Persistence of perennial ryegrass, tall fescue and cocksfoot following annual sowings: influence of grass species, ryegrass cultivar and pasture age on yield, composition and density

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Abstract

Persistence is an important component of perennial pasture-grass productivity. Defining traits that affect persistence is essential for improving pasture longevity through plant breeding and for identifying persistence traits that should be included in cultivar ranking indices. Compared with conventional longitudinal studies, where a single sowing is monitored over time, repeated annual sowings allow the effects on persistence of sowing year and the ensuing interactions between environment and age of pasture to be identified. An experiment was commenced in 2015 under sheep grazing in Canterbury and in 2016 under cattle grazing in Waikato, where eight cultivars of perennial ryegrass representing different ploidy, flowering date, and cultivar age (release date), and one cultivar each of tall fescue and cocksfoot were sown in four randomised complete blocks in autumn each year. This paper reports interim data on spring and autumn pasture yield, composition, and density of 3-year-old, 2-year-old and 1-year-old pastures exposed to the same environmental conditions within the same, single year. There were significant effects on yield, botanical composition, basal cover and tiller density due to cultivar, pasture age, and their interaction. When the confounding effect of year-to-year variation was removed by comparing each age cohort in the same year, the underlying differences among grass species and cultivars, and ages of pasture, is starting to reveal the nature of this influence on pasture persistence.

Keywords: *Dactylis glomerata*, *Festuca arundinacea*, *Lolium perenne*, pasture establishment, ryegrass cultivar

Introduction

The 2011 Pasture Persistence Symposium (Mercer 2011 and references therein) identified challenges to productive pasture longevity in New Zealand, especially for newer perennial ryegrass (*Lolium perenne*) cultivars. Poor pasture persistence concerns many farmers, especially in warmer and drier areas of the country. Unravelling the complex interacting biotic and abiotic factors that drive sown pasture community change is important for appropriate grazing management and for setting plant breeding objectives to ensure greater persistence of sown species.

Studies conducted to identify factors affecting persistence (Mercer 2011 and references therein) typically start with a sown experiment which is monitored over time i.e., a 'longitudinal' study (e.g., Tozer et al. 2014a, b; Lee et al. 2017, 2018). In such a design there is confounding between environmental factors during establishment and the subsequent effects of episodic stressors such as drought, insect or disease pressures which are often causes of poor persistence. However, there is no true replication in time. Successive annual sowings would provide that replication and allow the effects of establishment-year and pasture age when episodic stressors occur, to be disentangled and better identify critical factors affecting persistence.

Thus, to inform the DairyNZ Forage Value Index (FVI, Chapman et al. 2017) with persistence trait data (dry matter (DM) yield, botanical composition, basal cover and tiller density) for ranking perennial pasture grass species, a long-term (10 to 15 years) pasture persistence grazing trial was initiated in 2015 in Canterbury and in 2016 in Waikato.

The focus of the trial is on perennial ryegrass functional types and the effects of these attributes on persistence. This study aims to identify the most-limiting factors for persistence. This will inform which persistence traits to measure and the data required to feed the FVI. It also endeavours to identify when specific traits become most limiting/critical for persistence. This paper reports DM yield, botanical composition, basal cover and tiller density of 3-year-old, 2-year-old and 1-year-old pastures in the same year of measurement (age effects), from sites in Canterbury and Waikato. Interim data comparing the establishment year yield and composition of pastures sown in three successive years at each site have been published (Maxwell et al. 2018; Cosgrove et al. 2020).

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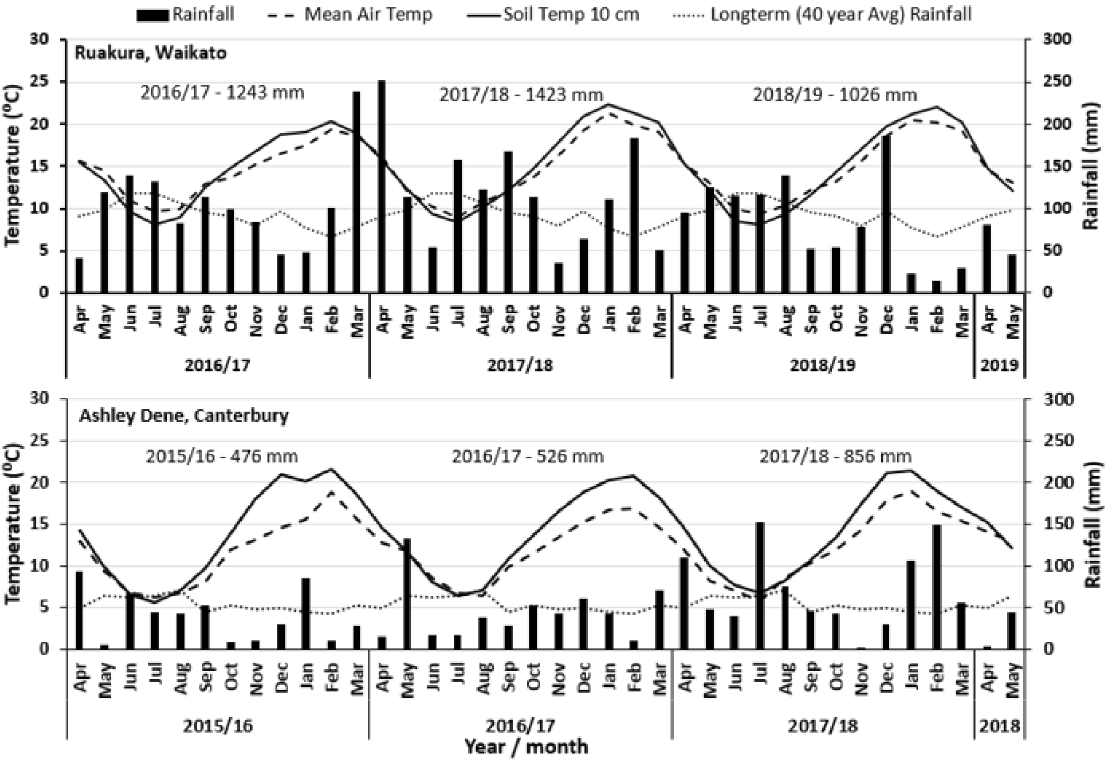

Figure 1 Annual and monthly rainfall, and average soil (0-10 cm depth) and air temperatures at pasture persistence experiment areas at Ruakura, Waikato and Ashley Dene, Canterbury, New Zealand.

Materials and Methods

Long-term persistence experiments have been set up under continuously stocked sheep grazing near Lincoln and under rotational cattle grazing near Hamilton.

Experimental sites

One site was established at the irrigated sheep unit of Lincoln University's Ashley Dene Research and Development Station near Burnham, Canterbury. The predominant soil types are shallow Balmoral and Lismore stony to very stony free-draining silt loam soils with low water holding capacity. Soil fertility levels are pH 6.0 – 6.2, Olsen P 30 – 33 ug/L and sulphate-S 7 – 10 mg/kg. The other site is situated at the AgResearch Ruakura Research Centre, near Hamilton, Waikato, on Te Kowhai silt loam soils with poor natural drainage. Soil fertility levels at this site are pH 5.8 – 6.0, Olsen P 30 ug/L and sulphate-S 10 – 12 mg/kg.

The areas available for each annual sowing at Ashley Dene (0.3 ha) and at Ruakura (0.5 ha) are in permanent pasture, grazed by sheep or dairy cattle, respectively. Each spring the area designated for sowing the following autumn was sprayed with glyphosate, cultivated (rotary tiller at Ashley Dene, discs followed by power harrow at Ruakura), rolled and sown with a brassica crop for grazing in early autumn. It was then sprayed again, cultivated, and rolled in preparation for sowing. For 2017 at Ashley Dene there was no brassica crop sown in spring and resident pasture was cultivated in autumn before sowing the experimental plots.

Weather data were recorded at the Ashley Dene experimental site and the Ruakura Weather Station located within 250 m of the experimental site. Mean air temperature, soil temperature (10 cm depth), and rainfall for the experimental period at each site are presented in Figure 1 and the site-specific papers (Maxwell et al. 2018; Cosgrove et al. 2020). The Ashley Dene site used partial irrigation, applied by a lateral irrigator at a rate of 40 mm every 12 days during November - March, but adjusted according to rainfall. For 2015/16, 2016/17 and 2017/18, irrigation totals were 500 mm, 500 mm and 200 mm, respectively. Rainfall was noticeably lower than the long-term monthly average on several occasions at Ruakura. Specifically, during the first growing season (December 2016, January 2017), second growing season (November and December 2017), and most noticeably during the third growing season (September and October 2018, and January, February, March and May 2019, Figure 1). At Ashley Dene the low rainfall occasions during the growing season were offset by the irrigation applied from November to March.

Experimental design

The study consists of repeated annual sowings, each of which is being monitored over time. Each year, eight cultivars of endophyte-infected (*Epichloë festucae* var. *lolii*) perennial ryegrass (comprising cultivars of different decades of release as a measure of cultivar age, diploids and tetraploids, and mid- and late-flowering dates) and one cultivar each of endophyte-infected (*E. coenophiala*) tall fescue (*Festuca arundinacea*) and endophyte-free cocksfoot (*Dactylis glomerata*) (Table 1), were drilled into a cultivated seedbed in a randomised complete block design with four replicates for each year of sowing. White clover (*Trifolium repens*) was broadcast-sown following drilling. Tall fescue and cocksfoot were included for comparison because of their generally recognised better persistence in drier environments, or in those with higher pest pressure, but were restricted to just one cultivar of each, because of finite experimental resources.

Each grass plot was 12 m × 4.2 m at Ashley Dene and 18 m × 4.5 m at Ruakura. The borders (6 m × 42 m) at the end of the experimental areas were cultivated in a similar manner and sown at 25 kg/ha with a mix comprised of equal proportions (adjusted for seed weight) of each of the 10 species/cultivars sown in the experimental plot areas.

Sowing and establishment

At Ashley Dene the plots were sown using a Flexiseeder precision plot drill fitted with tyne coulters (www.flexiseeder.com). At Ruakura the plots were sown using a modified Oyjord plot drill (Denmark) with Great Plains disc coulters and press wheel (Great Plains Ag, Kansas, USA). Coulter spacing was 15 cm for each drill. Sowing rates of bare, untreated grass seed were: diploid ryegrasses 20 kg/ha, tetraploid ryegrasses 28 kg/ha, tall fescue 25 kg/ha and cocksfoot 10 kg/ha. Superstrike®-treated white clover was broadcast over the entire area at 7 kg/ha, equivalent to 4 kg/ha bare seed.

Grazing management

Each annual sowing was stocked as a single unit, and sheep or cattle had free access across species/cultivars and replicates. At Ashley Dene the plots were continuously stocked with sheep from late winter, with stocking rate varied to maintain a sward height of 3 – 8 cm. Sheep were removed from plots for 3 weeks from 1 October and from 1 April to accumulate sufficient herbage for sampling. Plots were grazed to between 3 cm and 4 cm height before removal of sheep, and topped if necessary, to ensure an even sward height as accumulation commenced. At Ruakura the grazing protocol simulated a typical dairy rotation (MacDonald & Penno 1998). When accumulated herbage mass (above ground level) reached 2600 – 3000 kg DM/ha determined by visual assessment, plots were grazed over 24 – 48 h to leave 1500 – 1600 kg DM/ha. Under the rotational grazing management at Ruakura, sampling was conducted on the herbage mass which accumulated following grazing in early October and early April. Plots were topped following these grazing events, if necessary, to ensure an even sward height.

Table 1 Grass species, cultivar and endophyte strain (with range in infection rates for seed lots used 2015-2018), decade of cultivar release, ploidy, flowering date, sowing rate and source for each cultivar used.

Grass species	Cultivar and endophyte infection	Decade of release	Ploidy	Flowering date	Sowing rate (kg seed/ha)	Seed source
Perennial ryegrass	Grasslands Ruanui AR95[1] (98%)	1960s	Diploid	Mid	20	AgResearch
Perennial ryegrass	Grasslands Nui wild-type[1] (83[2]–51%)	1970s	Diploid	Mid	20	AgResearch
Perennial ryegrass	Grasslands Samson AR37[1] (99–90%)	1990s	Diploid	Mid	20	Agricom
Perennial ryegrass	Alto AR37[1] (93–89%)	2000s	Diploid	Late	20	Barenbrug
Perennial ryegrass	Request AR37[1] (93–89%)	2010s	Diploid	Mid	20	Agricom
Perennial ryegrass	Prospect AR37[1] (90–92%)	2010s	Diploid	Late	20	Agricom
Perennial ryegrass	Halo AR37[1] (90–94%)	2000s	Tetraploid	Late	28	Agricom
Perennial ryegrass	Base AR37[1] (88–93%)	2010s	Tetraploid	Late	28	PGGW Seeds
Tall fescue	Hummer MaxP[1] (100–89%)	2010s			25	Agricom
Cocksfoot	Savvy	2010s			10	PGGW Seeds
White clover	Grasslands Tribute				4[3]	Agricom

[1] Wild-type endophytes contain high levels of alkaloids peramine, lolitrem B, and ergovaline. AR95 endophyte = equivalent to wild-type endophyte. AR37 is a selected endophyte with epoxy-janthitrems, but no peramine, lolitrem B or ergovaline. MaxP (MaxQ in the USA) may contain either AR542 or AR584 selected endophytes which have peramine and lolines present but no ergovaline (Caradus et al. 2021); [2] estimated by linear interpolation from 2015 sowing based on 94% recorded in March 2013, and 51% recorded in November 2017. [3] bare seed equivalent.

Sampling and measurements

To facilitate the accumulation of herbage for sampling, nitrogen (N) fertiliser (SustaiN at Ruakura; urea at Ashley Dene) was applied at 30 kg N/ha in early October and 30 kg N/ha in early April, immediately following cattle grazing at Ruakura and when sheep were removed from plots at Ashley Dene. Measurements were restricted to these seasons to reflect pasture growth, composition and density under, typically, the most favourable conditions for grasses, particularly perennial ryegrasses, in spring (rising temperatures, generally adequate soil moisture, low prevalence of insect pests and disease) and under, typically, the least favourable conditions in autumn as pastures recovered from stress (high temperatures and humidity, high prevalence of insect pests and diseases and low soil moisture). Annual total DM production is highly correlated with these two extremes (Cosgrove 2011), and this sampling procedure is being used as a proxy for total yield that does not require yield measurement at every grazing during the year.

In spring and autumn, measurements consisted of DM yield and botanical composition. Autumn measurements included tiller density and basal cover. Pasture yield was measured using a lawn mower to cut a strip 0.46 m wide × 6 m long (Ruakura) or 12 m long (Ashley Dene) to a residual height of between 4 cm and 5 cm. After weighing the cut herbage, a subsample of at least 200 g was oven-dried at 80°C for 48 h (Ruakura) or 300 g was oven-dried at 65°C to a constant weight (Ashley Dene) to determine DM% and from this, DM yield was calculated. Pasture botanical composition was determined from 6 – 8 hand snip samples cut to ground level alongside the mown strip in each plot and combined into a single sample. This sample was sorted into sown grass, white clover, weeds (includes unsown grasses [predominantly temperate species *Bromus hordeaceus*, *Poa annua*, *Agrostis tenuis*, *Holcus lanatus* and the subtropical species *Digitaria sanguinalis*], other clover, broadleaf species) and dead matter, and each component was oven-dried at 80°C for 24 h and weighed separately. Sown grass basal cover and tiller density were measured as indicators of sward structure. Basal cover was determined by placing a 50 cm × 40 cm quadrat divided into 320, 2.5 cm × 2.5 cm cells (2000 cm^2) in four random positions within the mown strip of each plot, post-cutting. The number of cells with more than half their area occupied by a sown grass plant were counted (based on Virgona & Bowcher 2000) and expressed as a proportion of the total number of cells. Tiller density of sown grass cultivars was determined by randomly placing a 10 cm × 15 cm quadrat at right angles to drill rows in 10 random positions in each plot, and then cutting sown grass tillers inside the quadrat to ground level. Cut tillers from all 10 quadrats were combined, weighed, and 150 whole tillers randomly removed (loose leaves and daughter tillers enclosed within the parent tiller sheath were included but not counted). Non-sown grass material (other species and dead matter) was separated from sown grass material. Fresh weights for the subset of 150 counted tillers plus their loose leaves, and non-sown grass material were recorded separately, and applied to the total weight of cut herbage, to calculate tiller number per square metre.

Selection of datasets for comparison between sites

Data sets compared were from sampling of 3-year-old (sown 2015), 2-year-old (sown 2016) and 1-year-old (sown 2017) pastures in October 2017 and April 2018 at Ashley Dene, and 3-year-old (sown 2016), 2-year-old (sown 2017) and 1-year-old (sown 2018) pastures in November 2018 and May 2019 at Ruakura.

Statistical analysis

The influence of grass cultivar, pasture age, site, and their interaction on total pasture DM yield, botanical composition, and sown grass basal cover and tiller density for 3-year-old, 2-year-old and 1-year-old pastures at the Ashley Dene and Ruakura sites, were analysed using an unbalanced General ANOVA (Genstat Version 18, VSN International 2015) with site, pasture age and grass cultivar as fixed effects, and replicate blocks as random effects. The experimental unit was the mean value of the respective persistence trait from each plot. Mean separation was achieved using a Least Significant Difference (LSD) test with differences declared significant at $P \leq 0.05$. A P-value between 0.05 and 0.07 was considered a trend of note.

Results

Pasture persistence traits were different between Ashley Dene and Ruakura, with site influencing spring pasture yield ($P<0.001$), sown grass basal cover ($P<0.001$) and tiller density ($P<0.001$). Mean pasture yield at Ashley Dene in spring (2790 kg DM/ha) and autumn (2340 kg DM/ha) was greater ($P<0.001$) than at Ruakura (2660 and 1690 kg DM/ha, respectively). Mean basal cover of sown grass was greater at Ashley Dene at 29.1% compared to 12.5% at Ruakura ($P<0.001$, Table 2). Mean tiller density was higher at Ashley Dene with 6200 tillers/m^2 compared to 2030 tillers/m^2 at Ruakura ($P<0.01$, Table 2).

Pasture age influenced persistence traits at both sites (Tables 2-4). At Ashley Dene, 2-year-old pasture was higher yielding ($P<0.001$) than the 3-year-old and 1-year-old pastures in spring 2017, with the yields of 3-year-old and 1-year-old pastures being not significantly different from each other (Table 2). This trend was the reverse at Ruakura, with 3-year-old and 1-year-old pastures yielding higher ($P<0.001$) than 2-year-old pasture in spring 2018 (Table 2). In autumn, 1-year-old pasture at

Table 2 The influence of pasture age on mean total dry matter (DM) yield and botanical composition in spring at Ashley Dene, Canterbury (October 2017) and Ruakura, Waikato (November 2018), and mean total DM yield, botanical composition, and tiller density in autumn at Ashley Dene, Canterbury (April 2018) and Ruakura, Waikato (May 2019). Values are means for all 10 cultivars/species. Within rows within sites, different letters indicate differences between pasture ages at 5% level, ns = not significant.

	Ashley Dene						Ruakura					
	Pasture Age (years)			Mean	SEM	P-value	Pasture Age (years)			Mean	SEM	P-value
	1	2	3				1	2	3			
Spring												
Pasture yield (kg DM/ha)	2410 b	3260 a	2700 b	2790	141	<0.001	2790 a	2340 b	2860 a	2660	117	<0.001
Pasture composition (% of DM)												
Grass leaf	42.7 c	55.5 b	66.8 a	55.0	6.0	<0.001	86.0 a	59.6 b	44.6 c	63.4	5.1	<0.001
Grass stem	0 b	0.8 b	3.0 a	1.3	0.4	<0.05	0.1	0.6	3.1	1.3	0.3	ns
White clover	10.5 b	17.1 a	16.7 a	14.8	3.3	<0.01	5.8 c	14.7 b	22.3 a	14.3	3.1	<0.001
Other grasses [1]	3.0	2.5	2.1	2.5	1.7	ns	6.3 b	9.1 b	21.3 a	11.1	2.9	<0.01
Broadleaf weeds [2]	37.8 a	18.5 b	4.2 c	20.1	5.9	<0.001	0.3 b	12.0 a	10.1 a	7.5	1.9	0.001
Other clovers [3]	0.1	0.1	0	0.1	0.1	ns	0	0.8	0.9	0.6	0.4	ns
Dead	6.0	5.8	7.1	6.3	1.7	ns	1.6 a	1.0 ab	0.9 b	1.1	0.4	<0.05
Autumn												
Pasture yield (kg DM/ha)	2310	2610	2100	2340	168	0.063 ns	1750 a	1670 b	1640 b	1690	33	<0.01
Pasture composition (% of DM)												
Grass leaf	54.8 b	57.1 b	69.1 a	60.3	5.3	0.001	71.3 a	58.1 b	48.6 b	59.3	6.9	0.01
Grass stem	0	0	0	0	0	-	0	0	0	0	0	-
White clover	20.9 a	15.2 b	11.5 b	15.8	0.8	<0.01	19.6 a	2.6 c	8.3 b	10.2	3.0	<0.001
Other grasses [1]	0.1 b	0 b	2.4 a	0.8	0.4	<0.05	0.4 b	15.6 a	11.4 ab	7.6	0.7	<0.05
Broadleaf weeds [2]	0.7	1.0	0	0.6	0	ns	2.0 c	14.2 b	20.6 a	12.3	3.5	<0.001
Other clovers [3]	0.1	0.1	0	0.1	0	ns	0.4	0.1	0	0.2	0.2	ns
Dead	16.3 c	26.8 a	24.3 b	22.5	4.2	0.001	10.8	9.4	6.5	8.9	3.3	ns
Basal cover (%)	13.1 c	28.9 b	45.5 a	29.1	4.2	<0.001	19.1 a	11.1 b	7.4 c	12.5	1.5	<0.001
Tiller density (number/m^2)	6100 b	7130 a	5380 b	6200	1064	<0.01	2970 a	1680 b	1440 b	2030	368	<0.01

[1] Yorkshire fog *Holcus lanatus*, summer grass *Digitaria sanguinalis*, annual poa *Poa annua*, soft brome *Bromus mollis*, hairgrass *Vulpia bromoides*;
[2] nettle *Urtica urens*, chickweeds *Stellaria media* and *Cerastium glomeratum*, scrambling speedwell *Veronica persica*, shepherd's purse *Capsella bursa-pastoris*;
[3] suckling clover *Trifolium dubium*, subterranean clover *T. subterraneum*

Ruakura yielded more (P<0.01) than older pastures, while at Ashley Dene the numerically greater yield of 2-year-old pasture was approaching significance (Table 2).

At Ashley Dene, sown grass basal cover increased as pastures aged (P<0.001) at 13.1%, 28.9%, and 45.5% in 1-year-old, 2-year-old, and 3-year-old pasture, respectively. Basal cover of sown grasses at Ruakura in contrast, decreased with increasing pasture age (P<0.001, Table 2). Tiller density at Ashley Dene was highest in 2-year-old pasture (P<0.01) with 7130 tillers/m^2 compared to 6100 and 5380 tiller/m^2 for 1-year-old and 3-year-old pasture, respectively. At Ruakura, 1-year-old pasture (2970 tillers/m^2) had higher tiller density (P<0.01) than 2-year-old (1680 tillers/m^2) or 3-year-old pastures (1440 tillers/m^2, Table 2).

There were pasture age × cultivar interactions for spring DM yield at both sites (P<0.05, Table 3), and for basal cover and tiller density at Ruakura (P<0.001, Table 4). At Ruakura, cultivar influenced total pasture DM yield (Table 3) and basal cover and tiller density (Table 4). There was a wider divergence in DM yield values between cultivars as pastures aged at Ruakura compared with these same cultivars growing at Ashley Dene. Grass species and cultivars of 1-year-old pasture at Ashley Dene were similar to each other in DM yield, while grass cultivars of 1-year-old pasture at Ruakura varied widely in DM production, with Request producing the greatest amongst the perennial ryegrass cultivars at 3120 kg DM/ha and Halo producing the least at 2540 kg DM/ha (Table 3).

In 2-year-old and 3-year-

Table 3 The influence of grass species and cultivar and pasture age on mean total pasture dry matter (DM) yield in spring at Ashley Dene, Canterbury (October 2017) and Ruakura, Waikato (November 2018). Within rows within sites, different lower case letters separate means, and within columns, different upper case letters separate means, both at the 5% significance level, ns = not significant.

Pasture yield (kg DM/ha)	Ashley Dene					Ruakura				
	Pasture Age (years)					Pasture Age (years)				
	1	2	3	Mean	Cultivar ranking	1	2	3	Mean	Cultivar ranking
Grass cultivar										
Ruanui	2470 b A	3150 a B	3090 a A	2900	2	2920 a AB	2200 b ABC	2720 a C	2610 BCD	7
Nui	2430 b A	3560 a A	2700 b BC	2900	3	3020 a AB	2360 b ABC	2670 ab C	2680 BC	5
Samson	2440 b A	3240 a AB	2860 ab A	2850	4	3050 a A	2400 b ABC	2920 a BC	2790 AB	3
Alto	2250 b A	3450 a A	2450 b BC	2720	7	2710 ab ABCD	2460 b ABC	2910 a BC	2690 BC	4
Request	2450 b A	3320 a AB	2970 ab A	2910	1	3120 a A	2420 b ABC	3140 a AB	2890 A	1
Prospect	2380 b A	3470 a A	2570 b BC	2810	6	2700 b BCD	2520 b A	3270 a A	2830 AB	2
Halo	2550 b A	3180 a AB	2790 ab AB	2840	5	2540 a CD	2140 b C	2770 a C	2480 DE	9
Base	2350 b A	3150 a B	2450 b BC	2650	9	2630 a BCD	2230 b ABC	2870 a C	2580 CD	8
Hummer	2230 b A	2940 a B	2760 a AB	2640	10	2820 a ABC	2520 a A	2700 a C	2680 BC	6
Savvy	2540 b A	3190 a AB	2360 b BC	2700	8	2380 ab D	2150 b BC	2610 a C	2380 E	10
Mean	2410 c	3260 a	2700 b	2790		2790 ab	2340 b	2860 a	2660	
SEM	198	114	112	141		116	113	123	117	
P-value cultivar		ns					<0.001			
P-value pasture age		<0.001					<0.001			
P-value cultivar x pasture age		<0.05					<0.05			

Table 4 The influence of grass species and cultivar and pasture age on mean basal cover and tiller density in autumn at Ruakura, Waikato (May 2019). Within rows within sites, different lower case letters separate means, and within columns, different upper case letters separate means, both at the 5% significance level.

Grass cultivar	Basal cover (%)				Tiller density (number/m²)			
	Pasture Age (years)			Mean	Pasture Age (years)			Mean
	1	2	3		1	2	3	
Ruanui	21.4 a ABCD	9.1 b DEF	7.2 b AB	12.6 ABCD	3110 a CD	2210 ab AB	1650 b AB	2320 AB
Nui	14.0 a F	5.5 b F	2.9 b CD	7.5 F	1720 a EF	710 ab C	240 b D	890 D
Samson	26.7 a A	15.7 a A	7.2 b AB	16.5 A	4440 a AB	2390 b A	1200 c BCD	2680 AB
Alto	22.0 a ABC	10.6 b BCDE	10.6 b AB	14.4 ABC	3730 a ABC	2010 b AB	1560 b BC	2440 AB
Request	24.5 a AB	12.5 b ABCD	11.4 b A	16.1 A	4770 a A	2100 b AB	2560 b A	3140 A
Prospect	21.6 a ABC	13.5 a ABC	8.9 b AB	14.7 AB	3520 a BC	1210 b BC	1740 b AB	2160 ABC
Halo	17.1 a DEF	8.4 b EF	8.0 b AB	11.3 DE	2440 a DE	1340 a BC	1690 a AB	1820 BCD
Base	17.4 a EF	10.1 a CDE	9.2 b AB	12.1 CD	2000 a E	1660 a ABC	1850 a AB	1840 BCD
Hummer	18.2 a CDE	11.0 b BCDE	6.9 b BC	12.0 D	3080 a CD	1400 b ABC	1340 b BC	1940 BCD
Savvy	7.8 a G	14.4 a AB	1.9 a D	8.1 EF	870 ab F	1780 a AB	570 b CD	1070 CD
Mean	19.1 a	11.1 b	7.4 c	12.5	2970 a	1680 b	1440 b	2030
SEM	1.4	1.8	1.3	1.5	427	372	306	368
P-value cultivar		<0.001				<0.001		
P-value pasture age		<0.001				<0.01		
P-value cultivar x pasture age		<0.001				<0.001		

old pastures at Ashley Dene, a divergence in DM production started to emerge, favouring diploid cultivars of Nui, Alto and Prospect ranking highest in 2-year-old pasture, and Ruanui, Samson, and Request ranking highest in 3-year-old pasture, though not greater than tetraploid Halo ryegrass or Hummer tall fescue (Table 3). In 2-year-old pastures at Ruakura, divergence in DM production between perennial ryegrass cultivars was less, with Prospect the highest ranking ryegrass cultivar alongside Hummer tall fescue. These two cultivars were similar to all remaining cultivars, except Halo and Savvy cocksfoot (Table 3). In 3-year-old pastures at Ruakura, the diploid cultivars Prospect and Request ranked highest (Table 3). At both sites, Request ranked highest out of all the cultivars when ranking was based on the mean DM yield of different aged pastures, with this being significant at Ruakura (Table 3).

Basal cover did not differ between cultivars in any of the different pasture ages at Ashley Dene (data not presented). However, at Ruakura there was a divergence in basal cover between cultivars with Samson, Alto, Request and Prospect maintaining higher basal cover than other cultivars across all three pasture ages (Table 4).

Tiller density did not differ among cultivars in any of the different pasture ages at Ashley Dene, though there was an overall cultivar effect with Prospect having the highest tiller density (8880 tillers/m^2) averaged over the different aged pastures, followed by Samson and Request with 8360 and 7520 tillers/m^2, and all other cultivars having fewer than 6500 tillers/m^2 (data not presented). At Ruakura, divergence in tiller density among cultivars was evident in all pastures of different ages with Request showing the greatest tiller density amongst all cultivars (Table 4).

Botanical composition

At Ashley Dene, the DM proportions of grass leaf ($P<0.001$), grass stem ($P<0.05$), and white clover ($P<0.01$) in spring were greater in 2-year-old and 3-year-old pastures, while broadleaf weeds ($P<0.001$) were more abundant in 1-year-old pastures (Table 2). In contrast, at Ruakura, proportions of grass leaf ($P<0.001$) and dead matter ($P<0.05$) were greater in younger pastures, with greater abundance of white clover ($P<0.001$) and other grasses ($P<0.01$) in the 3-year-old pasture (Table 2). In autumn, the site-specific pattern of greater grass leaf proportion was maintained, with higher proportions occurring in older pasture at Ashley Dene but in younger pasture at Ruakura (Table 2). At Ashley Dene, 2-year-old autumn pasture had highest dead matter content, with 3-year-old pasture having more than 1-year-old pasture, but less than 2-year-old pasture (Table 2). In contrast to spring, white clover content in autumn was highest in 1-year-old pastures at both sites, while other grasses were greater in older pastures at both sites (Table 2). Broadleaf weeds increased with increasing pasture age at Ruakura (Table 2).

The proportion of grass leaf and other grasses in pastures at Ruakura was greater than at Ashley Dene in both spring and autumn (Table 5). At Ashley Dene in spring, Prospect had the lowest proportion of grass leaf (43.4%), alongside Hummer tall fescue (40.2%), with no difference between cultivars in autumn (Table 5). At Ruakura in spring, the perennial ryegrass cultivars of Samson, Alto, Request, Prospect, Halo and Base all shared high proportions of grass leaf (always greater than 67%). This was also observed in autumn for Samson, Alto, Request, and Base (Table 5).

In spring the proportion of white clover was highest for Ruanui, Alto and Halo at Ashley Dene, which was maintained into autumn for Ruanui and Halo, with Nui having higher white clover proportion in autumn compared to spring (Table 5). At Ruakura, ryegrass cultivars Ruanui and Nui, Hummer tall fescue and Savvy cocksfoot showed high proportion of white clover in spring (always greater than 17%), which was carried through into autumn for Savvy cocksfoot and Nui (Table 5).

Broadleaf weeds were more prevalent in Ashley Dene spring pastures (mean of 20.1%) than autumn (mean 0.6%, Table 5). The proportion of broadleaf weeds in pasture at Ruakura was higher in autumn (12.3%) compared with spring (7.5%), with Ruanui, Nui, Savvy, and Hummer having high broadleaf weed content (ranging from 14.8% to 21.6%, Table 5).

Other grasses were more prevalent at Ruakura than Ashley Dene in both spring and autumn pastures, with Nui and Prospect containing more unsown grass species than the other cultivars in autumn.

There was a pasture age × cultivar interaction for proportions of grass leaf and white clover at Ruakura in spring (Table 6). Grass leaf proportion declined in 2-year-old and 3-year-old pastures, with the cultivars Ruanui, Nui, Alto, Samson, Prospect, Halo, Hummer tall fescue, and Savvy cocksfoot showing the greatest decline with increasing pasture age, with Request and Base showing the least decline (Table 6). In contrast, white clover content increased as pastures at Ruakura aged, with Nui, Ruanui, Prospect, and Hummer tall fescue showing the greatest increase with increasing pasture age (Table 6).

In autumn, a pasture age × cultivar interaction was observed for proportions of grass leaf ($P<0.05$) and white clover ($P<0.001$) at both sites, which showed opposing trends for the grass leaf component of the sward. At Ruakura, grass leaf and white clover proportions decreased in general for all cultivars as pastures aged (data not presented). At Ashley Dene, grass leaf proportion increased for some cultivars (Base, Halo, Hummer, Prospect, Request, Ruanui and Samson) while other cultivars remained constant (Alto, Nui) or slightly decreased (Savvy; data not presented). White clover content generally decreased as pastures aged at Ashley Dene (data not presented).

Discussion

Typically, experiments investigating pasture persistence are based on a single sowing (e.g., Chapman et al. 2015; Lee et al. 2017, 2018). In these longitudinal studies the effects of aging on pasture yield and composition are invariably confounded with differences among years in, for example, weather. Differences among years in pasture yield and composition could be due to physiological or morphological changes in the sward or differences in weather variables such as rainfall and temperature. There is no way to separate these effects. This confounding becomes very important in studies related to pasture persistence which need to span multiple years to identify causal effects. Longer-term studies become particularly sensitive to variation among years in weather and biotic stressors which tend to occur as episodic events. Furthermore, sowing and early establishment are even more sensitive to those conditions and the year of sowing can by chance have a major and enduring influence on establishment and longevity. One way to disentangle that confounding would be to repeat sowings over several years, such that over time, in any single year a sequence of pastures of different ages, all exposed to the same conditions at the same time, would be available for comparison. This paper summarises interim data from an experiment being conducted at two contrasting sites using repeated annual sowings to help identify critical factors influencing pasture persistence.

Table 5 The influence of grass species and cultivar on morphological and botanical composition of pasture dry matter (DM) in spring and autumn at Ashley Dene, Canterbury (October 2017) and Ruakura, Waikato (November 2018). Within columns, means with different letters differ at the 5% significance level, ns = not significant (data presented are the mean of the three pasture ages).

		Ashley Dene							Ruakura						
		Morphological and botanical composition (% of DM)							Morphological and botanical composition (% of DM)						
	Grass cultivar	Grass leaf	Grass stem	White clover	Other grasses	Broadleaf weeds	Other clovers	Dead	Grass leaf	Grass stem	White clover	Other grasses	Broadleaf weeds	Other clovers	Dead
Spring															
	Ruanui	55.4 a	0	22.6 a	0.3 b	16.1	0	5.7 bc	60 bc	0	19.8 a	8.4 b	8.2 abc	0.4	1.2 abcd
	Nui	59.6 a	0	13.5 bc	1.3 b	19.1	0	6.5 bc	58.1 cd	0	22.8 a	8.5 b	7.7 abcd	0.7	0.9 cd
	Samson	58.6 a	0	14.4 bc	2.7 ab	19.7	0.2	4.6 c	67.4 ab	0	8.7 b	9.6 b	4.7 d	1.1	1.6 ab
	Alto	57.6 a	0	17.0 ab	1.1 b	30.5	0	5.2 bc	71.1 a	0	11.4 b	10.0 b	6.5 bcd	0.8	1.7 a
	Request	57 a	0	14.2 bc	2.0 ab	21.8	0.2	7.0 bc	73.6 a	0	11.1 b	23.0 a	6.1 cd	0.3	1.6 abc
	Prospect	43.4 b	0	14.9 bc	0.4 b	23.9	0	4.4 c	69.4 a	0	12.0 b	10.2 b	6.3 bcd	0.8	1.2 abcd
	Halo	57 a	0	17.2 ab	0.7 b	20.8	0	8.3 ab	72.1 a	0	10.6 b	10.5 b	9.5 ab	0.03	0.9 bcd
	Base	58.5 a	0	12.0 bc	0.9 b	18.9	0	6.2 bc	72.1 a	0	7.8 b	7.4 b	7.1 bcd	1.0	0.8 d
	Hummer	40.2 b	12.7	13.4 bc	9.4 a	19.2	0.4	4.8 c	49.1 de	2.9	19.2 a	8.3 b	7.8 abcd	0.2	0.8 d
	Savvy	62.6 a	0	8.9 c	6.7 a	11.4	0	10.5 a	40.9 e	10	19.2 a	27.8 a	10.8 a	0.5	0.8 d
Mean		55.0	1.3	14.8	2.5	20.1	0.1	6.3	63.4	1.3	14.3	11.1	7.5	0.6	1.1
SEM		6.1	0.4	3.3	1.7	5.9	0.1	1.7	5.1	0.3	3.1	2.9	1.9	0.4	0.4
P-value		<0.001	-	<0.05	<0.01	ns	-	<0.05	<0.001	-	<0.001	<0.001	<0.05	ns	<0.05
Autumn															
	Ruanui	54.1	0	21.3 ab	0.2	0.3	0	24.1 b	57.8 bc	0	10.1 bc	6.5 bc	19.2 ab	0.1	6.3
	Nui	58.6	0	17.6 abc	0.5	2.4	0	20.8 bc	34.5 d	0	17.4 ab	17.1 a	21.6 a	0.1	9.3
	Samson	63.7	0	14.7 c	1.1	0.1	0	20.4 bc	72.4 a	0	5.6 c	6.3 bc	7.1 d	0.0	8.6
	Alto	60.7	0	12.9 c	3.3	0.4	0	22.7 b	70.2 a	0	8.5 c	2.0 c	9.7 c	0.0	9.5
	Request	62.5	0	14.1 c	2.6	0.3	0	20.6 bc	72.3 a	0	6.8 c	3.7 bc	8.8 cd	0.3	8.1
	Prospect	57.5	0	16.3 c	0.0	0.6	0	25.6 ab	61.8 abc	0	9.7 c	11.3 ab	6.3 d	0.0	11
	Halo	61.5	0	17.4 abc	0.2	1.1	0	13.8 c	56.7 c	0	11.2 bc	8.8 bc	11.1 c	0.7	9.3
	Base	68.4	0	14.0 c	0.1	0.3	0	23.2 b	68.3 ab	0	5.7 c	8.3 bc	7.8 d	0.4	11.8
	Hummer	54.9	0	24.9 a	0.0	0.2	0	20.0 bc	62.3 abc	2.1	8.3 c	5.7 bc	14.8 b	0.1	6.8
	Savvy	61.3	0	5.2 d	0.3	0.0	0	33.2 a	37.2 d	13.3	18.8 a	6.4 bc	16.0 b	0.0	8.4
Mean		60.3	0	15.8	0.8	0.6	0	22.5	59.3	1.5	10.2	7.6	12.3	0.2	8.9
SEM		5.3	-	3.0	0.8	0.4	0	4.3	6.9	0.5	3.0	3.0	3.5	0.2	2.4
P-value		ns	-	<0.001	ns	ns	-	<0.01	<0.001	-	<0.001	<0.05	<0.001	-	ns

Table 6 The influence of grass species and cultivar and pasture age on the proportions of grass leaf and white clover in the pasture dry matter (DM) in spring at Ruakura (November 2018). Within rows, different lower case letters separate means, and within columns, different upper case letters separate means, both at the 5% significance level.

Grass cultivar	Grass leaf (% of DM)			White clover (% of DM)		
	Pasture Age (years)			Pasture Age (years)		
	1	2	3	1	2	3
Ruanui	88.0 a AB	48.6 b E	43.5 b BC	4.7 b B	28.3 a A	26.3 a BC
Nui	89.0 a A	51.4 b CDE	34 b CD	5.3 c B	26.4 b A	36.6 a A
Samson	91.7 a A	55.4 b BCDE	55 b AB	2.0 b B	6.4 b C	17.6 a CD
Alto	87.6 a AB	68.6 b AB	57.1 b AB	4.9 b B	10.8 ab C	18.6 a CD
Request	92.7 a A	65.8 b ABC	62.2 b A	2.8 b B	11.4 ab C	19.1 a BCD
Prospect	90.4 a A	71.8 b A	46.1 c BC	1.8 b B	7.5 b C	26.8 a ABC
Base	88.0 a AB	64.4 b ABCDE	64 b A	4.8 b B	14.5 a BC	12.4 ab D
Halo	91.7 a A	67.5 b AB	57.2 b AB	4.6 b B	6.4 b C	12.5 a D
Hummer	72.6 a BC	53.2 b BCDE	21.5 c D	7.5 b B	21.7 a AB	28.4 a AB
Savvy	67.9 a C	49.7 b DE	5 c E	20.1 ab A	13.3 b BC	24.3 a BC
Mean	86.0 a	59.6 b	44.6 c	5.9 c	14.7 b	22.3 a
SEM	3.8	7.9	3.7	2.0	3.5	3.7
P-value cultivar		<0.001			<0.001	
P-value pasture age		<0.001			<0.001	
P-value cultivar x pasture age		<0.01			<0.01	

Our hypothesis is that when measured in the same year and so exposed to the same environmental conditions and biotic and abiotic stressors, the different ages of pastures would reflect natural aging effects. It could also reveal if there are age-related differences in sensitivity to the biotic and abiotic stressors. The results indicate that in the same year of measurement, the 3-year-old, 2-year-old and 1-year-old pastures differed in DM yield in spring and autumn, and differed in most, but not all of the descriptors of botanical and morphological composition (proportions of grass leaf, white clover and broadleaf weeds in spring and grass leaf and white clover in autumn) and in the measures of pasture density (basal cover, tiller density). For other morphological components, differences were less consistent between seasons and sites. However, while there were significant differences among pasture ages, there were few consistent trends across sites or years identifiable in these interim data. One consistent difference was in the proportion of grass leaf. Within sites, the proportion of grass leaf was highest for the 3-year-old pastures at Ashley Dene, but at Ruakura the proportion was highest for the 1-year-old-pastures. While seasons were not statistically compared, yield at Ruakura in autumn was lower than in spring by a greater margin than at Ashley Dene, reflecting the very dry autumn at Ruakura (Figure 1). Sown grass tiller density in autumn at Ashley Dene (mean of 6200 tillers/m^2) was about 3-fold greater than at Ruakura (2030 tillers/m^2). This probably reflects the differences in grazing management of continuous stocking of sheep at Ashley Dene and rotational stocking of dairy cattle at Ruakura, and possibly climatic and pest pressure differences between sites. One factor that cannot be separated from influencing the comparisons among years at this early stage is sowing year conditions. Each age cohort was sown in a different year. Over time, as the number of individual sowings and the numbers of years of monitoring increase, it will be possible to systematically account for age and sowing year.

In comparing cultivars (the statistical effect of 'Cultivar' includes both cultivar and species), the same caveat relating to conditions in the year of sowing and the uncertain (at this interim stage) influences of this on yields and density of the different cultivars should apply. There were cultivar × pasture age interactions for spring yield at Ruakura (and approaching significance at Ashley Dene), and for proportions of grass leaf and white clover in spring, and basal cover and tiller density in autumn (Ruakura only). These interactions indicate that there were no consistent differences among cultivars across the different pasture ages.

Compared with the perennial ryegrasses, cocksfoot and tall fescue are slower establishing (Easton & Pennell 1993) and may be penalised by the autumn sowing, when spring would normally be recommended for these species. Both species have greater thermal time requirements for germination and emergence than ryegrass (Moot et al. 2000). This difference appears less critical at the warmer Ruakura site than at the cooler Ashley Dene site, and in some years tall fescue has established as well as perennial ryegrass (see interim establishment year data for the Ruakura site, Cosgrove et al. 2020). Both species were sown in autumn to avoid the confounding between grass species and sowing season that would otherwise occur. Although tall fescue established well at Ruakura initially (73% grass leaf component, 18% basal cover, and 3080 tiller/m^2) its performance in these persistence traits (basal cover, tiller density, and grass leaf proportion) has declined as pastures have aged at this site, being significantly lower than most ryegrass cultivars (Tables 4 and 6). Savvy cocksfoot's longevity at Ruakura has shown to be very poor after 2 years (Tables 4 and 6). In contrast, Savvy cocksfoot is faring better in general at Ashley Dene than at Ruakura (Tables 3 and 5).

Conclusions/Practical implications/Relevance

The interim results of this study indicate that even when compared under the same environmental conditions in the same year, and the effect of differences in climatic conditions (moisture and temperature) are removed, there remain differences and interactions among cultivars and pasture ages. This suggests that the interacting factors of cultivar and age have important influences on persistence. Systematically accounting for these effects will be possible as this experiment at two sites continues. This will provide information on the plant functional traits and their interactions with age and environmental factors that affect persistence of grass species and cultivars. Furthermore, it will be useful for plant breeding and management efforts to improve persistence and has the potential to help in cultivar ranking systems such as the Forage Value Index.

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