Talamini et al. 2021) to enable the sub clover to grow and set seed the following spring.

Balansa clover yield during establishment was greater in the CF-based than the RG-based pastures, probably due to the slower establishment of cocksfoot (Moot et al. 2000). However, despite a successful seed set, balansa clover yield was low in Year 2. This may be because it produces a high level of hardseededness and it did persist for at least 5 years in the pasture (Nori et al. 2019). This is consistent with previous work that has shown balansa clover will persist in a pasture for 3 or 4 years if left ungrazed during mid-September in its establishment year (Monks et al. 2008). The difficulty is the suggested management of a new seed set every 3 years. The level of balansa clover in all pastures was too low to justify the loss in grazing required to support a second reseeding event. From a practical perspective it is easier to accommodate the recommended on-farm management for sub clover (Olykan et al. 2019) than accommodate the need to let pastures grow to a high mass, as required for the top-flowering balansa clover.

Plantain yield was greater in RG-based pastures in Years 2-5 due to the lack of competition from ryegrass, which did not persist. This meant that these pastures were plantain-dominant, particularly in years when sub clover was not as succesful due to late or low rainfall in autumn/winter. However, in Year 8 plantain yield was low (108 kg DM/ha) indicating that it had not persisted beyond Year 5. Previous surveys have found plantain decreases to <20% pasture cover in grass/plantain pastures after 3 years (Dodd et al. 2019) but may retain a presence for 7+ years (Tozer et al. 2011).

For RG-based pastures the sown species proportion began to decline after 4 years at the rate of ~16% per year (Figure 2). This value is higher than the 10% per year decline reported for ryegrass/white clover pastures over nine growth seasons (Mills et al. 2014). The sown species proportion for CF-based pastures did not begin to decline until after Year 5 and then declined at a rate of 7.4% per year. Mills et al. (2014) reported a decline of 3.3% per year for cocksfoot pastures. The faster rate of decline in this experiment may be the result of the lower soil water holding capacity at this site, which places greater moisture stress on the sown species for a longer period over summer than on the Templeton soil used in the 'MaxClover' experiment. Thus, these persistence results support previous recommendations to use cocksfoot as the main dryland grass (Moloney 1991; Mills et al. 2014).

A greater yield was achieved in Year 8 in the RG-based pastures (Figure 1). However, these pastures were mostly comprised of unsown weed grasses which were of reduced quality compared with the sown species with a low ME and high ADF and NDF contents (Table 5). Sub clover had the highest crude protein %, which along with its N-fixing ability makes it an important component to maintain in dryland pastures.

Conclusions/Practical implications/Relevance

Climate change scenarios suggest that the east coast environments that this experiment is relevant to, will become increasingly dry for longer periods each summer (Salinger 2003). Thus, it would seem prudent for dryland farmers to reconsider their reliance on ryegrass-based pastures and increase their use of cocksfoot-based pastures and learn how to manage plantain and sub clover as appropriate companion species. The variable nature of autumn rainfall should also be recognised as likely to affect the contributon of sub clover to spring yields but it is the most suitable annual clover for dryland pastures (Mills et al. 2014). In years with a late break there may be a need for N fertilizer in early spring to increase pasture cover but rapid responses of grass to N may outcompete sub clover.

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