

# Inclusion of persistence in the DairyNZ Forage Value Index

Cameron I. LUDEMANN<sup>1\*</sup> and David F. CHAPMAN<sup>2</sup>

<sup>1</sup>DairyNZ Ltd, Private Bag 3221, Hamilton 3240, New Zealand

<sup>2</sup>DairyNZ Ltd, PO Box 85066, Lincoln University, Lincoln 7647, New Zealand

\*Corresponding author: cameronludemann@gmail.com

## Abstract

Inclusion of a persistence trait into the DairyNZ Forage Value Index (FVI) is an important step toward developing a holistic assessment of the relative value to dairy farm businesses of perennial ryegrass (*Lolium perenne*) cultivars. For the purposes of the FVI, 'persistence' was defined as the persistence over time of yield differences between diploid and tetraploid functional groups, and implemented (as an interim step) via two measures: a mean persistence scaling factor ( $\mu PS$ ) and a relative pasture renewal cost ( $RRC$ ). The values of  $\mu PS$  and  $RRC$  were estimated by analysing four long-term dry matter (DM) production data sets from across New Zealand, then applied to all cultivars in the 2019 FVI lists. Incorporating persistence reduced the difference in overall FVI value between tetraploids and diploids between \$117 and \$202/ha (depending on diploid heading date, and region), partially re-balancing the sharp rise in tetraploid values and rankings resulting from incorporation of the metabolisable energy (ME) content trait. Implementing persistence in the FVI at the ploidy level is the first step toward inclusion of cultivar-specific persistence information. This next step will require persistence data for cultivars, plus more information on processes and criteria used by farmers when they decide to renew pastures.

**Keywords:** Forage Value Index, *Lolium perenne*, plant breeding, selection, cultivars, yield

## Introduction

In 2019, the DairyNZ Forage Value Index (FVI) lists for perennial ryegrass (*Lolium perenne* L.) cultivar/endophyte combinations (hereafter referred to as 'cultivars') were expanded (from seasonal dry matter (DM) yield only) to include seasonal metabolisable energy (ME) content and persistence (Ludemann 2019). The methods for including DM and ME traits have been described by Chapman et al. (2017) and Ludemann et al. (2018), and the effects of including both traits on cultivar rankings have been reviewed by Ludemann et al. (2018). The objective of this paper is to describe the method for incorporating the persistence trait in the index, and to compare the effects of adding this trait to seasonal DM yield in the first three years post-sowing plus ME content on FVI rankings. 'Persistence' is defined for the purposes

of the FVI as the persistence of yield differences among perennial ryegrass genotypes over time following pasture establishment (after Parsons et al. 2011). Both the ME and persistence traits are formulated within the index at the functional group level (heading date and ploidy for ME; ploidy only for persistence) rather than the individual cultivar level since comprehensive cultivar data for both of these traits are not yet available.

Data for the DM yield of multiple ryegrass cultivars for the first three years after sowing are available from the National Forage Variety Trial (NFVT) system (e.g. Easton et al. 2001) and are used directly in the FVI for the seasonal DM yield traits (Chapman et al. 2017). However, there are very few data sets comparing long-term DM yield of ryegrass cultivars and these include only a small number of cultivars currently in the FVI. Recent publication of the long term DM yield of multiple cultivars in a range of environments (Chapman et al. 2015; Lee et al. 2017; Dodd et al. 2018a) has enabled comparative analysis of trends in the persistence of yield among perennial ryegrass functional groups. The methods presented here are based on these data.

## Methods

### FVI equations

Forage Value Index values and rankings for all perennial ryegrass cultivars included in the 2019 FVI lists (Ludemann 2019) were calculated using three different equations: 1) the pre-2019 FVI equation for perennial ryegrass based solely on seasonal DM yield ( $PVDM_a^{ix} \times EVDM_a^j$ , denoted 'FVI-A') (Chapman et al. 2017); 2) the DM yield equation with the addition of seasonal ME ( $LSMDM_a^{ij} \times PVME_a^{gj} \times EVME_a^j$ , denoted 'FVI-B') (Ludemann et al. 2018); and 3) the FVI-B equation with the addition of persistence of DM yield differences ('FVI-C').

The FVI-C equation was derived from FVI-B by including two elements which determine the economic value of persistence: a) a mean persistence scaling factor ( $\mu PS_t^{ij}$ ) describing a linear trend in DM yield over time ( $t$ ) for  $i$  functional group in  $j$  region; and b) a relative renewal cost for establishing a new pasture ( $RRC_t^{ij}$ ) so that:

$$FVI^{ij} = \mu PS_t^{ij} \times \sum (PVDM_a^{ix} \times EVDM_a^j) + (LSMDM_a^{ij} \times PVME_a^{gj} \times EVME_a^j) - RRC_t^{etj} \quad [\text{Equation 1}] \text{ (also equation FVI-C)}$$

$\mu PS_t^{ij}$  has a value between zero and one, and is derived from changes in DM yield beyond year 3 post-sowing. The general approach is shown in Figure 1, using  $t = 10$  years, which is the estimated mean life of dairy pastures under current management in New Zealand (Dodd et al. 2018b) and therefore adopted as the default value of  $t$  for the persistence trait in the FVI as described below.

For each cultivar in each long-term data set, the persistence scalar value ( $PS$ ) was derived from the slope of a line connecting two points: a) the mean DM yield for years 1 to 3 (point A in Figure 1); and b) the mean DM yield of the last 3 years of the available trial data (point B in Figure 1). For each data set, the overall  $PS$  for diploid and tetraploid ryegrasses was calculated from the mean of all cultivars in the respective functional groups, and then multiplied by a discount factor ( $DF_t$ ) to account for the diminishing value of DM (compared with its present value) after year 3 so that:

$$\mu PS_t^{ij} = \frac{\sum_t (PS_t^{ij} \times DF_t)}{t} \quad [\text{Equation 2}]$$

$$DF_t = \frac{1}{(1 + int)^{yr-3}} \quad [\text{Equation 3}]$$

where  $yr$  is the year the discount factor will be used and  $int$  is the interest rate expressed as a proportion (set to 0.03).

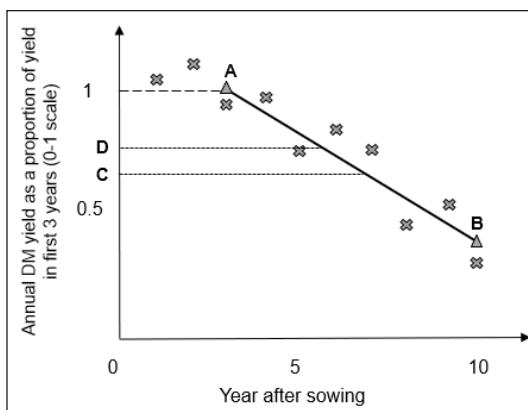
For each cultivar in each data set, a pasture renewal cost was calculated as:

$$\left( \frac{PVR_t^i}{Years_t^i} \right) \quad [\text{Equation 4}]$$

where  $(PVR_t^i)$  is the present value of renewal costs for  $i$  functional group, and  $Years_t^i$  is the number of years since sowing that  $i$  functional group would reach a yield decline threshold that triggers pasture renewal.

Renewal costs were calculated using: a) the Pasture Renewal Calculator (PRCT 2017) with updated cost assumptions from Askin and Askin (2016); b) an additional \$120/ha establishment cost for tetraploids compared with diploids to account for the extra 8 kg/ha recommended sowing rate for the former (Stewart et al. 2014) at a cost of \$15/kg seed; and \$0.25/kg DM average cost of the feed gap based on average economic values for autumn and late spring dry matter Ludemann (2019). The resulting renewal costs are shown in Table 1.

The yield decline threshold is an approximation of the point at which a farmer would decide to renew an old pasture. For the purposes of this analysis, we used the mean annual renewal rate for dairy pasture land of 10% (i.e. pastures are renewed, on average, every 10 years) reported by Dodd et al. (2018b) to interpolate



**Figure 1** Stylised representation of the use of annual dry matter (DM) yield in the calculation of the mean persistence scaling factor across a 10-year period.  $\otimes$  = hypothetical DM yield in each year; - - - - and 'A' = mean DM yield for first 3 years after sowing; 'B' = mean DM yield of last three years in the data set; 'C' = mean DM yield in years 4–10 inclusive as a proportion of mean DM yield in years 1–3; 'D' = mean DM yield in years 1–10 inclusive. The persistence scalar is derived from the slope of the line joining points A and B.

the threshold, as shown by point C in the hypothetical example in Figure 1.

The higher renewal cost for tetraploids versus diploids, and the steeper yield decline of tetraploids (presented in Results, below), leads to a simplification of the renewal component of FVI-C where:

$$RRC_t^{Tetj} = \left( \frac{PVR_t^{Tet}}{Years_t^{Tet}} \right) - \left( \frac{PVR_t^{Dip}}{Years_t^{Dip}} \right) \quad [\text{Equation 5}]$$

## Data used

Data from several long term (> 5 year) DM production trials (Chapman et al. 2015; Lee et al. 2017; Dodd et al. 2018a) were analysed to assess the differences in long term annual DM yield between diploid and tetraploid cultivars. All trials were conducted under grazing (sheep in Chapman et al. (2015); dairy cattle in the other studies). These data were used to calculate  $\mu PS_t^{ij}$  and  $RRC_t^{ij}$  for FVI-C using the methods described above. Sources of data used for the seasonal DM and ME traits (equations FVI-A and FVI-B) were described by Ludemann et al. (2018).

## Economic values for seasonal dry matter yield and metabolisable energy content

Economic values for the seasonal DM yield and seasonal ME content traits were calculated using the method described by Chapman et al. (2017) and Ludemann et al. (2018), with updated economic assumptions as described by Ludemann (2019). The

data used for FVI-C came from trials conducted in the upper North Island (UNI) and upper South Island (USI) regions used in the FVI (Chapman et al. 2017), therefore all three FVI equations were solved using the appropriate regional economic values for each trait in each data set.

Results

Annual DM yields for diploid and tetraploid cultivars included in each of the long-term trials are presented in Table 2, along with the mean persistence scalar values. When averaged across all trials: 1) diploid cultivars yielded 0.64 t DM/ha per year, or 5.6%, more than tetraploid cultivars; 2)  $\mu PS_t^{Dipj}$  was the same for mid- and late-heading diploids, although there were small differences between heading date functional groups in individual trials (data not included in Table 2); and 3) there was a consistent trend for a greater  $\mu PS_t^{ij}$  in diploid cultivars (i.e. a slower rate of decline in yield expressed as a proportion of mean yield in years 1-3, as per the y-axis in Figure 1; mean  $\mu PS_t^{Dipj}$  for all four trials = 0.75) compared with tetraploid cultivars (mean  $\mu PS_t^{Tetj}$  = 0.71).

Extrapolation of  $\mu PS_t^{Dipj}$  to 10 years post-sowing revealed a renewal trigger at the point where yield had fallen to ~ 0.4 of the mean yield in years 1-3 (point B in Figure 1), and 0.6 of mean yield accumulated in years 4 to 10 inclusive (indicated by point C in Figure 1. Because the rate of decline in yield after year 3 was greater in tetraploids ( $\mu PS_t^{Tetj}$  was lower), the mean yield trigger point of 0.6 was reached earlier, at 8.6 years post-sowing implying more frequent renewal, and a higher mean  $RRC_t^{Tetj}$  of \$40/ha/year =

$$\left(\frac{PVR C_t^{Tet}=\$1735\text{ (Table 1)}}{Years_t^{Tet}=8.6}\right)-\left(\frac{PVR C_t^{Dip}=\$1615\text{ (Table 1)}}{Years_t^{Dip}=10.0}\right)$$

Mean absolute FVI values for all perennial ryegrass cultivars eligible for the 2019 lists grouped according to functional types and calculated with all three FVI equations are shown in Table 3. The mid-season heading diploid functional group remained the lowest ranking irrespective of which FVI equation was used. However, tetraploids as a group moved above late season heading diploids when ME was included (FVI-B) and remained the highest-ranking group when persistence was added

Table 1 Summary of the present value of pasture renewal costs (PVRC) for diploid and tetraploid cultivars.

Functional group	Present value of renewal costs (\$/ha) (PVRC)		
	Establishment costs	Feed gap cost	Total
Diploid	\$1072	\$543	\$1615
Tetraploid	\$1192	\$543	\$1735
Difference in renewal costs between diploid and tetraploid cultivars			\$120

Table 2 Summary of the mean annual dry matter (DM) yield (tonnes DM/ha) of diploid (D) and tetraploid (T) perennial ryegrass cultivars, and the resulting persistence scaling factor used for including the persistence of yield trait in the DairyNZ Forage Value Index.

Trial location	Ploidy	Year after sowing								$\mu PS_t^{ij}$
		1	2	3	4	5	6	7	8	
Waikato <sup>1</sup>	D	17.6	10.1	6.8	7.4	10.9	9.1			0.78
	T	17.2	8.7	6.9	7.9	10.1	8.6			0.77
Canterbury <sup>1</sup>	D	16.5	21.7	14.0	9.9	15.4	13.0			0.73
	T	15.5	23.1	15.2	10.6	16.2	12.0			0.69
Canterbury <sup>2</sup>	D	15.5	12.2	16.1	13.7	11.0	9.9			0.65
	T	13.4	10.7	13.2	10.9	8.8	7.3			0.58
Hawkes Bay <sup>3</sup>	D	14.6	7.1	8.8	Not measured			10.8	6.1	0.82
	T	15.0	7.0	8.6				10.3	5.8	0.79
Mean (all trials)	D	16.2	12.8	11.4	10.3	12.4	10.7			0.75
	T	15.3	12.4	11.0	9.8	11.7	9.3			0.71

<sup>1</sup> From the 18 kg/ha seed rate treatment in Lee et al. (2017); <sup>2</sup> Dodd et al. (2018a); <sup>3</sup> Chapman et al. (2015)

(FVI-C) although the difference between the late season diploids and tetraploids was moderated by including persistence.

Discussion

Poor persistence of newly-sown pastures is a significant concern of New Zealand dairy farmers. In the upper North Island region, farmers report low confidence in the performance of pastures beyond two years post-sowing (Rijswijk & Brazendale 2016). Data from an earlier survey (Kelly et al. 2011) indicates that ~ 20% of dairy pasture area in the Waikato and Bay of Plenty region is renewed annually implying pasture life is only 5 years on average, well below reported expectations of 10 years of pasture life from other regions (Daly et al. 1999). The high importance that farmers attach to persistence means that this trait must be included in the FVI otherwise the index will not be considered relevant to their needs. The inclusion of persistence in the FVI in 2019, using the methods described here, is an interim step until such time as the data required to move to the cultivar-specific level are available. The methods applied here to functional groups should be equally applicable to individual cultivars.

The Irish Pasture Profit Index (PPI, O'Donovan et al. 2016) is the only other forage index that includes persistence as a trait. In the PPI, persistence is derived from the change in ground score (Camlin & Stewart 1978) for individual cultivars multiplied by a fixed coefficient of 1,683 kg DM/ha/year yield reduction per unit decline in ground score. Thus, the method used to include persistence in the FVI is similar to the PPI in the sense that it is related to the change in DM yield over time and the economic value of DM.

To date, a significant relationship between ground score and DM yield change has not emerged from New Zealand yield data sets, including the long-term trials used here (Dodd et al. 2018a), hence the same method could not be applied in the FVI. Instead, the difference between ploidy functional groups in the rate of decline

of annual DM yield from the mean of the DM yield measured in years 1 to 3 was used as a basis for deriving the persistence scalar values,  $\mu PS_t^{ij}$ .

It is acknowledged that the amount of long-term data available for the analysis reported here is still meagre, and inadequate for robust statistical analysis of trend differences. We also expect there will be genetic variation within functional groups: indeed, the identification and further development of variation at the cultivar level is to be encouraged because it is a viable pathway towards helping overcome the persistence problem in the future. Hence, as noted above, the approach is interim, and we expect that  $\mu PS_t^{ij}$  estimates will evolve, at both functional group and cultivar levels, as more data accumulate.

In the meantime, there is evidence to support the separation of diploid and tetraploid functional groups for persistence. At the mechanistic level, there is an *a priori* positive link between tiller populations and sward density (Matthew et al. 2000) and a negative relationship between perennial ryegrass ploidy level (n=2 or 4) and tiller density (e.g. Tozer et al. 2014). There is also emerging empirical evidence of physical differences in sward structure that could pre-dispose tetraploids to greater risk of persistence failure (Tozer unpublished data; NZPBRA unpublished data). As yet there is no evidence of differences among other functional groups (e.g. heading date) in physical sward persistence in pastures grazed by dairy cows in New Zealand.

The persistence scalar,  $uPS$ , has two effects in equation FVI-C. Firstly it scales yield downwards for both functional groups from year 4 on (equation 1), such that the FVI \$ value of yield is reduced by 25%. Thus, the total yield for the life of the pasture (years 1-10 for diploids, in this case) is 0.75 of the yield in years 1 to 3 inclusive (depicted by point D in Figure 1). The effect is seen most clearly for mid-season diploids in Table 3 since they are assigned a performance value of zero for ME (Ludemann et al. 2018) and do not incur

**Table 3** Mean FVI (\$/ha/year) calculated solely using seasonal dry matter (DM) yield ('FVI-A'), seasonal DM yield plus seasonal metabolisable energy (ME) content ('FVI-B'), and all three traits for three ryegrass functional groups in two dairy regions.

Dairy Region <sup>1</sup>	Functional Group <sup>2</sup>	FVI-A (\$)	FVI-B (\$)	FVI-C (\$)	Change in FVI when ME added (\$)	Change in FVI when persistence added (\$)
UNI	MD	191	191	143	0	-48
UNI	LD	236	320	239	84	-81
UNI	T	195	544	346	350	-198
USI	MD	158	158	118	0	-40
USI	LD	197	384	286	186	-97
USI	T	179	696	454	517	-242

<sup>1</sup> UNI=Upper North Island, and USI=Upper South Island; <sup>2</sup>MD=mid-season heading diploid, LD=late-season heading diploid, and T=tetraploid.

the relative renewal cost: for example, in UNI, the mean \$48/ha reduction from FVI-B to FVI-C (Table 3, which equates to 25%) is solely due to the decline in yield after year three.

Secondly, it determines the relative frequency of pasture renewal for diploids versus tetraploids via the renewal threshold trigger: the sharper the decline in yield, the sooner the threshold is reached. Thus, a further similarity between PPI and FVI is that both invoke a point in time at which a decision is made to renew a pasture (thus incurring a cost). In the PPI, this point is taken to be when DM yield declines to 50% of the first full year DM yield (O'Donovan et al. 2016), whereas in the FVI it is the point when yield drops to 0.6 of the mean yield in years 1 to 3 post-sowing. Both systems assign persistence performance values (change in ground score in PPI, persistence scalar in FVI) to cultivars (PPI) or functional groups (FVI) that determine the time elapsed before that point is reached.

The overall effect of including persistence via the methods described here is to re-frame the FVI into the decision-making window that farmers use when electing to renew a pasture, and the expectations that accompany that decision. Farmers essentially want to know how much high-quality feed a new pasture will produce, and for how long. While the decision could be to re-sow using a cultivar with a lower persistence scalar, and therefore recoup higher yield (e.g. in this analysis, for tetraploids in year 10 compared with the diploid option), the strong concern expressed by farmers about persistence indicates that many will actively select for the persistence sub-trait to progressively increase the longevity of their forage base. Selection for greater persistency of yield in high-yielding perennial ryegrass cultivars would be a better long-term solution for the pasture-based livestock industries, even though this presents a significant breeding challenge and would likely limit the rate of progress that can be made in other traits (Stewart & Hayes 2011).

Scaling DM yield and ME by *uPS* is therefore appropriate even though, theoretically, it could be argued to be a form of double-counting. Countering this, the relative renewal cost (equation 4) captures only the economic cost difference of pasture establishment associated with poor persistence and more-frequent pasture renewal: there are many other intangible management 'costs' associated with the resultant operations on farm (e.g. Tozer et al. 2011, Reynolds 2013) that are not captured in a purely economically-based index.

## Conclusions

Inclusion of ME and persistence trait information for perennial ryegrass in the FVI has resulted in a more holistic estimate of the relative value of perennial

ryegrass cultivars, albeit still at the functional group level. Persistence counter-balances to some degree the strong effect of ME on functional group rankings (Ludemann et al. 2018), since there is an inverse relationship between the two traits driven by the tetraploid functional group. Thus, while there are more data available for variation in ME among New Zealand perennial ryegrass cultivars (e.g. Cosgrove et al. 2018) than for persistence, it was essential to bring both traits into the FVI at the same time. Including ME alone would strongly favour tetraploids in the rankings, which could potentially worsen the persistence problem nationally if farmers simply choose the top-ranked cultivars from FVI lists. Simultaneous ME and persistence inclusion was only possible at the functional group level because of the near-complete absence of persistence data for cultivars. This critical gap is being addressed by NZPBRA and DairyNZ. Meanwhile, development of the persistence trait methodology has highlighted other specific knowledge gaps, particularly around current rates of pasture renewal in different regions, reasons for renewal, and farmer decision criteria. Better understanding of these factors is vital now that inclusion of persistence places the FVI directly into the time- and decision-frames used by farmers to manage their businesses.

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## REFERENCES

- Askin D, Askin V. 2016. *Lincoln Budget Manual 2016*. Lincoln, New Zealand: Lincoln University, 535 p.
- Camlin MS, Stewart RH. 1978. The assessment of persistence and its application to the evaluation of mid season and late perennial ryegrass cultivars. *Journal of the British Grassland Society* 33: 275-282.
- Chapman DF, Muir RD, Faville MJ. 2015. Persistence of dry matter yield among New Zealand perennial ryegrass (*Lolium perenne* L.) cultivars: insights from a long-term data set. *Journal of New Zealand Grasslands* 77: 177-184.
- Chapman DF, Bryant JR, Olayemi ME, Edwards GR, Thorrold BS, McMillan WH, Kerr GA, Judson G, Cookson T, Moorhead A, Norriss M. 2017. An economically based evaluation index for perennial and short-term ryegrasses in New Zealand dairy farm systems. *Grass and Forage Science* 72: 1-21.
- Cosgrove GP, Lee JM, Chapman DF, Stevens DR, Rossi L, King WM, Edwards GR. 2018. Metabolisable energy concentration in perennial ryegrass pastures:



- multi-site analysis of effects of cultivar, nitrogen fertiliser and white clover content. *Journal of New Zealand Grasslands* 80: 235-241.
- Daly MJ, Fraser T, Perkins A, Moffat CM. 1999. Farmer perceptions of reasons for perennial pasture persistence and the relationship of these with management practise, species composition and soil fertility. *Proceedings of the New Zealand Grassland Association* 61: 9-15
- Dodd MB, Chapman DF, Ludemann C, Griffiths W, Tozer K, Donnelly L. 2018a. The measurement of perennial ryegrass persistence. *Journal of New Zealand Grasslands* 80: 161-169.
- Dodd MB, Chapman DF, Ogle G. 2018b. Regrassing trends and drivers in the New Zealand dairy industry. *Journal of New Zealand Grasslands* 80: 177-185.
- Easton HS, Baird DB, Cameron NE, Kerr GA, Norriss M, Stewart AV. 2001. Perennial ryegrass cultivars: yield in multi-site trial plots. *Proceedings of the New Zealand Grassland Association* 63: 183-188.
- 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. In: Mercer CF Ed. *Pasture persistence*. Grassland Research and Practice Series No. 15. Dunedin, New Zealand: New Zealand Grassland Association, pp. 21-24.
- Lee JM, Thom ER, Waugh CD, Bell NL, McNeill DJ, Wilson DJ, Chapman DF. 2017. Trajectory and causes of decline in the botanical composition of dairy-grazed pasture in the Waikato. *Journal of New Zealand Grasslands* 79: 89-95.
- Ludemann CI, Wims CM, Chapman DF. 2018. Changes in rankings of cultivar/endophyte combinations in the DairyNZ Forage Value Index when a metabolisable energy trait is included. *Journal of New Zealand Grasslands* 80: 215-218.
- Ludemann CI. 2019. *The DairyNZ FVI Handbook 2019 edition*. Retrieved 2 February 2019 from: [www.dairynz.co.nz/fvi](http://www.dairynz.co.nz/fvi).
- Matthew C, Assuero SG, Black CK, Sackville-Hamilton NR. 2000. Tiller dynamics of grazed swards. In: Lemaire G, Hodgson J, Moraes A, Carvalho PCF, Nabinger C Eds. *Grassland ecophysiology and grazing ecology*. Wallingford, UK: CAB International, pp. 109-133.
- O'Donovan M, McHugh N, McEvoy M, Grogan D, Shalloo L. 2016. Combining seasonal yield, silage dry matter yield, quality and persistency in an economic index to assist perennial ryegrass variety selection. *Journal of Agricultural Science* 155: 556-568.
- 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.
- PRCT 2017. *Pasture Renewal Charitable Trust Resources*. Retrieved 22 June 2018 from: <http://www.pasturerenewal.org.nz/resources/pasture-calculators/>.
- Reynolds W. 2013. Addressing on-farm management to enhance pasture productivity and persistence. *Proceedings of the New Zealand Grassland Association* 75: 241-244.
- Rijswijk K, Brazendale R. 2016. Pasture renewal practices, experiences and attitudes: a comparison over time. *Journal of New Zealand Grasslands* 78: 51-56.
- Stewart A, Hayes R. 2011. Ryegrass breeding – balancing trait priorities. *Irish Journal of Agricultural and Food Research* 50: 31-46.
- Stewart A, Kerr G, Lissaman W, Rowarth J. 2014. *Pasture and forage plants for New Zealand*. Grassland Research and Practice Series No. 8. Fourth Edition. Dunedin, New Zealand: New Zealand Grassland Association.
- Tozer KN, Cameron CA, Thom ER. 2011. Pasture persistence: farmer observations and field measurements. In: Mercer CF Ed. *Pasture persistence*. Grassland Research and Practice Series No. 15. Dunedin, New Zealand: New Zealand Grassland Association, pp. 25-30.
- Tozer KN, Chapman DF, Bell NL, Crush JR, King WM, Rennie GM, Wilson DJ, Mapp NR, Rossi L, Aalders LT, Cameron CA. 2014. Botanical survey of perennial ryegrass-based dairy pastures in three regions of New Zealand: implications for ryegrass persistence. *New Zealand Journal of Agricultural Research* 57: 14-29.