Persistence of perennial ryegrass, tall fescue and cocksfoot following repeated annual sowings: influence of pasture age, grass species and cultivar in Canterbury

Thomas M. R. MAXWELL[1]*, Emma L. GORDON[1], Kate R. CRAWFORD[1], Belaraine F. JORDAN[1] and Gerald P. COSGROVE[2]

[1]*Faculty of Agriculture and Life Sciences, Lincoln University, PO Box 85084, Lincoln 7647, New Zealand*
[2]*Bioeconomy Science Institute, Grasslands Research Centre, Palmerston North 4442, New Zealand (retired)*
*Corresponding author: tom.maxwell@lincoln.ac.nz

Abstract

Persistence is an important determinant of sown perennial pasture-grass productivity. Defining traits that affect persistence is essential for improving pasture longevity through plant breeding and identifying criteria for inclusion in cultivar ranking indices (Forage Value Index). A repeated sowings experiment commenced in 2015 under continuous sheep grazing in Canterbury. Eight cultivars of perennial ryegrass representing different ploidy, heading date, and decade of cultivar release, and one cultivar each of tall fescue and cocksfoot were sown in autumn in each year for 10 years. This paper compares persistence trait data from a single sampling point (autumn 2025). Pasture age influenced production and composition more than grass cultivar. Peak yields occurred in 4- and 8-year-old pastures (~3430 kg DM/ha) and the lowest in 10-year old pasture (2494 kg DM/ha). Sown grass proportion dropped from 65% at establishment to around 50% in older stands. Persistence was strongly species dependent. Cocksfoot (cv. Savvy) showed the strongest persistence traits: highest sown grass proportion (61%), lowest unsown species (9%) and highest persistence score (8.2). Perennial ryegrass cultivars generally showed moderate and similar persistence, while tall fescue (cv. Hummer) performed poorly (27% sown grass, lowest tiller density and low persistence score). Persistence is an outcome driven by species morphology, establishment success, compatibility with regional soil and climatic conditions and regime of grazing management. This study reinforces the suitability of cocksfoot for long-term persistence on stony Canterbury soils, demonstrates autumn-sowing and relatively hard continuous grazing is detrimental to tall fescue persistence, while perennial ryegrass cultivars generally showed moderate and similar persistence.

Keywords: *Lolium perenne, Festuca arundinacea, Dactylis glomerata,* botanical composition, sequential sowings, tiller density, yield

Introduction

Success in New Zealand's pastoral farming systems is reliant on the efficient use of grazed pasture as the major portion of feed required for livestock production (Parsons et al. 2011). A main contributor to this pasture efficiency is pasture persistence, with Parsons et al. (2011) defining 'poor pasture persistence' as either, a decline in the population of a sown species or a reduction in the expression of specific traits within that species over time, such as yield, tiller density and basal cover. In practical terms, poor pasture persistence can result in reduced pasture production, increased weed ingress and higher costs for renewal of pastures (Tozer et al. 2011). As of 2025, renewal costs averaged around $1030/ha (DairyNZ 2025). When pastures fail to persist over a long period of time, the re-grassing investment can be considered 'pointless' as there is a reduction in pasture productivity and more reliance on less desirable, weedy species (Tozer et al. 2011) which is to the detriment of grazing livestock animal performance.

Despite ongoing improvements in breeding of pasture cultivars to improve persistence, real on-farm implementation has not created satisfactory feedback from farmers. Survey data from the Waikato and Bay of Plenty regions show that satisfaction with renewed pastures often drop sharply after the third-year post-establishment (Kelly et al. 2011). Factors such as climatic stress, pest pressure, soil types and ill-suited grazing management can all be antagonistic to the persistence of sown species. Long-term persistence research is limited, with most New Zealand studies lasting ≤3 years and not being able to compare differing pasture ages at one time point, leaving large gaps in understanding of persistence beyond the establishment phase. These challenges highlight the need to better understand how different species and cultivars perform overtime beyond the first few years post establishment under known management and ecological conditions. While perennial ryegrass *Lolium perenne* dominates New Zealand's pastoral systems, alternative grass

ISSN 2463-2872 (Print) ISSN 2463-2880 (Online) https://doi.org/10.33584/jnzg.2026.88.3908

species such as cocksfoot *Dactylis glomerata* and tall fescue *Festuca arundinacea*, which possess different morphological and physiological traits, may improve pasture resilience under specific environments. Dry, shallow soils are widespread across the Canterbury Plains, which tend to be prone to reduced persistence. This makes it an ideal region for assessing long-term pasture performance.

The Lincoln University Pasture Persistence Trial investigates the longevity performance of ten grass cultivars (eight perennial ryegrass cultivars, one cocksfoot and one tall fescue) across pastures aged 1 to 10 years within the long-term sequential sowing trial at the Ashley Dene Research and Development Station. The specific focus is to evaluate how pasture age, grass species and grass cultivar influence pasture persistence. Measuring dry matter yield, tiller density, botanical composition and visual persistence determine which species and cultivars show the best persistence under Canterbury's conditions (southern location and a relatively dry climate) relative to the sister trial located at Ruakura, Waikato (now abandoned). Further discussion assesses mechanisms that drive grass cultivar long-term success or decline (Maxwell et al. 2018; Cosgrove et al. 2020; Maxwell et al. 2021; Cosgrove et al. 2023).

The overall focus of this on-going Canterbury field trial is to compare eight perennial ryegrass cultivars varying in heading date, ploidy and decade of commercial release, along with comparison among three grass species over time. Findings from this research aim to contribute to an understanding of the main factors underpinning pasture persistence and provide guidance to farmers on grass cultivar selection and potential re-grassing strategies to improve the long-term performance, specifically under Canterbury conditions. This particular paper reports the persistence traits of the ten grass cultivars, from three grass species, using data collected in autumn 2025 from a series of nine 0.3 ha paddocks to explore how species, cultivar and pasture age contribute to variances in pasture performance in autumn.

Materials and Methods

Trial location and site description

The trial site is located 10 km from Lincoln town in the north-east corner (43°38'33"S 172°20'53"E) of Lincoln University's Ashley Dene Research and Development Station near Burnham, Canterbury, South Island, New Zealand. The soil type is classified as a Pallic Firm Brown Soil of the Lismore family, consisting of 100% of the Lismore_2a.1 sibling (Maanaki Whenua 2025). This soil is a stony silt loam, where the topsoil is of silt texture and moderately stony, over a gravel layer. It is generally well drained with moderate permeability (4-72 mm/h), low vulnerability to waterlogging and moderate water holding capacity, with a profile available water content (PAW) of 102 mm. Soil pH is 6.0-6.2, with an Olsen P of 30 ug/L and sulphate-S of 10-12 mg/kg. These are all within recommended fertility ranges for maximum pasture growth on dairy farms (Fertiliser Association of New Zealand 2023).

Climate

New Zealand lies within the Southern Hemisphere, where prevailing westerly winds drive highly variable weather patterns (Macara 2016). In the South Island, the Southern Alps impact regional climates, acting as a barrier that results in higher rainfall on the West Coast and drier conditions on the east coast, where the Canterbury region is characterised by highly variable weather patterns, cooler winters, warm summers, and moderate to low rainfall (long term average of 600 mm per annum at this field site). Records from 2015 to 2024 (Figures 1a, b and 2) show clear fluctuations between years, with annual rainfall ranging from below 400 mm in the driest years to more than 800 mm in wetter years. Average monthly air temperatures peaked in January–February (18–22°C) and dropped to 5–7°C through winter (June–July).

From June 2024 to June 2025, rainfall at Ashley Dene was highly variable, with totals ranging from less than 20 mm in November and February to over 150 mm in April (Figure 2). Mean monthly air temperature displayed typical seasonal variation, rising to ~18°C in January-February and falling to ~6°C in July. The distinct rainfall peak in autumn contrasted with drier periods in late spring and summer, while temperatures showed a smooth seasonal cycle. These conditions provide the climate for the 2024-2025 period, reflecting the period of when the data was collected.

Experimental design

The experimental layout followed a randomised complete block design of repeated establishments, with sequential annual sowings carried out from 2015 to 2024 (excluding 2023 due to failed establishment). Each year, 10 grass cultivars were sown into a cultivated seedbed in four randomised replicates per paddock, thus new additional replicates are added to the overall trial site each autumn. These included eight perennial ryegrass cultivars (*Lolium perenne*) infected with endophyte (*Epichloë festucae* var. *lolii*), selected to represent a range of ploidy (diploid and tetraploid), heading dates (mid and late season), and decades of release (Table 1). This wide range of perennial ryegrass cultivars were chosen to broadly represent the type of germplasm utilised for improved ryegrass-based pastures in NZ historically up to the commencement of the trial in 2015, thus included tetraploids. One cultivar of endophyte (*E. coenophiala*)-infected tall fescue (*Festuca arundinacea*) and one endophyte-free cultivar of cocksfoot (*Dactylis glomerata*) were also included.

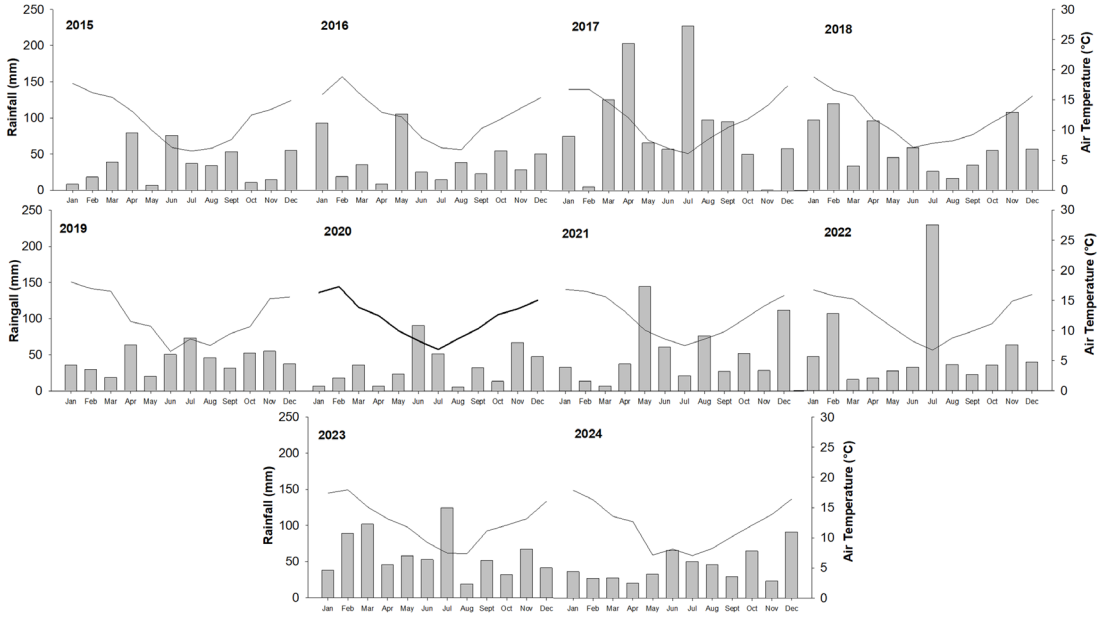


Figure 1 Monthly rainfall (bars) and mean air temperature (lines) recorded at Ashley Dene Research and Development Station, Canterbury, from 2015 to 2024.

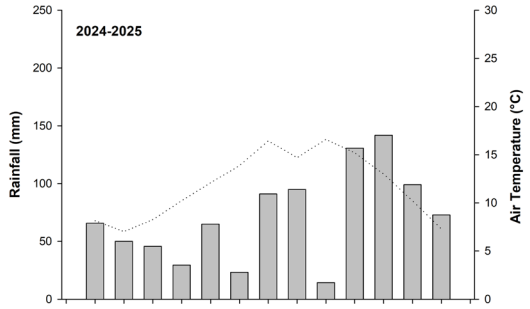


Figure 2 Average monthly rainfall (grey bars) and air temperatures (dotted line) recorded at the cemetery block Ashley Dene, Canterbury. Recorded for the June 2024-June 2025 to represent weather during the months of data collection (May). Rainfall and air temperatures were recorded at Broadfields from 1975-2025

White clover (*Trifolium repens*) was broadcast-sown over all the plots post-drilling. Each plot measures 12 m x 4.2 m, with 6 m x 42 m 'buffer' areas at the end of each paddock sown with a mixture of all ten cultivars to reduce edge effects.

Experimental Area

Paddock history

Pastures sown in 2015 and 2016 were established following a summer brassica break crop of 'Hunter' leafy turnip *Brassica napus* x *rapa*. Pastures sown in the subsequent years were established directly after permanent pasture. Prior to establishment, the existing brassica crop or old pasture were sprayed out using a glyphosate-based herbicide (Weedmaster® 540, containing 540 g/L glyphosate as the active ingredient). Spraying occurred in late February to early March at a rate of 2 L/ha in 200 L water/ha.

Preparation and sowing

Plots were sown in mid-March to mid-April using a Flexiseeder precision plot drill fitted with type coulters, with a coulter spacing of 15 cm (see for sowing rates). Bare grass seed was used for consistency as not all grass cultivar seed lines were available as treated seed at the time of sowing. Superstrike®-treated white clover was broadcasted across the entire area at 7 kg/ha, equivalent to 4 kg/ha of bare seed. The Superstrike® seed coating includes pesticide for protection against clover cyst, lesion and root-knot nematodes, as well as nutrients such as lime and molybdenum. The 2020 sowing (Pasture age 5) was done in spring (September) owning to Covid-19 national lockdown during autumn of that year.

Weed and pest control

Broad leaf weed control was implemented in late autumn/early winter following the establishment of the trial. The target weeds included nettle (*Urtica urens)*, chickweeds (*Stellaria media, Cerastium glomeratum*), scrambling speedwell (*Veronica persica)*, and shepherd's purse (*Capsella bursa-pastoris)*. Control

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

Grass species	Cultivar and endophyte infection	Decade of release	Ploidy	Heading date (days)	Sowing rate (kg seed/ha)	Seed source
Perennial ryegrass	Grasslands Ruanui AR95[1] (98%)	1960s	Diploid	Mid (0*)	20	AgResearch
Perennial ryegrass	Grasslands Nui wild-type[1] (83[2]–51%)	1970s	Diploid	Mid (0*)	20	AgResearch
Perennial ryegrass	Grasslands Samson AR37[1] (99–90%)	1990s	Diploid	Mid (+3)	20	Agricom
Perennial ryegrass	Alto AR37[1] (93–89%)	2000s	Diploid	Late (+14)	20	Barenbrug
Perennial ryegrass	Request AR37[1] (93–89%)	2010s	Diploid	Mid (-7 to +7)	20	Agricom
Perennial ryegrass	Prospect AR37[1] (90–92%)	2010s	Diploid	Late (+12)	20	Agricom
Perennial ryegrass	Halo AR37[1] (90–94%)	2000s	Tetraploid	Late (+25)	28	Agricom
Perennial ryegrass	Base AR37[1] (88–93%)	2010s	Tetraploid	Late (+25)	28	PGGW Seeds
Tall fescue	Hummer MaxP[1] (100–89%)	2010s		Early-Mid	25	Agricom
Cocksfoot	Savvy	2010s		Mid	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 is equivalent to wild-type endophyte. AR37 (Epichloë sp. LpTG-3) 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. *0 = October 22nd.

was achieved through the application of the selective broad-leaf herbicide *Pulsar* (active ingredients: 200 g/L bentazone and 22 g/L MCPB), which was applied at a rate of 5 L/ha in a total spray volume of 300 L water/ha.

Irrigation

Partial irrigation was used, applied by a lateral irrigator at a rate of 40 mm every 12 days during November through until March. Application rates were adjusted based on rainfall, with irrigation used to offset periods of low rainfall and soil moisture during vital growing periods of mid-late spring, through summer and early autumn.

Grazing management

Each annual sowing was stocked as a single unit, with sheep given unrestricted access across all species, cultivars, and replicates. From late winter, plots were continuously stocked with sheep, with the stocking rate adjusted as needed to maintain a target sward height of 4-8 cm. Sheep were removed 3 weeks prior to 1st October and 1st April to allow sufficient herbage accumulation for sampling. Prior to removal, plots were grazed to a residual of 3-4 cm and topped if necessary to ensure even sward height as regrowth started. To support regrowth during these sampling periods, nitrogen fertiliser (urea, 46% N) is applied at 30 kg N/ha in early October and again in early April, immediately after sheep are removed from the plots.

Sample collection

To capture pasture growth and persistence under stressful seasonal conditions, all measurements were carried out in autumn (April) 2025, representing a period of recovery from the more challenging conditions of summer-early autumn (e.g. low moisture, high pest and disease prevalence etc.).

Persistence scoring

Prior to the pasture yield cuts, three independent observers scored the plots for the proportion of sown grass present/remaining from the total visible pasture mass of the plot. Each plot was scored on a scale of 1-9, where 9 = ≥90% sown grass cultivar present, 8 = 80%, 7 = 70%, 6 = 60%, 5 = 50%, 4 = 40%, 3 = 30%, 2 = 20%, 1 = ≤10%. The three scores of the observers were then averaged to give the mean persistence score per plot.

Dry matter yield

Pasture dry matter (DM) yield was assessed by mowing a 12 m strip to a residual height of 4 cm using a 0.46 cm wide rotary lawn mower. The cut herbage was weighed immediately, and a subsample of approximately 300 g was oven dried at 65°C for 48 hours to determine DM percentage. Total DM yield per plot was then calculated based on dry and fresh weights.

Botanical composition

Botanical composition was determined using a subsample taken from the tiller density sample. Samples were manually separated into the following categories: sown grass, unsown grass, white clover, weeds, and dead matter. Each component was over-dried at 65°C for 48 hours and weighed to determine relative composition by dry weight.

Tiller density

Tiller density of the sown grass was determined by

Table 2 Influence of pasture age and grass cultivar on pasture yield in autumn at Ashley Dene, Canterbury (April 2025). Across rows, different bold upper case letters separate means of the significant main effect (pasture age), while different lower case letters separate means of the significant interaction effect (specific grass cultivar across pasture ages), all at the 5% significance level, ns = not significant.

Pasture yield (kg DM/ha)		Pasture age (years)										
		1	3	4	5	6	7	8	9	10	Mean	SEM
Grass Species	***Grass cultivar***											
Perennial ryegrass	Ruanui	3085^{b}	3494^{a}	3397^{a}	2718^{c}	3033^{b}	3017^{b}	3285^{ab}	3234^{ab}	2267^{d}	3059	92
Perennial ryegrass	Nui	3045^{abc}	3217^{ab}	3415^{a}	2832^{bcd}	2890^{bc}	2773^{cd}	3430^{a}	3465^{a}	2445^{d}	3057	130
Perennial ryegrass	Samson	2833^{bcd}	3506^{a}	3151^{ab}	2952^{bc}	2982^{bc}	2735^{cd}	3447^{a}	3475^{a}	2481^{d}	3062	127
Perennial ryegrass	Alto	2993^{b}	3429^{a}	3240^{ab}	2983^{b}	3008^{b}	3102^{b}	3184^{ab}	3022^{b}	2462^{c}	3047	92
Perennial ryegrass	Request	3020^{bc}	3296^{ab}	3461^{a}	2841^{c}	3062^{bc}	2986^{bc}	3063^{bc}	3097^{bc}	2332^{d}	3018	98
Perennial ryegrass	Prospect	2963^{cd}	3474^{a}	3290^{abc}	2936^{cd}	2997^{bcd}	2735de	3463^{a}	3367^{ab}	2395^{e}	3069	104
Perennial ryegrass	Halo	3217^{abc}	3260^{ab}	3518^{a}	3252^{ab}	2807^{c}	2997^{bc}	3329^{ab}	3174^{abc}	2264^{d}	3091	130
Perennial ryegrass	Base	3050^{abc}	3337^{a}	3304^{a}	2901^{bc}	2750^{cd}	2841^{bc}	3392^{a}	3122^{ab}	2444^{d}	3016	110
Tall Fescue	Hummer	3350^{ab}	3166^{ab}	3323^{ab}	3131^{ab}	2948^{b}	3039^{ab}	3470^{a}	3213^{ab}	2457^{c}	3122	150
Cocksfoot	Savvy	3250^{bc}	2996^{bcd}	3691^{a}	3033^{bcd}	2867^{cd}	2890^{cd}	3434^{ab}	3698^{a}	2632^{d}	3166	149
Mean		**3081^{BC}**	**3318^{AB}**	**3379^{A}**	**2958^{C}**	**2934^{C}**	**2911^{C}**	**3350^{A}**	**3287^{AB}**	**2418^{D}**	**3071**	
SEM		102	126	103	128	116	130	120	137	104		118
Significance	**Grass cultivar**								ns (0.325)			
	Pasture age								<0.001			
	Grass cultivar × Pasture age								0.033			

using a 10 cm x 15 cm quadrat placed perpendicular to the drill rows in four randomly selected positions within each plot. Herbage within each quadrat was cut to ground level and grouped into a single sample per plot. From this, 150 whole entire tillers were selected and counted in a methodical format from front of sample to back. Remaining non-sown grass and dead material was separated and weighed. The fresh weights from the counted tillers (plus loose grass) and total quadrat herbage material were used to estimate tiller density (tillers/m^2).

Statistical analysis

The influence of grass cultivar and pasture age, as well as their interaction, on total pasture DM yield, botanical composition, tiller density and persistence score for all plots was analysed using a two-way ANOVA (Genstat version 24, VSN International 2015) with cultivar and age as fixed effects, and replicate blocks as random effects. Graphs were generated in Microsoft Excel.

Results

Pasture yield

Pasture age affected yield (P<0.001) and interacted with grass cultivar (P=0.033) (Table 2, Figure 3). Mean yield varied between 2900 and 3400 kg DM/ha over the 1 to 9 year aged pastures, with the 10 year old pasture being notably lower at ~2400 kg DM/ha. There was no general decline with increasing pasture age (Figure 2, Table 2). Across pasture ages, mean yield was highest for 4, 8, 3, 9 and 1 year-old pastures (3379, 3350, 3318, 3287 and 3081 kg DM/ha, respectively) and lowest in 10-year-old pastures (2418 kg DM/ha; Table 2 and Figure 3). The interaction with cultivar occurred for all cultivars (and species) with pasture ages 4, 8 and 9 having the highest yields for all grass cultivars. For grass cultivars compared within any given pasture age, pasture age x grass cultivar interaction approached statistical significance in 9 year-old pasture (P=0.065) and in 4 year-old and 1 year-old pasture (P=0.084 and P=0.087, respectively). Cocksfoot (cv. Savvy) had the numerically highest pasture yield (3698 kg DM/ha; Table 2 and Figure 3) amongst all cultivars across all pasture ages.

Although overall grass cultivar yield differences were not significant, Savvy cocksfoot tended to be higher in the mid-age pastures, particularly in the 4-year-old pasture. All grass cultivars followed a similar trend from pasture ages 4 to 10 years, characterised by a mid-age peak, a dip around 6- and 7-year-old pastures and a sharp decline by year 10 (Figure 3). Given the non-significant cultivar and significant interaction effects, these rankings are interpreted as observed trends rather

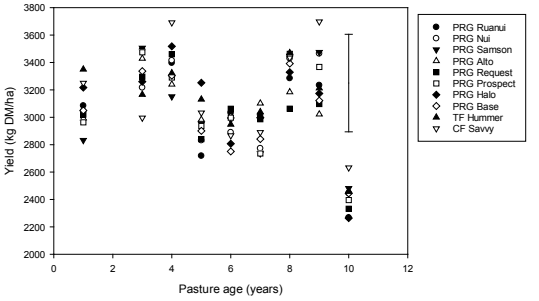


Figure 3 Pasture yield (kg DM/ha) for grass cultivars across pasture ages in autumn at Ashley Dene, Canterbury (April 2025). Error bar shows average LSD (least significant difference at 5% level) between yield means across years.

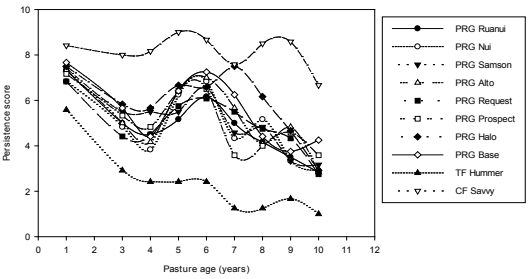


Figure 4 Persistence score for grass cultivars across pasture ages in autumn at Ashley Dene, Canterbury (April 2025). PRG = perennial ryegrass, TF = tall fescue and CF = cocksfoot.

than statistically confirmed yield differences amongst grass cultivars. It should also be considered that these yields represent total pasture yield, which includes sown species, unsown species, white clover, weeds and dead material. Therefore, the data does not isolate the yield contribution of the sown species alone.

Persistence Score

Strong main effects of both grass cultivar and pasture age, as well as a significant interaction between grass cultivar and pasture age strongly influenced persistence scores (Table 3). Across grass cultivars, mean persistence scores ranked Savvy cocksfoot (8.2) greater than ryegrass tetraploids Halo (5.9) and Base (5.6), which were in turn greater than all ryegrass diploids Alto, Samson, Prospect, Request (5.3-4.9), with Hummer tall fescue ranked the lowest (2.3) ($P<0.001$; Table 3). Savvy cocksfoot visually maintained the greatest proportion of sown species over all pasture ages. All perennial ryegrass cultivars showed moderately high (tetraploids) to moderate persistence, with Hummer tall fescue the least visually persistent across pasture ages (Table 3).

Pasture age affected visual persistence ($P<0.001$) with distinct groupings of persistence score (Table 3). Mean persistence score was highest in 1-year old pastures (7.2) with 5- and 6-year old pastures scoring moderately high with 6.0 and 6.4, respectively (Table 3, Figure 3). Pastures aged 4, 7, 8 and 9 scored moderately low with 4.8, 5.1. 4.7 and 4.3, respectively, while 10-year old pastures scored lowest with 3.3 (Table 3).

The grass cultivar x pasture age interaction highlights that visual persistence scoring changed differently between grass cultivars as pastures aged. Savvy cocksfoot maintained consistently high visual persistence across the increasing pasture ages, ranging from 6.7 in 10-year-old pastures and 8.4 in 1-year old pasture (Table 3, Figure 4). In contrast, Hummer tall fescue visual persistence scores dropped markedly from 5.6 in 1-year old pasture 1.0 in 10-year-old pasture, suggesting low long-term survivability (Table 3, Figure 4) under the conditions of this trial. Amongst the perennial ryegrass cultivars, a generally similar pattern of moderately high – moderate early persistence (7.7-6.8) was seen, with a drop in persistence score in 4-year old pasture (3.8-5.5) followed by a slight middle-age peak in pasture ages 5, 6 and 7 (5.0-7.0), then a decline in older stands (2.8-5.2) (Table 3, Figure 4). Notably, the tetraploid perennial ryegrass cultivars of Halo and Base showed moderately high visual persistence scores in mid-older aged pastures (6.4-7.5) (Table 3, Figure 4).

Tiller density

Both grass cultivar and pasture age influenced autumn grass tiller density ($P<0.001$, Table 4) while there was no grass cultivar x pasture age interaction ($P=0.641$).

Prospect, Request, Halo, Samson, Alto and Ruanui ryegrass cultivars had the highest tiller densities (~3000-3600 tillers/m^2), while Base and Nui were lower at ~2700 tillers/m^2. Hummer tall fescue (1118 tillers/m^2) and Savvy cocksfoot (1745 tillers/m^2) were the least tiller dense cultivars (Table 4).

Tiller density was greatest in 5-year old pasture (4041 tillers/m^2). Nine-year old pasture showed the lowest tiller density (1790 tillers/m^2) with 1- and 6-year old pastures having 3296 and 3273 tiller/m^2 (Table 4).

Botanical composition

Grass cultivar and pasture age strongly influenced botanical composition of autumn pasture yield, affecting the proportion of sown grass, unsown species, white clover, and dead material (Table 5).

Sown grass proportion was highest in pastures of Savvy cocksfoot (61%) and tetraploid perennial ryegrass Halo (59%) and Base (55%), with all diploid perennial ryegrass cultivars having around 50% sown grass proportion, while Hummer Tall fescue pasture had the lowest sown grass proportion of 27% (Table 5). In contrast, Hummer tall fescue pastures contained the most unsown species proportion of predominately weedy grass species at 44%. Savvy Cocksfoot, diploid

Table 3 Influence of pasture age and grass cultivar on persistence score in autumn at Ashley Dene, Canterbury (April 2025). Different bold upper case letters separate means of significant main effects (pasture age and grass cultivar). Within columns, different lower case letters separate means of interaction effect (grass cultivars within a single pasture age) while across rows, different upper case letters separate means of interaction effect (single grass cultivar across pasture ages), all at the 5% significance level.

Persistence score		Pasture age (years)										
		1	3	4	5	6	7	8	9	10	Mean	SEM
Grass species	***Grass cultivar***											
Perennial ryegrass	Ruanui	7.3 $^{bc\ A}$	5.0$^{bc\ BC}$	4.5$^{bc\ BCD}$	5.2$^{b\ BC}$	6.2$^{b\ AB}$	5.0$^{bc\ BC}$	4.2$^{b\ CD}$	3.5$^{b\ CD}$	2.8$^{b\ D}$	4.9^{D}	0.6
Perennial ryegrass	Nui	6.8 $^{c\ A}$	4.8$^{bc\ BCD}$	3.8$^{cd\ CDE}$	6.3$^{b\ AB}$	6.8$^{b\ A}$	4.3$^{bc\ CDE}$	5.2$^{b\ ABC}$	3.3$^{b\ DE}$	2.9$^{b\ E}$	4.9^{D}	0.5
Perennial ryegrass	Samson	7.4 $^{bc\ A}$	5.5$^{bc\ BC}$	5.5$^{b\ BC}$	5.5$^{b\ BC}$	6.6$^{b\ AB}$	4.6$^{bc\ CD}$	4.8$^{b\ C}$	3.3$^{b\ DE}$	3.2$^{b\ E}$	5.2^{CD}	0.4
Perennial ryegrass	Alto	7.3 $^{bc\ A}$	5.0$^{bc\ BC}$	4.2$^{bc\ CD}$	6.4$^{b\ AB}$	7.0$^{b\ A}$	5.7$^{abc\ ABC}$	4.1$^{b\ CD}$	4.8$^{b\ BC}$	2.8$^{b\ D}$	5.3^{CD}	0.5
Perennial ryegrass	Request	6.8 $^{c\ A}$	4.4$^{c\ CD}$	4.5$^{bc\ CD}$	5.8$^{b\ ABC}$	6.1$^{b\ AB}$	5.5$^{abc\ ABCD}$	4.8$^{b\ BCD}$	4.3$^{b\ D}$	2.8$^{b\ E}$	5.0^{D}	0.4
Perennial ryegrass	Prospect	7.2 $^{bc\ A}$	5.3$^{bc\ ABCD}$	4.8$^{bc\ BCD}$	6.4$^{b\ ABC}$	6.5$^{b\ AB}$	3.6$^{c\ D}$	4.0$^{b\ D}$	4.6$^{b\ CD}$	3.6$^{b\ D}$	5.1^{CD}	0.6
Perennial ryegrass	Halo	7.5 $^{b\ A}$	5.8$^{b\ AB}$	5.7$^{b\ AB}$	6.7$^{b\ AB}$	6.6$^{b\ AB}$	7.5$^{a\ A}$	6.2$^{b\ AB}$	4.7$^{b\ BC}$	2.9$^{b\ C}$	5.9^{B}	0.7
Perennial ryegrass	Base	7.7 $^{b\ A}$	5.7$^{bc\ BCD}$	4.4$^{bc\ CDE}$	6.4$^{b\ AB}$	7.3$^{b\ AB}$	6.3$^{ab\ ABC}$	4.4$^{b\ CDE}$	3.8$^{b\ E}$	4.3$^{b\ DE}$	5.6^{BC}	0.6
Tall Fescue	Hummer	5.6 $^{d\ A}$	2.9$^{d\ B}$	2.4$^{d\ BC}$	2.4$^{c\ BC}$	2.4$^{c\ BC}$	1.3$^{d\ D}$	1.3$^{c\ D}$	1.7$^{c\ CD}$	1.0$^{c\ D}$	2.3^{E}	0.3
Cocksfoot	Savvy	8.4 $^{a\ AB}$	8.0$^{a\ AB}$	8.2$^{a\ AB}$	9.0$^{a\ A}$	8.7$^{a\ AB}$	7.6$^{a\ BC}$	8.5$^{a\ AB}$	8.6$^{a\ AB}$	6.7$^{a\ C}$	8.2^{A}	0.3
Mean		7.2^{A}	5.3^{C}	4.8^{CD}	6.0^{B}	6.4^{B}	5.1^{C}	4.7^{CD}	4.3^{D}	3.3^{E}	5.2	
SEM		0.2	0.4	0.5	0.5	0.4	0.6	0.7	0.6	0.5		0.5
Significance	**Grass cultivar**								<0.001			
	Pasture age								<0.001			
	Grass cultivar × Pasture age								0.026			

Table 4 Influence of pasture age and grass cultivar on tiller density in autumn at Ashley Dene, Canterbury (April 2025). Different bold upper case letters separate means of significant main effects (pasture age and grass cultivar), at the 5% significance level.

Tiller density (number/m^2)		Pasture age (years)										
		1	3	4	5	6	7	8	9	10	Mean	SEM
Grass species	***Grass cultivar***											
Perennial ryegrass	Ruanui	4423	3193	2202	4255	3554	2544	3001	1689	2849	3079^{AB}	645
Perennial ryegrass	Nui	2545	3401	1778	3830	3027	1708	3294	1586	3703	2764^{B}	661
Perennial ryegrass	Samson	3917	2909	3335	4582	3555	3817	2556	1375	2109	3128^{AB}	715
Perennial ryegrass	Alto	3352	2052	1846	5144	4588	3789	2906	2016	3806	3278^{AB}	575
Perennial ryegrass	Request	3906	3054	2795	4986	4398	3527	3174	2213	3259	3479^{A}	684
Perennial ryegrass	Prospect	4140	3052	3714	4014	4230	2338	2589	3619	4699	3599^{A}	648
Perennial ryegrass	Halo	3181	3857	4459	4003	3259	3722	2136	2256	3697	3397^{AB}	827
Perennial ryegrass	Base	3174	2405	2061	3596	3901	2565	2229	1755	3240	2769^{B}	494
Tall Fescue	Hummer	2376	1419	809	3862	452	224	136	357	430	1118^{C}	254
Cocksfoot	Savvy	1941	2205	1905	2132	1764	1900	1179	1032	1646	1745^{C}	294
Mean		3296^{B}	2755^{BCD}	2490^{CD}	4041^{A}	3273^{B}	2613^{CD}	2320DE	1790^{E}	2944^{BC}	2836	
SEM		503	490	719	834	587	567	382	284	852		580
Significance	**Grass cultivar**									<0.001		
	Pasture age									<0.001		
	Grass cultivar × Pasture age									0.641		

Request and tetraploid Halo perennial ryegrass pastures contained the least unsown proportions (9, 15, and 16%, respectively) with all other perennial ryegrass cultivars having 19-24% unsown proportion (Table 5). For white clover, Savvy cocksfoot contained the least (0.2%) with all other grass cultivar pastures having a similar proportion of around 2% white cover (Table 5). Dead matter held a narrow range between 22-30%, with all diploid perennial ryegrass cultivars having the highest dead matter content and perennial ryegrass tetraploids Halo and Base the least (Table 5).

Sown grass proportion was highest in 1-year-old pastures (65%) along with 10-year-old pastures (60%), while 3, 4, 5, 7, 8, and 9-year old pastures had the lowest sown grass proportions (39-47%) (Table 5). The proportion of unsown species was highest in 3, 4, and 7 year old pastures (33-35%), and lowest in 1-year old pasture (2%) (Table 5). White clover followed a similar pattern, with the highest content in 1-year old pastures (6.5%) with 5- and 6-year-old pastures having around 3% and all remaining pasture ages with less than 1% (Table 5). Dead material ranged between 21-36% with 1, 5, 6, 8, and 9 year-old pastures showing the highest dead matter (26-36%) while all remaining pasture ages were ≤24% (Table 5).

When comparing botanical composition of an individual grass cultivar across all pasture ages, there was a significant interaction on sown grass % in Savvy cocksfoot ($P<0.01$), Hummer tall fescue ($P<0.001$), Base tetraploid perennial ryegrass ($P<0.05$) and Alto diploid perennial ryegrass ($P<0.01$) pastures (Table 6). Savvy cocksfoot pastures show a clear pattern of moderately high sown grass proportion (75-80%) in younger aged pastures (1, 3 and 4), medium sown grass proportion (48-56%) in mid to older aged pastures (5, 6, 7, 8 and 9) with 10-year old pasture an outlier with 60% sown grass (Table 6). Hummer tall fescue pastures show a clear pattern of lower sown grass proportion with increasing pasture age, except for 5-year old pasture with an outlier of 65% (Table 6). Base and Alto perennial ryegrass pastures are similar in their pattern of sown grass proportion being moderately high in 1-year old pastures (65-71%) and medium to low from pasture ages 3 to 9, except for 10-year old pasture (71-80%) (Table 6).

When comparing botanical composition of all grass cultivars within a given pasture age, grass cultivar interacted with pasture age for sown grass proportions in 3, 6, 7, 8 and 10-year old pastures (Table 6). Within 3-year old pasture, Savvy cocksfoot contained the highest (75%) and Hummer tall fescue the lowest (19%) sown grass proportions, with all other grass cultivars having similar sown grass proportions (36-52%) (Table 6). This pattern changed in older pastures with both tetraploid perennial ryegrass cultivars of Base and Halo consisting showing moderately high sown grass proportions compared to diploid perennial ryegrass cultivars in general, with the exception of Nui in 6-year old pasture (63%) and Request in 8-year old pasture (60%) (Table 6). Ten-year old pasture was an outlier with all perennial ryegrass cultivars and Savvy cocksfoot showing moderately high (57-68%) and high (71-80%) sown grass proportions (Table 6).

Grass cultivar x pasture age interaction also influenced the unsown proportion in Nui, Samson, Alto, Request, Base perennial ryegrass pastures and Hummer tall fescue pastures (Table 6) and within pasture ages 3, 4, 6, 7, 8 and 10 (Table 6), with patterns in unsown species proportion inversely related to the sown grass proportion patterns described earlier. Hummer tall fescue pastures contained the highest unsown species proportion across all pasture ages except in 5-year old pasture, while Savvy cocksfoot pastures generally contained the least (Table 6). Amongst perennial ryegrass cultivars, unsown species proportion was generally lower for tetraploids Base and Halo, and higher for diploid cultivars (Table 5 and 6).

Discussion

The majority of studies investigating pasture persistence tend to be based on a single sowing (Chapman et al. 2015; Lee et al. 2017). In contrast, this study takes a longitudinal approach, looking at the effects of aging pasture and grass species and cultivar on persistence related traits (yield, botanical composition, tiller density and persistence score), while also considering the potential confounding effect of abiotic and biotic factors on these outcomes. With this approach, all sowing years are exposed to the same conditions at the same time, therefore making a sequence of pastures of different ages comparable. This is the first complete set of data from the Lincoln University long-term pasture persistence trial which uses one sampling point (autumn 2025) to compare the ten grass cultivars (and three grass species) across the gradient of increasingly mature pasture ages.

Pasture yield

Pasture age primarily influenced dry matter yield, with no direct effect of cultivar, suggesting that the magnitude of changes observed in yield were driven by the age of the stand more so than specific grass species or cultivar. This was supported by the evident grass cultivar x pasture age interaction, reflecting the over-riding influence of pasture age on yield and other persistence traits. Yields peaked in the 4- and 8- year-old pastures (3379 and 3350 kg DM/ha, respectively). Contrastingly, yield was lowest in the 10-year-old pastures (2418 kg DM/ha). Although cultivar effects were small compared with the larger influence of sward age, this is consistent with findings from Maxwell et

Table 5 Influence of grass cultivar and pasture age on botanical composition of pasture yield (kg DM/ha; Table 2) in autumn at Ashley Dene, Canterbury (April 2025). Within columns, different uppercase letters separate means at the 5% significance level.

Main effect		Botanical composition (% of DM)			
		Sown grass	Unsown	White clover	Dead
Grass species	***Grass cultivar***				
Perennial ryegrass	Ruanui	45^{D}	23^{B}	1.6^{A}	30^{A}
Perennial ryegrass	Nui	47^{D}	22^{BC}	2.1^{A}	30^{AB}
Perennial ryegrass	Samson	48^{CD}	24^{BC}	2.2^{A}	26^{ABC}
Perennial ryegrass	Alto	47^{CD}	24^{B}	1.4^{A}	28^{AB}
Perennial ryegrass	Request	53^{BCD}	15^{DE}	2.1^{A}	30^{A}
Perennial ryegrass	Prospect	47^{D}	22^{BC}	2.1^{A}	29^{AB}
Perennial ryegrass	Halo	59^{AB}	16^{CD}	1.9^{A}	22^{C}
Perennial ryegrass	Base	55^{ABC}	19^{BCD}	1.5^{A}	25^{BC}
Tall Fescue	Hummer	27^{E}	44^{A}	2.3^{A}	26^{ABC}
Cocksfoot	Savvy	61^{A}	9^{E}	0.2^{B}	30^{AB}
Significance		<0.001	<0.001	<0.001	0.043
Pasture age (years)					
1		65^{A}	2^{D}	6.5^{A}	26^{AB}
3		46^{BCD}	33^{A}	0.9^{C}	21^{C}
4		42^{CD}	34^{A}	0.5^{C}	24^{BC}
5		47^{BCD}	15^{C}	2.6^{B}	35^{AB}
6		51^{B}	18^{C}	2.7^{B}	28^{BC}
7		43^{BCD}	35^{A}	0.9^{C}	21^{C}
8		47^{BC}	16^{C}	0.9^{C}	36^{A}
9		39^{D}	26^{B}	0.4^{C}	35^{A}
10		60^{A}	18^{C}	0.3^{C}	21^{C}
Significance		<0.001	<0.001	<0.001	<0.001
Mean		49	22	1.7	28
SEM		7.9	5.9	0.74	5.2

al. (2018), who reported no difference in yield between grass species and grass cultivars, but a significant difference in yield between establishment years. It is worth nothing that our trial design and timing of data collection is unlikely to identify pasture grass breeding efforts for increased yield at the fringes of the growing season (late winter/early spring, and late autumn).

The lowest yield in the oldest stand (pasture age 10) could be attributed to the natural decline in yield over time. However, despite lower total yield, the botanical composition components of the 10-year-old pasture did not consistently differ statistically from that of younger pastures, suggesting that the reduced yield may reflect other abiotic or biotic factors rather than a decline in persistence. The trait of yield is not a fully accurate or representative determinant of pasture persistence, as it does not consider the botanical composition of the yield. For example, Hummer tall fescue at 8 years-old yielded 3470 kg DM/ha, however, only 15% of this was sown grasses, whereas 52% was unsown grasses. Maxwell et al. (2018) had similar findings, where the highest yielding pasture age (1-year-old pasture, 2409 kg DM/ha) had the lowest grass leaf proportion (42.6%) compared to other pasture ages.

When considering the botanical composition of 4- and 8-year-old pasture, there was no statistical difference from pasture age 4 to 10 years, suggesting that all pasture ages were similar in sown grass persistence. When considering yield of all components, the peak in 4- and 8-year-old pastures can be attributed to the abiotic conditions at the time of these pasture ages establishment. In the 4-year old pasture (established in autumn 2021), rainfall was approximately 150 mm in May. In the 8-year-old pasture (established autumn

Table 6 Influence of grass cultivar and pasture age interaction on botanical composition of pasture yield (kg DM/ha; Table 2) in autumn at Ashley Dene, Canterbury (April 2025). Across rows, different lower case letters separate means of a single grass cultivar across pasture ages. Within columns, different upper case letters separate means of different grass cultivars within a pasture age, all at the 5% significance level. ns = not significant.

Sown grass (%)		Pasture age (years)											
		1	3	4	5	6	7	8	9	10	Significance	Mean	SEM
Grass species	***Grass cultivar***												
Perennial ryegrass	Ruanui	53	51 ^{B}	28	51	59 ^{AB}	37 ^{B}	40 ^{BCD}	33	57 ^{A}	ns	45	9.6
Perennial ryegrass	Nui	56	43 ^{B}	37	42	63 ^{A}	37 ^{B}	55 ^{ABC}	27	59 ^{A}	ns	47	8.8
Perennial ryegrass	Samson	66	36 ^{BC}	45	48	54 ^{AB}	45 ^{AB}	49 ^{ABC}	30	61 ^{A}	ns	48	9.0
Perennial ryegrass	Alto	71^{a}	41$^{b\ B}$	30^{b}	39^{b}	50$^{ab\ AB}$	49$^{b\ AB}$	34$^{b\ CD}$	38^{b}	71$^{a\ A}$	0.004	47	7.4
Perennial ryegrass	Request	58	46 ^{B}	34	51	55 ^{AB}	46 ^{AB}	60 ^{AB}	52	74 ^{A}	ns	53	7.8
Perennial ryegrass	Prospect	61	46 ^{B}	43	37	47 ^{B}	31 ^{BC}	47 ^{ABC}	42	64 ^{A}	ns	47	7.9
Perennial ryegrass	Halo	74	52 ^{B}	50	44	56 ^{AB}	70 ^{A}	65 ^{A}	54	68 ^{A}	ns	59	10.9
Perennial ryegrass	Base	65^{ab}	47$^{bcd\ B}$	38^{d}	41^{cd}	63$^{abc\ AB}$	54$^{bcd\ AB}$	60$^{abcd\ AB}$	46^{bcd}	80$^{a\ A}$	0.019	55	7.3
Tall Fescue	Hummer	69^{a}	19$^{c\ C}$	32^{b}	65^{a}	10$^{c\ C}$	8$^{c\ C}$	15$^{c\ D}$	16^{c}	8$^{c\ B}$	<0.001	27	4.0
Cocksfoot	Savvy	77^{ab}	75$^{abc\ A}$	80^{a}	51^{d}	55$^{d\ AB}$	56$^{cd\ AB}$	49$^{d\ ABC}$	48^{d}	60$^{bcd\ A}$	0.005	61	6.2
Significance		0.091	0.004	0.063	ns	<0.001	0.005	0.016	ns	0.005			
Unsown (%)													
Grass species	***Grass cultivar***												
Perennial ryegrass	Ruanui	3	27 ^{BC}	44 ^{A}	16	16 ^{BCD}	40 ^{B}	14 ^{BC}	28	15 ^{B}	0.061	23	8.2
Perennial ryegrass	Nui	4^{d}	27$^{abc\ BC}$	38$^{a\ A}$	15^{bcd}	4$^{d\ D}$	40$^{a\ B}$	11$^{cd\ BC}$	33^{ab}	21$^{abcd\ B}$	0.008	22	6.6
Perennial ryegrass	Samson	2^{d}	32$^{abc\ B}$	32$^{abc\ A}$	16^{cd}	20$^{bcd\ BC}$	37$^{ab\ B}$	15$^{cd\ BC}$	46^{a}	13$^{cd\ B}$	0.002	24	6.1
Perennial ryegrass	Alto	1^{c}	44$^{a\ AB}$	41$^{a\ A}$	22^{abc}	14$^{bc\ BCD}$	23$^{ab\ BC}$	24$^{ab\ B}$	28^{ab}	17$^{bc\ B}$	0.012	24	6.8
Perennial ryegrass	Request	2^{d}	25$^{ab\ BC}$	32$^{a\ A}$	16^{bc}	9$^{cd\ CD}$	26$^{ab\ BC}$	5$^{cd\ BC}$	14^{bcd}	7$^{cd\ B}$	<0.001	15	4.0
Perennial ryegrass	Prospect	2	33 ^{B}	32 ^{A}	25	26 ^{B}	42 ^{B}	13 ^{BC}	18	12 ^{B}	0.051	22	6.9
Perennial ryegrass	Halo	1	35 ^{B}	31 ^{A}	13	19 ^{BC}	10 ^{C}	10 ^{BC}	17	11 ^{B}	ns	16	7.0
Perennial ryegrass	Base	2^{d}	38$^{a\ AB}$	38$^{a\ A}$	16^{bcd}	8$^{cd\ CD}$	25$^{abc\ BC}$	9$^{cd\ BC}$	32^{ab}	4$^{d\ B}$	<0.001	19	5.1
Tall Fescue	Hummer	2^{e}	58$^{bc\ A}$	47$^{cd\ A}$	6^{e}	55$^{bc\ A}$	76$^{a\ A}$	52$^{bcd\ A}$	40^{d}	61$^{b\ A}$	<0.001	44	4.2
Cocksfoot	Savvy	2	6 ^{C}	5 ^{B}	6	9 ^{CD}	25 ^{BC}	3 ^{C}	6	19 ^{B}	0.068	9	4.2
Significance		ns	0.01	0.005	ns	0.001	0.001	<0.001	0.08	<0.001		49	7.9

2017), rainfall was approximately 125 mm in April, meaning soil moisture would have been more adequate at the time of sowing for both sowing years. Cosgrove et al. (2020) suggested that differences at the time of establishment have consequences on the stability of pasture yield and the future resilience of these plots exposed to unpredictable, biotic and abiotic stressors. Because the soil moisture and temperature at the time of sowing for pasture age 4- and 8-years was higher than other sowing years, this may explain the reason why yield is significantly higher than other pasture ages.

These findings show that although pasture age strongly influences total dry matter production, yield alone does not capture the complete picture of persistence. Interpreting yield alongside sown grass proportion, weed ingress and tiller density provides more of an accurate representation of pasture longevity.

Botanical composition

Pasture age

Proportion of sown grasses tended to show a general gradual decline post establishment, where one-year old pasture had the highest sown species (65%) with the lowest unsown species ingress (2%). By contrast, the 4-year-old pasture showed an increase in unsown species (33%) but only a small reduction in sown grasses (46%), offset by a decrease in dead material (21.0%) compared to that of other pastures ages (36% in 8-year-old pastures). Similarly, 7 year-old pasture had a large proportion of unsown species (35%), also offset by a lower dead material content (21%). This could be attributed to the 2018 (7-year-old) and 2021 (4-year-old) sowing year paddocks being situated in the leeward side of a *Pinus radiata* shelterbelt, therefore

subjected to more shading compared to other paddocks. Dodd et al. (2005) had similar findings, stating that increase in shading levels lead to a significantly reduced net herbage growth and sown pasture species composition, where there was no difference in grass content, however a gain of 5-20% in weed content and a loss in dead matter down to between 0 and 6% in more shaded pastures.

White clover was notably the highest in 1-year old pasture (6.5%) compared with all other ages, with the next highest proportion occurring in 6-year-old pastures (2.7%). An explanation for this lowered clover content could be due to a natural decline in aging pastures, as justified by McCahon et al. (2021), who found a consistent decline in clover content over a 4-year period, from approximately 30% in newly established pastures to less than 5% after 4 years. Paddocks with the increased shading from the shelterbelt (pasture ages 7, 4 and 3) had a noticeably higher proportion of unsown species such as browntop (*Agrostis capillaris*). Grasses with dense canopies, such as browntop, have been shown to adversely affect clover persistence by limiting light interception and soil resources (Woodfield and Caradus, 1996).

Species and cultivar

Grass species influenced botanical composition of the sward regardless of its age, affecting the proportion of sown grasses, unsown species and white clover ($P<0.001$), while the proportion of dead material remained similar among grass cultivars. Savvy cocksfoot maintained the highest proportion of sown species (61%), indicating strong persistence under the management and climatic conditions at this stony Canterbury location. This superior performance is consistent with cocksfoot's morphological attributes, particularly its deeper and wider root system relative to perennial ryegrass allowing greater access to subsoil moisture during drier periods, improving its drought tolerance (Moloney 1993; Talamini et al. 2021).

Perennial ryegrass cultivars maintained the second-highest proportion of sown grass after cocksfoot, suggesting moderate persistence across pasture ages. This aligns with ryegrass' known competitive growth habit due to its prostrate form, prolific tillering and rapid establishment (hence canopy closure), which enhances the species ability to suppress weed ingress (Kemp et al. 1999). Hummer tall fescue showed the lowest mean sown grass content (27%) and the greatest ingress of unsown species (44%), highlighting its poorer persistence under the management conditions at this stony soil location compared with the ryegrasses and cocksfoot. Similar results were reported by Tozer et al. (2014), who found unsown species proportions in tall fescue swards increased to 28-40% by the third-year post-establishment, compared with unsown proportions of 7-13% in perennial ryegrass swards. This greater weed ingress is typically attributed to tall fescue's slower establishment rate and more open canopy structure, which allows competing species to invade. Tall fescue also has a higher thermal time requirement (Moot et al. 2000), making it less suited to autumn sowing in Canterbury. In this study, all grass cultivars, including Hummer tall fescue, were sown in autumn to keep experimental conditions the same, which may have further disadvantaged tall fescue's establishment and competitive capability, contributing to its lower sown grass species content.

On a cultivar basis, tetraploid and diploid perennial ryegrass yields showed a difference in sown grass and unsown species components, with both ploidy groups maintaining moderate proportions of sown grass across pasture ages (55-59% and 45-53%, respectively). Although diploid cultivars are expected to persist better than tetraploids due to their typically higher tiller densities (Balocchi and López, 2009), this pattern was not observed in the present study. One possible reason is that the main distinction between the cultivars, endophyte type (AR37 for Base, wild-type for Nui) may not have reaped the full benefits of extra protection AR37 possesses over wild-type (Hume et al., 2007) in the dry Canterbury climate, where it is less humid and there is less pest pressure compared to more northern NZ locations. Further explanation is discussed under tiller density.

Differences in white clover content among species were also evident. Hummer Tall fescue contained the highest mean proportion of white clover (2.3%), consistent with Tozer et al. (2014) findings, who reported that the slower establishment of tall fescue allows white clover to establish more readily in the early years. In contrast, lower clover content of Savvy cocksfoot may reflect the plant morphology of larger leaves, which can increase shading of the stolon layer during establishment and reduce clover growth. Hummer tall fescue has a more open sward, allowing for light to reach the soil surface, hence support clover growth. Savvy cocksfoot had the lowest white clover content, aligning with Woodfield and Caradus (1996), who noted that cocksfoot's dense, tufted sward suppressed legume growth by restricting light and soil nutrient availability within the canopy. Overall, these differences reflect how legume persistence is strongly affected by grass species morphological and physiological aspects.

Comparing the mean sown grass proportion of the different grass cultivar swards across increasing pasture age, Savvy cocksfoot maintained the highest sown-grass proportion (61%) and the lowest unsown species ingress (9%) with Hummer tall fescue showing the opposite pattern (Table 6). Pasture ages 5 and 10

were outliers that do not follow the general pattern of decreasing sown grass proportion with increasing pasture age. Pasture age 5 was sown in spring 2020 due to the disruption of Covid-19 lockdowns. Notably, sown grass (65%) and tiller density (3862 tillers/m^2) of Hummer tall fescue of Pasture age 5 was significantly higher (Tables 6 and 4), reflecting this more favourable and advisable spring sowing conditions for this species. Pasture age 10 may have volunteer ryegrass masking as sown grass, which would explain the high sown grass component observed for the oldest pasture here.

Tiller density

Grass cultivar and pasture age influenced tiller density. Tall fescue recorded the lowest mean tiller density (1118 tillers/m²) over all the pasture ages, reflecting the grazing management and site (soil and climate) conditions of this trial working against tall fescue's persistence in combination perhaps with its slower establishment and more open canopy structure. Because tall fescue develops tillers more slowly and is less competitive in the early stages (particularly under autumn sowing as previously discussed), it is more susceptible to ingress from other species, especially under close continuous grazing management. This pattern aligns with Tozer et al. (2014), who reported that tall fescue pastures accumulate greater proportions of unsown species due to their slower canopy closure, as well as their weaker suppression of competing grasses. Although tall fescue is typically considered a deep-rooted and drought-tolerant species, the very stony soil type is likely to affect its productivity at Ashley Dene. At the site, stony silt loam sits over a dense gravel layer, creating a physical barrier to deeper rooting species. Work by Talamini (2022), also at the Ashley Dene site, showed that tall fescue extracted water to a maximum of 1.0 m, compared to 1.6 m at the Ladbrook's site, where the soils are finer and roots can penetrate further. With a restricted root system, tall fescue cannot fully take advantage of its usual, renowned drought tolerance traits. This is supported by West et al. (2007), who found that after 35 days of withholding water, tall fescue tiller survival can fall from 100% to below 20%.

Savvy cocksfoot had the second lowest tiller density (1745 tillers/m²) despite having the highest proportion of sown species across pasture ages. This reflects its growth morphology. Cocksfoot has a tufted growth nature with larger, thicker leaves and a deeper, more fibrous root system (Kemp et al. 1999), allowing it to maintain competitiveness without producing a moderately high number of tillers. Importantly, this morphology helps to explain why cocksfoot still produced higher tiller densities than tall fescue, even though both are considered drought tolerant species. With the stony soil at Ashley Dene restricting deep rooting, cocksfoot's fibrous root system can access water laterally across the profile, giving it a competitive advantage over tall fescue in these environments.

Reasoning for lower tiller densities in cocksfoot compared to ryegrass species are described by Matthew and Hamilton (2011), who noted that when herbage mass declines, grasses with smaller leaves increase tiller density to maintain sufficient light interception required for photosynthesis. In contrast, larger leafed species rely less on tiller recruitment to maintain pasture cover. Cocksfoot, therefore, preserves light interception and ground cover through leaf size and tuft structure rather than dense tillering. This aligns with our botanical composition results, where Savvy cocksfoot maintained the highest sown grass proportion (despite having lower tiller numbers) because its morphology allows for strong competitive capability even at lower tiller densities.

Two perennial ryegrass cultivars (Nui and Base) had the highest tiller densities out of the three species across all pasture ages, with average ryegrass tiller populations being 244% greater than tall fescue and 70% greater than cocksfoot. This species-level difference is driven by morphological and physiological features, where perennial ryegrass is known for its higher tillering characteristics, with a prostrate growth form and short leaf sheaths (Kemp et al. 1999). Grazing management which favours higher tiller densities of perennial ryegrass (i.e. more continuous grazing pressure) is a significant contributing factor to persistence of the species under any livestock grazing system conditions, provided nutrients and moisture are not overly limiting.

Although grass species differed markedly, tiller density did not differ greatly between tetraploid and diploid perennial ryegrass cultivars. This is notable because research reports that diploids generally have higher tiller density than tetraploids due to their smaller leaf size and greater tillering potential (Balocchi and López 2009). Similar research to the present study by Cosgrove et al. (2020) found a higher mean tiller density in tetraploid Base (2310 tillers/m²) than in diploid Nui (1450 tillers/m²). They also showed that tiller density is strongly cultivar specific, rather than ploidy driven, with newer diploid cultivars such as 'Request' achieving higher densities (3780 tillers/m²) than both tetraploid cultivars in the same trial.

A key distinction between Nui and Base in both the Cosgrove et al. (2020) study and this present study is endophyte type. Base contains the AR37 endophyte, while Nui carries a wild-type strain. AR37 is known to give strong protection against pests such as root aphids, porina, and in the warmer northern NZ regions, black beetle. This often leads to better persistence where insect pressure is high (Hume et al. 2007). However, the advantages typically experienced in pastures infected with AR37 may not be realised in the Canterbury

region, where climate is drier, soil is cooler, and insect activity tends to be lower. This could give some explanation as to why tetraploid and diploid perennial ryegrass cultivars performed similarly in tiller density, as there is no clear evidence that the AR37 endophyte acted as an advantage under these conditions.

Persistence score

The persistence score was a measure that worked alongside other traits as an indication of how well each cultivar persisted as pastures aged. The general trend was that persistence declined over time, with mean scores falling from 7.2 in 1-year-old pastures to 3.3 by year 10, mirroring the age-related declines seen in sown grass proportion (Tables 5 and 6) and tiller density (Table 4). Savvy cocksfoot consistently achieved the highest persistence scores (mean 8.2), which fits with its strong botanical composition where it maintained the greatest proportion of sown species (61%) over all pasture ages. In contrast, Hummer tall fescue recorded the lowest persistence score (mean 2.3), reflecting its poorer botanical composition with a sown grass proportion of 27%, higher unsown species ingress and the lowest tiller density of all cultivars. These alignments show that visual scoring works well when considered alongside yield, botanical composition and tiller density. Visual scoring does have its limitations, however, as it is subjective therefore prone to variation between assessors. In addition, it was often difficult to visually distinguish between different perennial ryegrass cultivars within a plot (e.g. if Nui was spreading into Base), meaning that cultivar persistence may be harder to assess accurately using this method alone.

Practical implications

Savvy cocksfoot consistently ranked the highest across all persistence traits, indicating that it is well suited to Canterbury's dry, stony soils. Farmers looking for long-term persistent grass-based pastures on stony soil under continuous sheep grazing should prioritise cocksfoot cultivars such as Savvy or other suitable cultivars of this grass species.

Neither tetraploid or diploid perennial ryegrass cultivars showed a significant advantage over the other in yield, sown-grass content, tiller density or persistence score. The expected diploid vs tetraploid differences did not translate into practical advantages in this study. Perennial ryegrass remains a good general option on a species level, however cultivar differences were moderate to minimal. Ruanui and Nui cultivars are over 40 years old and are no longer widely used commercially. Their persistence was generally comparable and like the more modern diploid ryegrasses (i.e. Samson, Alto, Request and Prospect) that have been bred for higher persistence and better stress tolerance. The general lack of difference between newer diploids and tetraploids in this study so far may not reflect the expected performance gap between current diploids and tetraploids.

Tall fescue is poorly suited to shallow, stony soils like Ashley Dene. Despite being generally drought tolerant, tall fescue performed poorly across all persistence traits. Therefore, tall fescue is not recommended for shallow, stony soils as it will not express its full drought tolerant potential unless rooting depth can reach 1.5 m and below. The continuous grazing management regime for this long-term persistence study may have disadvantaged tall fescue as well.

Establishment conditions are an important factor to master to ensure long-term persistence. Yield peaks in this study aligned with years that had better climatic conditions (higher soil moisture and temperatures) at sowing. Practically, farmers implementing these species and cultivars should ensure sowing conditions are optimal rather than going off specific dates.

Conclusions

- Pasture age influenced production and composition, with total pasture yields highest for 4- and 8-year-old pastures and lowest in 10-year old pastures. The proportion of sown grass dropped from 65% at establishment to around 50% in older stands. However, pasture age effects were better evaluated alongside grass species and grass cultivar differences rather than as a standalone driver of persistence, as evidenced by pasture age interaction with grass cultivar for most traits (yield, botanical composition, and persistence score).
- Persistence was strongly species dependent. Savvy (cocksfoot) showed the strongest persistence traits, highest in sown grass proportion, lowest in unsown species and the highest persistence score. Perennial ryegrass cultivars generally showed moderate and similar persistence, while Hummer (tall fescue) performed poorly across all traits.
- Ploidy did not influence persistence. Despite theoretical expectations that diploids should tiller more densely than tetraploids, diploid cultivars and tetraploid cultivars did not differ markedly in yield, tiller density or botanical composition, indicating that ploidy was not a meaningful determinant of persistence under the conditions at Ashley Dene. Tetraploid cultivars, notably Halo, performed better than diploids in mid to older pasture ages for all traits.
- Persistence reflects the combined effects of plant morphology and physiology and how well these effects combine for each species to suit the soils, climate and management at a particular site. At Ashley Dene, the ryegrasses maintained the densest

tiller populations (around 2900-3000 tillers/m²), cocksfoot persisted well due to its fibrous root system that suits shallow, stony soils. Tall fescue performed poorly because its deeper-rooting traits and higher thermal time requirements were restricted in this trail's establishment timing (mid-autumn), soil type and grazing management regime. Taken together, the characteristics of Savvy cocksfoot place it as the strongest performer, tetraploid and some diploid perennial ryegrasses as moderately persistent, and Hummer tall fescue as the weakest. This highlights the importance of considering multiple persistence traits to understand the long-term performance of a pasture.

ACKNOWLEDGEMENTS

The authors wish to thank the T R Ellett Agricultural Research Trust for financially supporting the data collection for this study and for their continued support of the Lincoln University Pasture Persistence Trial.

REFERENCES

Balocchi OA, López I F. 2009. Herbage production, nutritive value and grazing preference of diploid and tetraploid perennial ryegrass cultivars (*Lolium perenne* L.). *Chilean Journal of Agricultural Research 69*: 331-339. https://doi.org/10.4067/S0718-58392009000300005

Chapman D, Muir P, Faville M. 2015. Persistence of dry matter yield among New Zealand perennial ryegrass (*Lolium perenne* L.) cultivars: Insights from a long-term dataset. *Journal of New Zealand Grasslands 77*: 177-184. https://doi.org/10.33584/jnzg.2015.77.463

Cosgrove GP, Trolove MR, Staincliffe MR, Tozer KN. 2020. Persistence of perennial ryegrass, tall fescue and cocksfoot following sequential annual sowings: Pasture yield, composition and density in three establishment years under cattle grazing in Waikato. *Journal of New Zealand Grasslands 82*: 149-159. https://doi.org/10.33584/jnzg.2020.82.451

Cosgrove GP, Maxwell TMR, Wynne-Jones B, Edwards GR, Staincliffe MR, Tozer KN. 2023. Persistence of Perennial Ryegrass, Tall Fescue and Cocksfoot Following Sequential Annual Sowings: Influence of Species, Cultivar and Pasture Age on Inter-Annual Variability in Yield and Botanical Composition. In *XXV International Grassland Congress (IGC 2023)*. International Grassland Congress 2023. doi:10.52202/071171-0116

DairyNZ. (2025, January 22). *2024–25 mid-season update: Willsden, Canterbury owner System 3*. https://www.dairynz.co.nz/media/irrjel2f/canterbury-owner-2024-25-budget-actuals-mid-season-update.pdf

Dodd MB, McGowan AW, Power IL, Thorrold BS. 2005. Effects of variation in shade level, shade duration and light quality on perennial pastures. *New Zealand Journal of Agricultural Research 48*: 531-543. https://doi.org/10.1080/00288233.2005.9513686

Fertiliser Association of New Zealand. 2023. Fertiliser use on New Zealand dairy farms (Rev. ed.). Editors: Ants Roberts & Jeff Morton. https://www.fertiliser.org.nz

Hume DE, Ryan DL, Cooper BM, Popay AJ. 2007. Agronomic performance of AR37-infected ryegrass in northern New Zealand. *Proceedings of the New Zealand Grassland Association 69*: 267-273. https://doi.org/10.33584/jnzg.2007.69.2673

Kelly S, Smith E, Brazendale R. 2011. Pasture renewal in the Waikato and Bay of Plenty regions: An overview of farmer practice, experience and attitudes. *NZGA: Research and Practice Series 15*: 21-24. https://doi.org/10.33584/rps.15.2011.3215

Kemp PD, Matthew C, Lucas RJ. 1999. Pasture species and cultivars. In: J. White & J. Hodgson. Eds. *New Zealand Pasture and Crop science.* Oxford University Press, Auckland, pp. 83-100.

Lee JM, Thom ER, Wynn K, Waugh D, Rossi L, Chapman DF. 2017. High perennial ryegrass seeding rates reduce plant size and survival during the first year after sowing: Does this have implications for pasture sward persistence? *Grass and Forage Science 72*: 382-400. https://doi.org/10.1111/gfs.12243

Maanaki Whenua 2025. S-map sibling report: Lismore_2a.1 (Lism_2a.1). Landcare Research New Zealand Limited. https://smap.landcareresearch.co.nz

Macara GR. 2016. The climate and weather of Canterbury (2nd ed.). NIWA Science and Technology Series, No. 68. National Institute of Water and Atmospheric Research (NIWA).

Matthew C, Hamilton S. 2011. Analysing persistence of grass swards in terms of tiller birth and death. *Pasture persistence Symposium: Grassland Research and Practice Series 15*: 63-68. https://doi.org/10.33584/rps.15.2011.3225

Maxwell TMR, Edwards GR, Cosgrove, GP. 2018. Persistence of ryegrass, tall fescue and cocksfoot following sequential annual sowings: Pasture yield, composition and density in three establishment years under sheep grazing in Canterbury. *Journal of New Zealand Grasslands 80*: 169-176. https://doi.org/10.33584/jnzg.2018.80.289

Maxwell TMR, Tozer KN, Edwards GR, Cosgrove GP. 2021. 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. *Resilient Pastures Symposium: Grassland Research and Practice Series*

17: 285-296. https://www.nzgajournal.org.nz/index.php/rps/article/view/3466

McCahon K, McCahon A, Ussher G. 2021. Diversified pastures at the front line of climate change in Northland: Farmers' experiences, new directions and wider implications for other parts of the country. *Resilient Pastures Symposium: Grassland Research and Practice Series 17*: 213-224. https://doi.org/10.33584/rps.17.2021.3474

Moloney SC. 1993. Selection, management and use of cocksfoot cultivars in North Island pastoral farming. *Proceedings of the New Zealand Grassland Association 55*: 119-125. https://doi.org/10.33584/jnzg.1993.55.2097

Moot D, Scott W, Roy A, Nicholls A. 2000. Base temperature and thermal time requirements for germination and emergence of temperate pasture species. *New Zealand Journal of Agricultural Research 43*: 15-25.

Parsons AJ, Edwards GR, Newton PCD, Chapman DF, Caradus JR, Rasmussen S, Rowarth, JS. 2011. Past lessons and future prospects: Plant breeding for yield and persistence in cool-temperate pastures. *Grass and Forage Science 66*: 153-172. https://doi.org/10.1111/j.1365-2494.2011.00785.x

Talamini Junior MV. 2022. Understanding the physiology and agronomic performance of four perennial grass species under different nitrogen and water conditions in New Zealand drylands (Doctoral thesis, Lincoln University).

Tozer KN, Bourdôt GW, Edwards GR. 2011. What factors lead to poor pasture persistence and weed ingress? *Pasture Persistence Symposium: Grassland Research and Practice Series 15*: 129-138. https://doi.org/10.33584/rps.15.2011.3195

Tozer KN, Minnee EMK, Cameron CA. 2014. Performance of sown species and weed ingress in new dairy pastures based on tall fescue and perennial ryegrass. *New Zealand Plant Protection 67*: 231-237. https://doi.org/10.30843/nzpp.2014.67.5785

West C, Volaire F, Lelievre F. 2007. Tiller survival after drought of 'Grasslands Flecha' tall fescue as influenced by endophyte. *6th International Symposium on Fungal Endophytes of Grasses: Grassland Research and Practice Series 13*: 267-269. https://doi.org/10.33584/rps.13.2006.3075

Woodfield DR, Caradus JR. 1996. Factors affecting white clover persistence in New Zealand pastures. *Proceedings of the New Zealand Grassland Association 58*: 229-235