Persistence of the yield advantage of perennial ryegrass cultivars: concept, evidence and implications

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Abstract

Pasture persistence can be defined several ways, but a key outcome for farmers is that the yield advantage of a new pasture compared to the pasture it replaced persists for several years after sowing. The concept of persistence of the yield advantage can also be applied to genetic evaluation of cultivars in species such as perennial ryegrass to determine the true value of pasture renewal and cultivar selection. We analysed 8 years of yield and tiller density data from pastures sown to four perennial ryegrass cultivars representing different functional types at two locations, Waikato (non-irrigated) and Canterbury (irrigated). 'Grasslands Nui' SE (Nui) was designated as the baseline cultivar. A significant yield advantage over Nui was observed for two cultivars (Alto AR37 and Halo AR37). Peak yield advantage occurred 4 or 5 years post-sowing, then declined by approximately 50% and became non-significant by Year 8. The pattern was very similar at both locations. Tiller density data indicated a shift in sward structure over time consistent with size-density trade-offs in the diploid cultivar Alto AR37 but not in the tetraploid cultivar Halo AR37. The implications for economic evaluation systems such as the DairyNZ Forage Value Index are discussed.

Keywords: evaluation systems, pasture persistence, plant traits

Introduction

Pasture renewal is standard practice for maintaining the productivity of New Zealand's dairy, beef and sheep industries. It is also the mechanism by which superior forage cultivars are introduced and therefore through which gains in productivity traits achieved through plant breeding (Lee et al. 2012; Harmer et al. 2016) are captured. Pasture establishment is also costly, but it is generally assumed that the productivity benefits of new pastures substantially exceed the costs of establishment (Stewart et al. 2014). Typically, the yield of a new pasture will exceed that of the pasture it replaced in the first few years post-sowing but will subsequently decline, setting up a regular cycle of pasture renewal spanning, for example, 12-18 years (6-8% of pasture land per year) in the New Zealand dairy industry (Sanderson & Webster 2009; Pasture Renewal Charitable Trust 2013).

Yield decline post-sowing is often equated to loss of pasture 'persistence' which Parsons et al. (2011) noted may be due to i) depletion of the physical population of plants that established when the new pasture was sown (i.e., plant mortality rates exceed plant recruitment rates, e.g., Lee et al. 2017a) or ii) a decline over time within the surviving population in the expression of the initial yield advantage trait. In the latter case, the initial yield advantage could be the result of soil disturbance during cultivation releasing nitrogen (N) through mineralisation. The release of plants from the need to build infrastructure such as an extensive root system or storage capacity for carbon (C) and N to optimise their long-term 'fitness' under fluctuating environmental conditions has also been implicated (Parsons et al. 2011). Both of these are transient effects. Populations of some pests such as grass grub (*Costelytra giveni*) may be suppressed by cultivation before reaching a peak 2 or 3 years after sowing (East & Willoughby 1983) which would also initially favour high yield of the newly sown pasture.

Disentangling these different mechanisms is important for identifying ways of increasing the persistence of the yield advantage of a new pasture. Forage plant improvement is one key pathway for achieving this goal. There is ample evidence (e.g., Easton et al. 2001; Harmer et al. 2016) from cultivar evaluation systems that perennial ryegrass breeding has increased dry matter yield (DMY). However, most of this evidence comes from trials conducted for only 3 years: there is much less information available to gauge what happens thereafter.

This knowledge gap is accentuated when economic forage evaluation systems such as the DairyNZ Forage Value Index (FVI) are developed to include the trait of persistence. Ludemann & Chapman (2019) proposed that, for the FVI, the persistence trait be defined as the persistence of the yield advantage of cultivars, but noted that there are very few data sets from which the general

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trajectory of yield change beyond 3 years post-sowing can be quantified, let alone the genetic component of ‘persistence of yield’. Based on the limited long-term data available at the time, they proposed further that a persistence scalar be used to represent the general decline in DMY from a peak at around 3 years post-sowing that was evident in their data. This would thus scale the $ value of the DMY trait downward when 3-year DMY data are extrapolated out to 10 years post-sowing.

The objective of the analysis reported here was to quantify the persistence of the yield advantage of a range of perennial ryegrass functional types in dairy pastures in two regions grown over 8 years. The data used in the analysis were from an earlier study (Lee et al. 2017b, 2018) which was established in autumn 2011 and monitored continuously until autumn/early winter 2020.

Materials and Methods

Sites and treatments

The experiment was conducted in two dairying regions in New Zealand: Waikato in the North Island and Canterbury in the South Island. The experimental sites were located at DairyNZ Scott Farm in Waikato (-37.772, 175.378; 40 m a.s.l.; Matangi silt loam soil; non-irrigated) and the Lincoln University Research Dairy Farm in Canterbury (-43.638, 172.462; 10 m a.s.l.; Wakanui silt loam over a mottled sandy loam phase; irrigated).

At each site, four perennial ryegrass cultivars, each representing different functional types within the species, were sown at 18 kg/ha of ryegrass seed and 4 kg/ha of white clover seed in 108 m^2 plots. There were five replicates of each cultivar. The trials were sown on 29 March 2011 and 30 March 2011 in Waikato and Canterbury, respectively. Details of site preparation, establishment methods and post-sowing management were presented by Lee et al. (2017b, 2018).

The perennial ryegrass cultivars were: ‘Grasslands Nui’ infected with standard endophyte (SE), ‘Grasslands Commando’ infected with AR37 endophyte, Alto AR37 and Halo AR37 (hereafter referred to as Nui, Commando, Alto and Halo). These cultivars were selected to represent the range of functional types available within the perennial ryegrass commercial cultivar lists in 2010. Nui is a diploid cultivar with a mid-season flowering date selected from plants collected from a sward aged 40 years at a dairy farm in south Auckland in the 1960s and released commercially in 1976 (Armstrong 1977). The other three cultivars were released commercially after 2000. Commando, a diploid with a similar flowering date to Nui, was bred from New Zealand ecotypes. Alto, a diploid that flowers 14 days later than Nui, is based on late-heading material from Nui and material from north-west Spain. Halo is a tetraploid classified as very late-season flowering (25 days later than Nui; Lee et al. 2012) and is also partly based on material from north-west Spain.

Pre-sowing tests for endophyte viability confirmed endophyte infection percentages of 87, 74, 84 and 78% of seedlings for Nui, Commando, Alto and Halo, respectively (immuno-blot assessment method). During the first 4 years, Commando had a lower endophyte infection level than the other three cultivars (81% vs. 88%, respectively) but this effect dissipated by autumn 2016 when all cultivars averaged 86% infection across both sites.

Grazing and fertiliser management

Plots were rotationally grazed by dairy cows at both sites. Between 9 and 12 grazing events occurred per year at each site following typical grazing intervals for dairy systems in each region. Pre-graze herbage mass was 2500-3500 kg dry matter (DM)/ha, with a target post-grazing residual of 1600 kg DM/ha (approximately 50 mm residual stubble height). At each grazing a discrete group of cows was allocated to each main plot; the number of cows in each group was determined by pasture availability above the desired residual and expected cow intake.

Nitrogen fertiliser was also applied as urea at both sites, four times per year at the Waikato site (three applications from early spring to early summer, and one in autumn) and after every grazing at the Canterbury site (Table 1). Maintenance levels of other macro-nutrients were applied annually as required based on the results of soil tests conducted in early spring each year.

Measurements

Herbage accumulation: Until December 2012 at the Waikato site, and August 2013 at the Canterbury site, pasture mass was estimated by quadrat cuts on the day before grazing. Herbage samples (n = 2) were cut to the approximate post-grazing height (50 mm) within square quadrats (0.2 m^2) placed randomly within each plot in three of the five replicates. Samples or 100 g blended sub-samples were oven-dried at 95°C (Waikato) or 65ºC (Canterbury) to constant weight (approximately 48 or 72 hours, respectively). After December 2012 (Waikato) or August 2013 (Canterbury), one 5 m-long × 1.5 m-wide strip was cut to 55 mm above ground level from the centre of each plot in all five replicates using a Haldrup F-55 forage harvester (Haldrup GmbH, Ilshofen, Germany). Cutting height was reduced to 40 and 45 mm at the Canterbury and Waikato sites, respectively, in 2015. The fresh weight of the cut herbage was recorded using the on-board weighing system and a representative sample (~1000 g fresh weight) was then collected from the cut material. This sample was mixed thoroughly in the laboratory and duplicate sub-samples (~150 g fresh weight) were oven-dried at 95°C to constant weight over approximately 48 hours to calculate seasonal and total annual herbage accumulation as specified above.

Botanical composition: Samples of herbage (between 500 and 1000 g fresh weight) were collected in late winter/early spring (August/September), late spring (November), summer (January) and autumn (April). After thorough mixing, a 100-150 g sub-sample was hand dissected into the following categories: perennial ryegrass leaf, perennial ryegrass reproductive stem (including seedhead), white clover, unsown species and dead material. Up until December 2012 at the Waikato site, and August 2013 at the Canterbury site, hand shears were used to cut six 0.5 m-long strips per plot to the approximate post-grazing height on three of the five replicates. Thereafter, herbage was collected from the material cut by the Haldrup harvester on all replicate plots. Dissected material was oven-dried at 95°C to constant weight over approximately 48 hours and weighed to determine botanical composition as a proportion of harvested herbage biomass on a DM basis.

Tiller density: Perennial ryegrass tiller population densities were calculated from the total number of live ryegrass tillers counted in five randomly placed frames (5 cm × 20 cm) per plot once per year (in autumn) from 2011 to 2020 inclusive.

Climate and irrigation

Daily data for rainfall and maximum and minimum temperatures were obtained for the period March 2011 to June 2020 inclusive from the Cliflo climate database (https://cliflo.niwa.co.nz) for the Ruakura weather station (Cliflo station agent number 26177) representing the Waikato site, and the Broadfields climate station (agent number 17603) representing the Canterbury site. Irrigation application data were obtained from farm records for the Lincoln University Research Dairy Farm for the Canterbury site.

Data and statistical analysis

Data for total pasture DMY from each harvest were apportioned to the five Forage Value Index seasons corresponding to each location (DairyNZ 2020). The resultant seasonal DMY was multiplied by the perennial ryegrass percentage from the botanical composition measurements for the corresponding season to derive perennial ryegrass DMY. Seasonal total pasture and perennial ryegrass DMY were then summed for complete years encompassing the FVI seasons from early spring to winter inclusive, beginning with early spring 2011. This resulted in eight complete years of data, balanced for seasons within years.

Nui was designated as the baseline cultivar for determining persistence of any yield advantages that were observed. Absolute differences (in kg DM/ha/yr for DMY or tillers/m^2 for tiller density) between Nui and the three other cultivars were calculated for each replicate and year at each location using the following equation:

$$\text{absolute difference}_{i\text{-}k} = \text{variable}_{i\text{-}k} - \text{variable}_{Nui}$$

where i-k = cultivars Commando, Alto or Halo, and variable = total pasture DMY, perennial ryegrass DMY or tiller density. Three-year moving averages were then

Table 1 Nitrogen (N) fertiliser application in each year at each site: total N applied per year, number of applications, and average rate of N applied per application.

Production year (early spring to winter)	Waikato			Canterbury		
	Total (kg N/ha)	Number	Average (kg N/ha)	Total (kg N/ha)	Number	Average (kg N/ha)
2011/12	147	4	37	198	6	33
2012/13	141	4	35	264	8	33
2013/14	147	4	37	280	9	31
2014/15	147	4	37	225	9	25
2015/16	149	4	37	225	9	25
2016/17	135	4	34	200	8	25
2017/18	147	4	37	270	10	27
2018/19	99	3	33	265	10	27
2019/20	75	3	25	200	8	25
Mean	132	4	35	236	9	28

calculated for each variable, resulting in six moving averages (denoted Years 3 to 8, where 'Year 3' is the moving average of Years 1, 2 and 3, 'Year 4' is the moving average of Years 2, 3 and 4, and so on).

Individual year, and moving-average data for the absolute difference in total pasture DMY, perennial ryegrass DMY and tiller density were then subject to repeated measures analysis of variance separately for each location using a compound symmetry covariance pattern in the Proc Mixed procedure in SAS/STAT 15.1 where cultivar (Commando, Alto, Halo), year, and their interaction were included as fixed effects and block was included as a random effect. Results are presented as least-square means with 95% confidence intervals for each cultivar and year, as well as P-values for the hypothesis that there was no difference between Nui and each individual cultivar treatment. Three-year moving averages are used rather than individual year means to describe trends over time, with particular emphasis on perennial ryegrass DMY.

Results

Climate

At the Waikato site, late summer-early autumn was often drier and warmer than average during the study, while winter-early spring was often warmer than average. In 2013, 2014, 2019 and 2020, cumulative rainfall in the months January to March inclusive was 23% to 36% of the 30-year mean (average 29%; Additional online file: Table A1). Mean maximum temperatures in the same months were also 1.6°C to 3.0°C (average 2.2°C) above the long-term mean (Additional online file: Table A2). Cumulative winter-early spring rainfall was generally close to the 30-year mean apart from 2011 (+26%) and 2019 (-31%). From 2013 to 2019, May-July maximum and minimum temperatures were, on average, 1.1°C and 0.2°C, respectively, above the 30-year mean.

Rainfall was also variable at the Canterbury site. Total annual rainfall was 25% greater than the 30-year mean in 2013 and 2018, and 28% below the mean in 2015 (Additional online file: Table A3). Winter-early spring was often milder than normal. From 2013 to 2019 inclusive, mean maximum temperatures in the period June to August inclusive were 0.5°C to 1.3°C above the 30-year mean (average 0.8°C) while mean minimum temperatures were, on average, 0.5°C above the 30-year mean (Additional online file: Table A4).

Dry matter yields and ryegrass tiller density

There was substantial inter-annual variation in both of the DMY variables and in tiller density at both sites over the 8 years available for analysis. Data for the baseline cultivar Nui are presented in Table 2 to illustrate the trends.

At the Waikato site, the total annual DMY of pastures based on Nui varied 3-fold from the maximum (Year 1, 2011/12) to the minimum (Year 3, 2013/14; Table 2). Perennial ryegrass yield as a percentage of total annual yield declined from around 70% in Years 1-3, to 46% in Years 4 and 5, and 37% in Years 6-8. Ryegrass tiller density fell below 1000/m^2 in Year 6 before recovering partially in Years 7 and 8.

In Canterbury, total DMY of pastures based on Nui varied by a factor of two, however perennial ryegrass consistently contributed around 73% of total yield from Years 2 to 8 inclusive (Table 2). Tiller density in pastures sown with Nui also remained relatively stable throughout the 8 years.

Total pasture yield was significantly lower for all three cultivars compared with Nui in the first year at the Waikato site, and perennial ryegrass yield was also lower for Commando compared with Nui in Year 1 (Additional online file: Table A5). Thereafter, relatively few statistically significant yield differences (total pasture, or perennial ryegrass) were observed at this site: where they did occur, they were only observed for Alto and Halo and were all positive.

Several significant yield advantages to Alto or

Table 2 Least-square annual means for total pasture yield, perennial ryegrass yield and perennial ryegrass tiller density in pastures based on cultivar Nui at the Waikato and Canterbury sites.

Site	Variable	Year							
		1 2011/12	2 2012/13	3 2013/14	4 2014/15	5 2015/16	6 2016/17	7 2017/18	8 2018/19
Waikato	Total pasture yield (kg DM/ha)	19150	9485	6055	6790	10290	8865	10330	11150
	Perennial ryegrass yield (kg DM/ha)	13610	6005	4195	3075	4815	3080	3815	4340
	Tiller density (no./m^2)	3270	3400	3030	2580	1395	950	2370	2860
Canterbury	Total pasture yield (kg DM/ha)	14540	20220	13080	10510	15030	13110	16315	15715
	Perennial ryegrass yield (kg DM/ha)	8810	16030	9840	7560	10970	9310	10435	12015
	Tiller density (no./m^2)	4185	4155	6210	5835	6265	5635	4735	3615

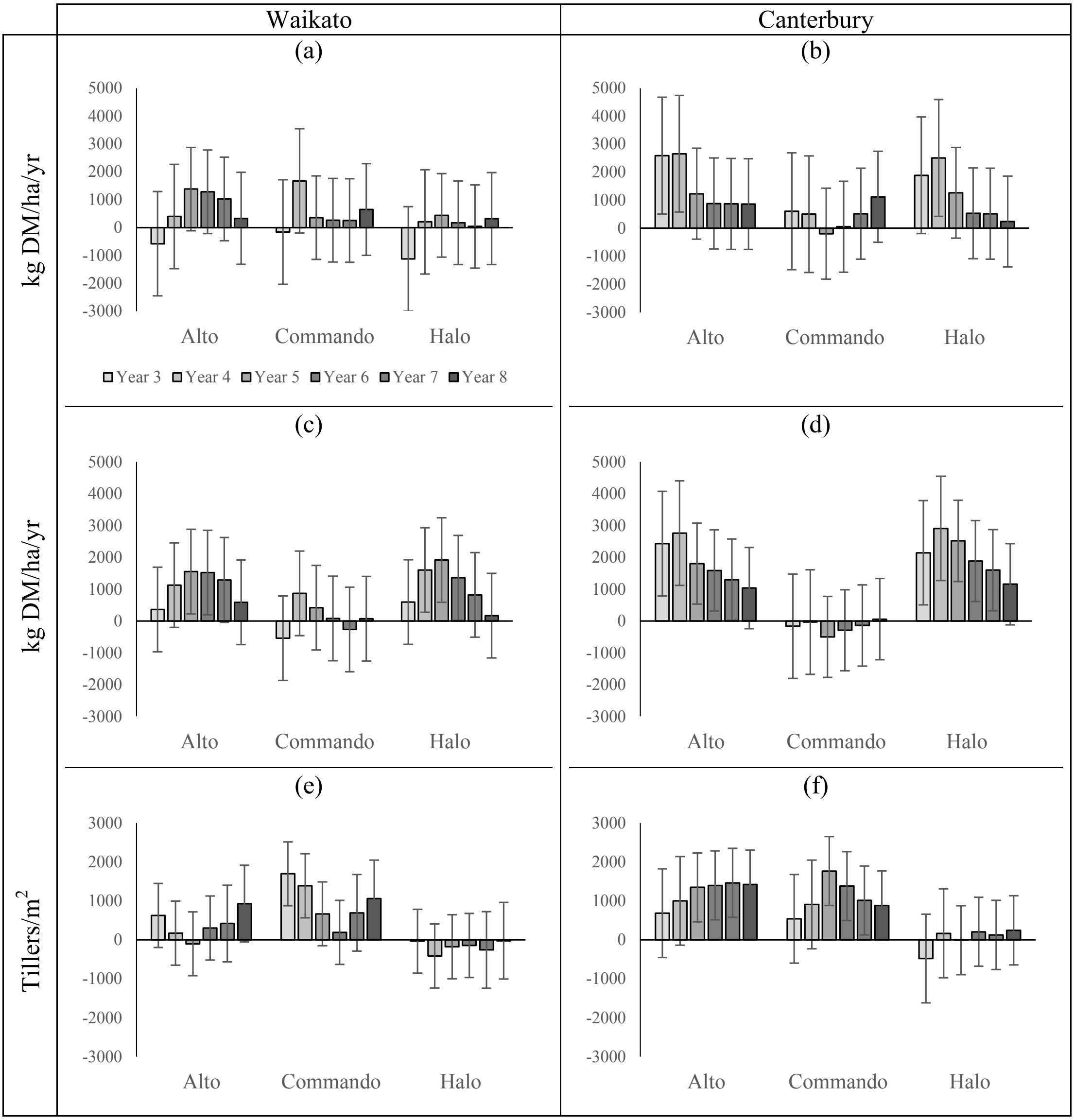

Figure 1 Moving 3-year average difference between Alto, Commando or Halo and Nui (where Nui equals the zero baseline) for total annual pasture dry matter (DM) yield (a and b), perennial ryegrass DM yield (c and d), and tiller density (e and f) at two locations (Waikato, Canterbury) over 8 years. Bars are 95% confidence intervals.

Halo compared with Nui were observed throughout the 8 years at the Canterbury site. No significant yield advantages were observed for Commando, but this cultivar often sustained significantly higher tiller density compared with Nui; this trend was also evident at the Waikato site (Additional online file: Table A5).

Trends in yield and tiller density

The difference in moving-average total annual DMY between Nui and the other three cultivars was not significant at any stage at the Waikato site (Figure 1a). In Canterbury, Alto and Halo both had significantly greater total annual DMY than Nui for the first 3 or 4 years (moving-average basis) after sowing, but not thereafter (Figure 1b).

Perennial ryegrass DMY advantages (moving-average basis) to Alto and Halo were more frequent and more sustained than was the case for total annual DMY advantages. A statistically significant ryegrass DMY advantage to Alto and Halo was observed earlier (by Year 3) and to a greater extent (maximum difference of +2800 to +2900 kg DM/ha/yr compared with Nui) at the Canterbury site compared with at the Waikato site (Year 4 for Halo and Year 5 for Alto; and +1600 to +1900 kg DM/ha/yr). The ryegrass DMY advantage peaked in Year 5 in Waikato (Figure 1c) and Year 4 in Canterbury (Figure 1d), and then declined at both sites. No ryegrass DMY advantages were observed for Commando in any year at either site.

Tiller density differences followed different trends over time, between locations and among cultivars. Ryegrass tiller density (moving-average basis) in pastures based on Commando was often greater than in pastures based on Nui. This difference was not consistent across years at the Waikato site (Figure 1e) while at the Canterbury site it was significant from Year 5 onwards (albeit with a declining trend, Figure 1f). Alto tiller density did not differ from Nui at the Waikato site (Figure 1e) but was significantly greater from Year 5 onwards at the Canterbury site (Figure 1f). Tiller density of pastures based on Halo and Nui was similar at all stages (Figures 1e and f).

Discussion

General pattern of decline in DMY advantage

A necessary condition for quantifying the existence and persistence of DMY advantages is that a clear yield difference is evident in at least some cultivars compared to the baseline (in this case Nui). This condition was met in the late-season heading diploid Alto and the very-late heading tetraploid Halo at both sites, but not by the mid-season diploid Commando at either site (Figure 1). The DMY advantage of Alto and Halo declined after the peak for both cultivars, such that by Year 8, neither cultivar differed from Nui at either site (Figures 1c and d).

Two conclusions can be drawn from these results. Firstly, the maximum yield difference of higher-yielding cultivars relative to the baseline was not sustained, therefore the true yield difference of those cultivars over an extended period of time was less than what was indicated by the 3-year data alone. Dry matter yield (either for total pasture, or just perennial ryegrass) over the 8 years of measurement was between 65% and 88% of the DMY measured in Years 1 to 3 inclusive. The value at the low end of this range (65%) was for ryegrass DMY in Waikato (the equivalent figure for Canterbury was 87%), reflecting more severe conditions for perennial ryegrass growth in general at the Waikato site. Total annual ryegrass DMY in Nui pastures in Waikato declined to around 4 t DM/ha in Years 7 and 8 versus 10.4 to 12.0 t DM/ha in Canterbury (Table 2).

Secondly, long-term cultivar ranking positions indicated by 3-year data should be predicted well by ranking positions based on 3-year DMY. For example, Commando yielded less than or similarly to Nui at both sites in all years, whereas Alto and Halo out-yielded Nui significantly at some point in the 8-year moving-average sequence and generally substantially out-yielded Commando throughout. At the Canterbury site, the ryegrass DMY advantage of both cultivars over Nui was still statistically significant in Year 7 post-sowing. Chapman et al. (2015) also concluded that relative DMY of ryegrass cultivars in the first 3 years post-sowing was a good predictor of relative DMY up to 8 years post-sowing, albeit with indications that this relationship weakened in Year 10.

Implications for indexing systems

Including the persistence trait, as it is defined above, in the FVI using data such as shown in Figure 1 will result in lower economic values for yield-related traits as explained by Ludemann & Chapman (2019) but little if any change in cultivar performance values and relative ranking positions. Importantly, the trends leading to these conclusions were very similar in the two regions in which this study was conducted, even though conditions for perennial ryegrass growth were very different between them. In countries like New Zealand where the size of the grass seed market is relatively small, breeders place a high priority on stability of yield across the range of environments in which cultivars are likely to be used (Stewart & Hayes 2011), essentially dampening the effects of genotype × environment interactions (G×E). Hence, it may not be necessary to account for G×E when including the persistence of the yield-advantage trait in the FVI. The further inference from this is that most of the genotype and G×E influence on relative ryegrass cultivar performance is captured in the first 3 years of DMY data collected post-sowing in standard evaluation trials (e.g., Easton et al. 2001). The caveat here is that these conclusions are still based on a very limited amount of data.

Two further implications of this analysis of ‘persistence’ in the context of evaluation systems require comment. Firstly, the ryegrass DMY advantage did not peak until Years 4 or 5 (moving-average basis) post-sowing (Figures 1c and d) which suggests that 3-year trials may be missing some of the yield potential of higher-performing cultivars. As noted above, however, this should only affect the size of the yield and therefore economic difference between high and lower ranking cultivars, and have no effect on relative cultivar rankings.

Secondly, in the upper North Island, ryegrass plant populations can collapse sharply within 2-4 years post-sowing under some combinations of weather/climate, soil type and other factors such as pest/disease incidence and grazing management. This was observed at the Waikato site in this study (Lee et al.

2017a, and see tiller density data in Table 2), where the two very dry summer/autumns in 2012/13 and 2013/14 (Additional online file: Table A1) plus increasing grass grub populations led to substantial loss of ryegrass plant numbers in all four cultivars by the end of Year 4 (Lee et al. 2017a). Nonetheless, Alto and Halo were still able to express yield advantages over Nui after Year 4, albeit from a low base (Table 2).

Under less-severe conditions in the upper North Island, there is evidence of genetic differences in ryegrass population survival within 3 years, driven largely by endophyte strain (e.g., Thom et al. 1999). If sufficient evaluation trials are conducted in the upper North Island, with a broad range of entries and suitable cultivar plus endophyte controls, these genetic differences should appear in standard 3-year evaluation data sets and therefore be captured in the FVI.

Reasons for decline in yield advantage

Climatic, nutrient (N) supply, genetic contamination, and plant growth strategy reasons can be proposed for the decline in the ryegrass DMY of Alto and Halo compared with Nui.

Climate. The very low summer/autumn rainfall at the Waikato site in the last 2 years of the study (2018/19 and 2019/20, Additional online file: Table A1) may have suppressed the yield potential of the higher-yielding cultivars and narrowed the yield gap with Nui. However, when 3-year moving-average summer-autumn rainfall was regressed against 3-year moving-average ryegrass DMY advantage, no relationship was evident across the duration of the study (data not presented). Furthermore, the declining trend was very similar at the irrigated Canterbury site, so short/medium term climate conditions do not appear to be involved.

Nitrogen. Less N fertiliser was applied at the Waikato site in 2018/19 and 2019/20 (Table 1) due to changes in the experimental design described by Griffiths et al. (2021). Chapman et al. (2019) observed that the absolute difference in DMY between high- and low-ranking cultivars for DMY was related positively to total N supply (from fertiliser and N fixation). However, the difference in moving-average N fertiliser applied per year was smaller than indicated in Table 1, and could have been compensated for by increased biological N fixation from clover. Also, the decline in ryegrass DMY advantage in the latter years of the sequence was similarly steep at the Canterbury site, where the total annual N fertiliser inputs were reasonably consistent throughout the trial.

Genetic contamination. This is unlikely to have contributed to the decline in ryegrass DMY advantage. Faville et al. (2020) confirmed that the ryegrass populations at both sites remained genetically true-to-type for the sown cultivar-endophyte combinations, at least up until the end of Year 5 post-sowing.

Plant growth strategy. Plants such as ryegrass may exhibit differences in growth strategy during the life cycle of a pasture. Parsons et al. (2011) proposed that in the early stages post-sowing, plants may be released to some degree from the C and N costs of ‘infrastructure’ such as tillers, roots and storage organs necessary to survive under fluctuating and often sub-optimal conditions for growth (including grazing). Ryegrass plants in old pastures develop a complex morphological structure including significant basal stem and internode tissue on both vegetative and reproductive tillers (Brock & Fletcher 1993), all of which carries associated maintenance energy costs. Hence, initial yields may be high, e.g., Year 1 in Waikato and Year 2 in Canterbury (Table 2).

Some insights into growth strategy can be drawn from comparison of the ryegrass DMY advantage and the differences in tiller density between Alto or Halo and Nui. For Alto at both sites, the decline in ryegrass DMY advantage post-peak was mirrored by an increase in tiller density relative to Nui (Figures 1c and e, and Figures 1d and f). This implies a change in sward structure of pastures based on Alto toward greater tiller density but less biomass production per tiller. This was not observed in phenotypic comparisons of survivor plants collected from both sites from Years 1 to 5 inclusive (Faville et al. 2020), but the sampling period may have missed subsequent changes. O’Connor et al. (2020) reported significant phenotypic shifts in survivor plants of the mid-season diploid cv. ‘Grasslands Samson’ AR1 collected 9 years after sowing in a dry, east coast, North Island environment. The survivors had greater tiller number, more reproductive tillers and greater lamina sheath length than plants grown from seed of the same cultivar.

Conversely, in this study, the tetraploid Halo exhibited no change in tiller density compared with Nui (Figure 1). Its advantage in ryegrass DMY over Nui declined more sharply than was the case for Alto, especially at the Waikato site (Figures 1c and e), indicating more-limited capacity to adapt through size-density compensation mechanisms (Matthew et al. 2000).

These observations provide some support for applying a different persistence scalar for diploids versus tetraploids in the FVI as proposed by Ludemann & Chapman (2019). Additional corroborating evidence and deeper analysis of possible mechanisms (Matthew et al. 2000) is needed to increase confidence and help identify key traits.

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SUPPLEMENTARY MATERIAL

Additional Online File 1: Table A1-Monthly rainfall (mm) for the Waikato site; Table A2-Monthly maximum and minimum temperatures (°C) for the Waikato site; Table A3-Monthly rainfall (mm) and irrigation (Irrig; mm) for the Canterbury site; Table A4-Monthly maximum and minimum temperatures (°C) for the Canterbury site; Table A5-Significance (P-value) of the difference between individual cultivars and Nui SE in total annual pasture yield, perennial ryegrass yield and tiller density. https://www.nzgajournal.org.nz/index.php/rps/article/view/3452

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