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Estimated Annual Value of a Forage Cultivar Selection Decision Tool for New Zealand Sheep and Beef Farmers[1]

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Abstract

In 2011, the New Zealand dairy industry developed a forage cultivar selection decision support tool called the DairyNZ Forage Value Index (FVI). Since then, there has been considerable interest shown in development of a FVI-type cultivar evaluation system for the New Zealand sheep and beef industry. The New Zealand Pastoral Industry Forage Strategy for example recommended actions to develop a FVI for the sheep and beef industry and to have closer collaboration between the sheep and beef industry, the dairy industry and the New Zealand Plant Breeding and Research Association. This is unsurprising since the dairy industry estimated the value of the benefits of the DairyNZ FVI as approximately $NZ160 million each year. The present study provides a cost benefit analysis of a forage cultivar selection decision support tool (DST) across the New Zealand sheep and beef industry. The analysis was performed using a nitrogen fertiliser/barley replacement cost method to estimate the value of forage dry matter. The value of sheep and beef farmers choosing 5 star rated cultivars of perennial ryegrass compared to 3 or 1 star rated cultivars was extrapolated to the eight Beef + Lamb NZ Farm Classes and to the whole sheep and beef industry. Multiple scenarios were examined to assess the net present value and modified internal rate of return of investment in the DST. These scenarios reflected differences in assumed rates of adoption over a 10-year period and differences in implementation costs. The modified internal rate of return over a 10-year period was estimated to range between 27 and 62 per cent depending on whether an annual cost of the DST was assumed to be $NZ0.5 million or $NZ1 million under the adoption scenarios considered. The NPV ranged between $NZ6 million and $NZ45 million. This highlights the potential value of improved farmer selection of ryegrass cultivars through a cultivar selection DST in a sheep and beef context in New Zealand.

Key words: forage value index, evaluation, genetic improvement.

Introduction

In 2011, the New Zealand dairy industry developed a forage cultivar selection decision support tool (DST) called the DairyNZ Forage Value Index (FVI) (Chapman et al., 2017) for perennial ryegrass (*Lolium*

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perenne) and the shorter term annual (*Lolium multiflorum*) and hybrid (*Lolium boucheanum*) ryegrasses. This has allowed rural professionals/farmers and plant breeders to independently evaluate the performance of different cultivars of ryegrass for the dairy industry.

Since then, there has been considerable interest shown to develop a FVI-type cultivar evaluation system for the New Zealand sheep and beef industry. The New Zealand Pastoral Industry Forage Strategy for instance recommended actions to develop a FVI for the sheep and beef industry (Morrison, 2017) and to have closer collaboration between the sheep and beef industry, the dairy industry and the New Zealand Plant Breeding and Research Association (NZPBRA). This is unsurprising since the dairy industry put a value of the benefits of the DairyNZ FVI as approximately $NZ160 million each year (DairyNZ, 2017).

In developing the DairyNZ FVI, the dairy industry created the 'DairyNZ FVI framework' by which new traits could be included in the evaluation information to provide a more holistic assessment of ryegrass cultivar performance. These results are published as 'star ratings' (1-5 star with 5 being 'best') for each cultivar which are based on a NZ dollars per hectare per year estimated value in a farmer choosing that cultivar (Chapman et al., 2017, DairyNZ, 2020b). The 'DairyNZ FVI Framework' also provides a framework by which other forage-based industries (such as the sheep and beef industry) could use to create their own industry-specific cultivar decision support tool (DST). However, to do this requires estimation of industry specific trait economic weights. Trait economic weights indicate the potential change in farm operating profit per unit change in the trait of interest (McEvoy et al., 2011). There are multiple methods of estimating trait economic weights based on economic modelling techniques. These techniques often use proxies to estimate the value of pasture DM if it is used on the farm and are an abstract means by which economists attempt to estimate the marginal value product of pasture throughout the year, because in reality we can never truly know. For example, in Australian sheep and beef systems, Ludemann and Smith (2016) described two methods. One was based on the cost of replacing or acquiring the unit change in dry matter (DM) (the 'replacement cost method') and the other was based on the opportunity cost of changes in livestock production (the 'change in livestock production method'). Ludemann and Smith (2016) used a replacement cost method based on acquiring the DM feed as barley, while economic weights estimated using the change in livestock production method were based on the opportunity cost of changes in liveweight gain in growing sheep and cattle or in stocking rates. In one New Zealand study, the sheep and beef economic weights for perennial ryegrass were estimated through changes in livestock production (Ludemann, 2020). Regardless of the method used, the true value of DM from pasture according to Johnson and Hardin (1955) should be not more than the cost of acquiring it through the most economic means such as through purchased barley or pasture responses from added nitrogen fertiliser (the replacement value), and not less than the highest net price realisable of selling it off-farm such as standing forage or hay (the salvage value).

Use of the price of barley to estimate the replacement cost of pasture DM (for estimating forage trait economic weights) has the advantage that it uses well defined market prices, but these prices may not necessarily reflect the inter-seasonal variation in value of forage DM by farmers. Some New Zealand sheep and beef farmers may be limited in their ability to feed barley to their livestock due to the extensive nature of their farming operation and the costs of delivery. In addition, the application of nitrogenous fertiliser has long shown to improve availability of feed from forage in New Zealand pasture-based farm systems (Hudson and Woodcock, 1931). In some seasons, the cost of additional forage DM may be lower than buying in barley feed. This is due to the (relative) ease by which nitrogen fertiliser can be applied and the relatively high DM to nitrogen response rates in some seasons which can be up to 28 kg DM/kg nitrogen (Sun et al., 2008). The application of nitrogen and associated pasture DM responses (which vary by season) is therefore a potential alternative or complementary method for estimating the replacement cost (the maximum value) of forage DM.

The purpose of this study is therefore to assess the value of a sheep and beef forage cultivar selection DST to the New Zealand sheep and beef industry when estimates of the economic value for the seasonal DM trait is assessed from the replacement cost method (based on nitrogen fertiliser and barley).

Method

Net present values and modified internal rates of return

The net present values (NPV) and modified internal rates (MIRR) of return on investing in a New Zealand sheep and beef forage cultivar selection DST were estimated over a 10-year period. A 10-year period was chosen to align to standard investment periods used by the New Zealand pasture industry and in particular the investment period used in the economic analysis of the DairyNZ FVI (DairyNZ, 2017). The MIRR was used instead of the internal rates of return (IRR) because IRR has proven to overestimate returns on agricultural investment (Hurley et al., 2014). The IRR method assumed interim cash surpluses receive returns on investment that are the same as that received in the project they were generated (Alston et al., 2011). This assumption is relaxed in the MIRR so that returns from surpluses made each year receive a rate of return that is different to the main investment (Xudong et al., 2012). For the present study it was assumed the interest rate paid on the capital used in the cash flows was equal to a nominal 3 per cent discount rate and the interest earned on reinvested cash flows was 3 per cent.

The NPV were estimated based on the annual economic surpluses or deficits. Annual economic surpluses or deficits in each year were estimated as the economic benefits minus the economic costs of the DST. There is uncertainty over what the costs of implementing a DST for the New Zealand sheep and beef industry would be. However, DairyNZ invests in a FVI and the costs of the DairyNZ FVI could provide an indication of the likely costs of a sheep and beef DST. Unfortunately, recent publicly available estimates of the direct annual costs of operating the DairyNZ FVI are difficult to disentangle from the costs of research that supports the FVI. For instance, in the 2019-20 financial period DairyNZ allocated $NZ1.65 million to a project called Forage Value-Supporting Research (DairyNZ, 2020a) which included the operational and supporting research component of the DairyNZ FVI. To estimate the cost of only the operational costs of the DairyNZ FVI, one has to look back at the annual reports from 2014-2015 and 2015-2016 periods where the operational aspects of the DairyNZ FVI were allocated $NZ0.27 million and $NZ 0.4 million respectively (DairyNZ, 2016, DairyNZ, 2015). It must be noted that these direct costs to DairyNZ do not include the costs of the many field experiments required to support the FVI-many of which are administered by the New Zealand Plant Breeding and Research Association. Therefore two scenarios were modelled to assess the NPV and MIRR of investment in the sheep and beef DST based on annual economic costs of $NZ0.5 million per year and $NZ1 million per year.

The annual economic benefits (whose method of calculation is described in the next section) of the DST to sheep and beef farmers who sow perennial ryegrass were multiplied by the estimated cumulative adoption of the tool over time. There is considerable uncertainty in prediction of rates of adoption of any technology. In fact, current theory suggests that adoption in agriculture should be defined as a dynamic process, and there is no consistent explanation for why farmers adopt (or do not adopt) new technologies or practices (Montes de Oca Munguia et al., 2021). Some researchers have even rejected the notion of adoption frameworks to analyse technological change (Glover et al., 2016, Hermans et al., 2021). However, researchers still acknowledge the predicted rates of adoption are necessary for understanding the impact of technology in agricultural systems (Montes de Oca Munguia et al., 2021). To address the uncertainty in rates of adoption in agriculture Kuehne et al. (2017) developed the Adoption and Diffusion Outcome Prediction Tool (ADOPT). ADOPT was developed to predict the speed and peak level of adoption of technologies by famers. The ADOPT model was therefore used in this study to provide an indication of the speed and peak level of adoption of a sheep and beef forage cultivar selection DST. Key assumptions used in ADOPT for a sheep and beef forage cultivar selection DST are shown in Appendix 1. The ADOPT model provided an estimated 6-year period from first introduction of the DST to near-peak adoption level, and peak adoption would be about 80 per cent based on assumptions shown in Appendix 1. To account for uncertainty in the estimates from the ADOPT model, a second adoption scenario was examined. This was based on a halving of the ADOPT-estimated peak adoption rate (from 80 per cent to 40 per cent) and a 4 year increase in the time to near-peak adoption (from year 6 to year 10) using a 4 per cent (in absolute terms) increase in cumulative adoption each year.

Estimation of annual benefit to the New Zealand sheep and beef industry

The estimated annual total benefit in New Zealand dollars of the sheep and beef forage cultivar selection DST (herein referred to as the DST) to the New Zealand sheep and beef industry (DSTbenefit) was calculated as:

$$DSTbenefit = \sum_{i=1}^{n}\left(A \times P \times EVDST_{x-y} \times S\right) \quad \text{(Equation 1),}$$

where, 'n' is the number of Farm Classes that contribute to the New Zealand sheep and beef industry (n=8). 'A' is the area (in ha) of land sown in new grass each year in each 'Farm Class' category. The area (in ha) of land sown in new grass each year in each 'Farm Class' category ('A') was calculated as the number of farms in each Farm Class (N_Farms) multiplied by the mean area of land sown into new grass (A_ngrass) using data from Beef + Lamb New Zealand (B+LNZ) (2019). 'P' is the proportion of land sown in new grass sown as perennial ryegrass each year, and 'S' is the scaling factor (0-1) to scale the estimated benefit of FVI for cultivars from a small plot level to the farm level (Chapman et al., 2019). The $EVDST_{x-y}$ is the economic value of the sheep and beef DST using the DairyNZ FVI Framework for perennial ryegrass cultivar selection decisions in a sheep and beef context. The $EVDST_{x-y}$ was calculated using Equation 2:

$$EVDST_{x-y} = DST_{SRx} - DST_{SRy} \quad \text{(Equation 2),}$$

where DST_{SRx} is the mean DST value of perennial ryegrass cultivars in x star rating (SR) band (in $NZ/ha/year), and DST_{SRy} is the mean DST value of perennial ryegrass cultivars in y star rating band using the DairyNZ FVI Framework (the DST value for a cultivar is the sheep and beef equivalent to the DairyNZ FVI cultivar value). For scenario analysis the 5 and 3 star rating bands were used as the star rating bands chosen for the DST_{SRx} and DST_{SRy} respectively (DST_{SR5}-DST_{SR3}). A comparison was also made between 5 and 1 star rated cultivars (DST_{SR5}-DST_{SR1}). The DSTbenefit equation was applied to data for each of the 8 Farm Classes (B+LNZ, 2019) shown in Table 1. The DST_{SRx} and DST_{SRy} were estimated for the 8 Beef + Lamb NZ Farm Classes using the replacement cost (R) method as described in the following section.

Estimation of DST cultivar values using the replacement cost (R) method

The following equation was used to estimate the $NZ/ha/year values for each ('i') cultivar in the DST using the replacement cost (R) method:

$$\mathrm{R}\, DST^{i} = PVDM_{a}^{ix} \times EWDM_{a}^{ij} \quad \text{(Equation 3).}$$

Table 1. Description of key parameters of the Farm Classes used in this study

Parameter (units)	Farm class (where S.I.=South Island and N.I.=North Island).								
	1. S.I. High Country	2. S.I. Hill Country	3. N.I. Hard Hill Country	4. N.I. Hill Country	5. N.I. Intensive Finishing	6. S.I. Finishing Breeding	7. S.I. Intensive Finishing	8. S.I. Mixed Finishing	9. All Classes NZ
Number of farms (N_{Farms})	200	620	920	3055	1045	1820	1040	465	9,165
Effective Grazable Area (ha/farm)	8158	1572	819	420	283	493	239	396	684
Total pastoral land area of commercial sheep and beef farms (ha across New Zealand)	1632000	975000	753000	1283000	296000	897000	249000	184000	6269000
Average area of new grass (ha/farm) (A_{ngrass})	25	21	6	6	11	21	10	5	16
Effective grazable area in new grass each year (%)	0.31%	1.34%	0.79%	1.40%	3.96%	4.21%	4.18%	1.26%	2.31%
Proportion of 'new grass' area sown as perennial ryegrass (0-1) (P)	0.50	0.50	0.50	0.50	0.60	0.60	0.60	0.60	0.53
Scaling effect (0-1 scale) of ryegrass performance in small plot trials versus farm situation (S)	0.65	0.65	0.65	0.65	0.80	0.80	0.80	0.80	0.69
Area of land in new grass each year (ha) (A)	5000	13020	5952	17912	11714	37788	10400	2325	104111

Source: Data taken from the 2017/18 Beef + Lamb-Economic Service Sheep and Beef Farm Survey (B+LNZ, 2019)

The $PVDM_a^{ix}$ were performance values for the seasonal DM production trait (for season 'a', mega-region 'x' and cultivar 'i') estimated using the method described by Chapman et al. (2017) and cultivar performance data from the New Zealand Plant Breeding and Research Association National Variety Trial (NFVT) (Easton et al., 2001) that are updated each year and available at www.nzpbra.org/forage-trials/results. The trait economic weighting for the seasonal DM trait ($EWDM_a^{ij}$) (for season 'a', cultivar 'i', and region 'j') was estimated using the lesser value for the opportunity cost of pasture DM from either the equivalent energy in barley (barley replacement method) or additional pasture DM from application of nitrogen fertiliser (nitrogen fertiliser replacement method).

Barley replacement cost method

The barley replacement cost economic weight ($bEWDM_t$) for seasonal DM was based on the equation developed by Ludemann and Smith (2016) as follows:

$bEWDM_t = \Delta DM_t \times BU_t \times PE_t \times Feed\$_t$ (Equation 4).

The periods of time (t) were based on the season definitions described by Chapman et al. (2017) as winter, early spring, late spring, summer and autumn. The ΔDM_t is the change in DM production in t period (set to 1 kg DM grown in each period), BU_t is the barley utilised by livestock (as a proportion), PE_t is the pasture energy content of the additional perennial ryegrass DM production (expressed in megajoules of metabolizable energy per kg DM), and $Feed\$_t$ was estimated as:

$Feed\$_t = \frac{MPF_t + AFE_t}{1000kg\_tonne \times FProp_{DM} \times FProp_U \times FE_t}$ (Equation 5).

Assumptions and values used for Equations 4 and 5 are described in Table 2 (in order of mention).

Nitrogen fertiliser replacement cost method

The nitrogen fertiliser replacement cost economic weight ($nEWDM_t$) for seasonal DM for 't' period was estimated as follows:

$nEWDM_t = \frac{NFert\$_t}{NR_t}$ (Equation 6).

The $NFert\$_t$ was the real 5 year mean cost of nitrogen fertiliser (in $NZ/kg N) for 't' point in time. The NR_t was estimated as follows:

$NFert\$_t = \frac{MPNFert\$_t + ANFert_t}{N\% \times 10}$ (Equation 7).

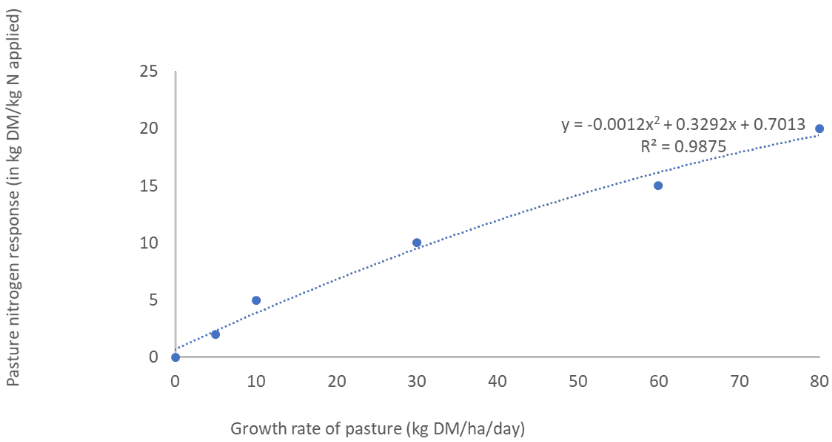
The $MPNFert\$_t$ is the real mean market price of the (Urea) nitrogen fertiliser (in $NZ/tonne) over t period (5 years), $ANFert_t$ is the real mean additional expenses for nitrogen fertiliser for transporting and applying the fertiliser over t period (5 year period), the N% is the percentage of nitrogen in the fertiliser and 10 is a multiplier to convert the nitrogen percentage into a value of kg nitrogen per tonne of fertiliser.

The NR_t in Equation 6 is the nitrogen response of pasture DM to application of nitrogen fertiliser in units of kg DM per kg N in t period. Nitrogen response of pasture can depend on environmental factors such as what is the plant's most limiting factor for growth (the Sprengel-Liebig Law of the Minimum) (van der Ploeg et al., 1999). Therefore, the pasture DM response to nitrogen can be particularly variable in the seasons when non-nitrogen factors are most limiting (eg radiation/temperature in winter and soil moisture in summer). Instead of applying nitrogen response rates based on an 'average' for each season, it was estimated based on an empirical relationship using data from DairyNZ (2011) and Shepherd and Lucci (2011). A polynomial regression equation was chosen to represent the relationship between pasture DM growth rates and pasture DM nitrogen responses as it had a high coefficient of determination (R^2=0.99) (Figure 1 and Equation 8). The polynomial equation (Equation 8, Figure 1) was applied to monthly mean growth rates (x) to estimate the likely pasture DM production response (NR_t) to the applied nitrogen.

$NR_t = -0.0012x^2 + 0.03292x + 0.7013$ (Equation 8).

The mean growth rates shown in Appendix 2 were used in the estimation of economic values for seasonal DM production using the nitrogen fertiliser replacement cost method. However, a limitation of the nitrogenous fertiliser replacement cost method becomes apparent in seasons with low pasture growth rates/low temperatures. As shown in Figure 1 in periods of low temperature, the additional use of nitrogenous fertiliser will return nil to low responses in pasture DM production. This will create unrealistically high economic weights for seasonal DM production. To counter this limitation, the replacement cost method ('Nitrogen fertiliser/barley replacement cost hybrid method') used in this study used the minimum economic weights for pasture DM production from each season from either the nitrogen fertiliser or barley replacement cost method. This meant in cooler seasons, if the economic weight of pasture DM production using the nitrogen fertiliser method became greater than that of the barley replacement cost, then the barley replacement cost economic weights would be used. For brevity, FVI results of the nitrogen fertiliser replacement cost method were not included in this article. Only results of the barley replacement cost and barley/nitrogen fertiliser 'Hybrid' replacement cost methods were reported.

Figure 1. Correlation between pasture growth rates and pasture nitrogen responses



Source: based on empirical data from DairyNZ (2011) and Shepherd and Lucci (2011)

Results

Economic weights for seasonal dry matter (DM) production trait

Table 4 includes the economic weights for the seasonal DM trait using the replacement cost method. The trait economic weights tended to result in the lowest relative economic weights in the late spring season when there were greater daily rates of pasture growth. Although there was some variation in relative trait economic weights between Farm Classes, generally the seasons with the greatest economic weighting for the seasonal DM production trait were in winter and autumn.

Table 2. Assumptions used to estimate the barley replacement cost economic weight

Abbreviation	Description	Units	Value	Reference
BU_t	Proportion of Barley utilised by livestock	kg consumed/kg offered	0.95	
PE_t	Pasture energy content of perennial ryegrass DM	MJME/kg DM	See Table 3	Upsdell et al. (2017)
MPF_t	The 5 year (Sept 2014 to Aug 2019) mean real market price of Barley feed for t years selected	$NZ/tonne	386	DairyNZ economics team (2020)
AFE_t	Additional Barley feed expenses such as transporting, handling and feeding out Barley on chosen farm system (on top of market price) for t years	$NZ/t present day value	25	
FPropDM	Barley dry matter as a proportion of fresh weight	kg DM/kg fresh weight	0.90	Rayner (2007)
Feed$t	Barley replacement cost of feed per unit energy utilised	$NZ/MJME utilised	0.04	
PPropU	Proportion of pasture utilised by livestock	kg consumed/kg offered	0.7	Byrne et al. (2012)
FE_t	Mean barley metabolisable energy content	MJME/kg DM	13.00	Rayner (2007)

Table 3. Monthly metabolizable energy (ME) content of pasture

Month	Season* for South Island	Season* for North Island	**Mean monthly ME content of pasture
January	Summer	Summer	10.1
February	Summer	Autumn	9.8
March	Summer	Autumn	9.8
April	Autumn	Autumn	10.3
May	Autumn	Winter	10.8
June	Autumn	Winter	10.9
July	Winter	Early Spring	10.9
August	Winter	Early Spring	11.1
September	Early spring	Late Spring	11.1
October	Early spring	Late Spring	11.2
November	Late spring	Summer	10.8
December	Late spring	Summer	10.4

*As defined by DairyNZ in their FVI for perennial ryegrasses. **Mean monthly ME content of ‘sheep/beef’ pasture from Upsdell et al. (2017) in megajoules of metabolisable energy per kilogram of dry matter (MJME/kg DM).

Cultivar decision support tool (DST) values

Table 5 includes DST values for cultivars in the 5, 3 and 1 star rated groups based on the replacement cost method of estimating the trait economic weight for seasonal DM production. Across the 8 Farm Classes the mean DST value of cultivars in the 5 star rated category was $NZ278/ha/year, for the 3 star category it was $NZ145/ha/year, and for the 1 star category it was $NZ3/ha/year.

Estimation of annual benefit to New Zealand sheep and beef industry

When the value of selecting 5 star rated cultivars compared with 3 or 1 star rated cultivars using the sheep and beef DST was extrapolated to the New Zealand sheep and beef industry (Table 6) the total annual benefit to the industry ranged between $NZ5.9 million and $NZ12.1 million. A large proportion of the total benefit went to the South Island Finishing Breeding Farm Class with approximately 45 per cent of the value being attributed to this Farm Class. Together, the South Island Hill Country, North Island Hill Country, North Island Intensive Finishing, and South Island Intensive Finishing Farm Classes were estimated to receive a large proportion of the total value. Together these four Farm Classes were estimated to receive about 45 per cent of the total value.

The annual benefit of the potential sheep and beef DST to the sheep and beef industry ('DSTbenefit' from Equation 1) was equally sensitive to changes in the proportion of land sown in new grass sown as perennial ryegrass each year ('P') as it was to the scaling factor ('S') that scaled the benefit of DST for cultivars from a small plot level to the farm level. In a scenario analysis, when the proportion of land in the sheep and beef industry sown each year into pasture was increased from the current ~2.3 per cent to a value closer to that of the New Zealand dairy industry (9 per cent) (based on a 8-10 per cent range reported by Thomas et al. (2014)) the total benefit of the sheep and beef DST increased 3.9 times to between $NZ22.9 million and $NZ47 million each year. This was based on the scenario comparing the value of selecting 5 star rated cultivars compared with 3 star rated cultivars and 5 star rated cultivars compared with 1 star rated cultivars respectively.

Results of the 10 year cost benefit analysis indicated substantial NPV and MIRR. This was the case assuming either $NZ0.5 million per year or $NZ1 million per year annual costs of the DST. Positive NPV and MIRR were also estimated across the two contrasting scenarios. These scenarios included the value of farmers selecting 5 star compared with 3 star cultivars (Table 7) and the value of farmers selecting 5 star compared with 1 star cultivars (Table 8). The greatest MIRR and NPV was estimated as 62 per cent and $NZ44.7 million respectively for scenario A in Table 8. This assumed $NZ0.5 million per year costs of the DST, peak adoption occurring in year 6 with peak adoption at 80 per cent of farmers who sow perennial ryegrass. By contrast, the lowest MIRR and NPV were 27 per cent and $NZ5.8 million respectively for scenario C in Table 7. This scenario assumed cumulative adoption plateaued at 40 per cent of applicable farmers after 10 years post-introduction with annual costs of the DST at $NZ1 million per year.

Discussion

The aim of this study was to assess the value of a sheep and beef DST to the New Zealand sheep and beef industry when estimates of the economic weightings for the seasonal DM trait were based on a replacement cost method. Estimates of value for the DST to the industry were made based on different assumptions for rates of adoption and ongoing costs of the DST. The values were also estimated based on the value of farmers changing from selecting 1 star rated cultivars to selecting 5 star rated cultivars or (more conservatively) changing from selecting 3 star rated cultivars to selecting 5 star rated cultivars. Regardless of method used there appeared to be substantial value ($NZ5.9 to $NZ12.1 million each year) to the industry of a sheep and beef DST if all farmers who sow perennial ryegrass were to use the DST. A large proportion of the total benefits of a sheep and beef DST was expected to be received by those in the South Island Finishing Breeding Farm Class (~45 per cent) followed by the North Island Intensive Finishing Farm Class (~12%) and South Island Hill Country (~12%). This was a function of the relative areas of land sown into pasture each year from these Farm Classes as a proportion of the total land area in the industry.

Table 4. Seasonal dry matter (DM) trait economic weights estimated using the replacement cost method for the decision support tool (R DST) cultivar values (where seasons are defined in Table 3)

Season	Seasonal DM trait economic weights ($NZ/kg DM) for each Farm Class (where S.I.=South Island and N.I.=North Island).							
	1. S.I. High Country	2. S.I. Hill Country	3. N.I. Hard Hill Country	4. N.I. Hill Country	5. N.I. Intensive Finishing	6. S.I. Finishing Breeding	7. S.I. Intensive Finishing	8. S.I. Mixed Finishing
Winter	$0.28	$0.28	$0.19	$0.18	$0.19	$0.28	$0.28	$0.31
Early spring	$0.19	$0.19	$0.16	$0.17	$0.18	$0.13	$0.12	$0.33
Late spring	$0.14	$0.14	$0.09	$0.10	$0.08	$0.10	$0.10	$0.29
Summer	$0.17	$0.17	$0.12	$0.10	$0.15	$0.14	$0.11	$0.31
Autumn	$0.28	$0.28	$0.13	$0.13	$0.20	$0.28	$0.28	$0.31

Table 5. Mean cultivar decision support tool (DST) values for 5, 3, and 1 star rated cultivars using the replacement cost (R) methods for estimating trait economic weightings (where the number in subscript after 'DST' denotes the star rating category)

	Farm class (where S.I.=South Island and N.I.=North Island).							
Parameter (units)	1. S.I. High Country	2. S.I. Hill Country	3. N.I. Hard Hill Country	4. N.I. Hill Country	5. N.I. Intensive Finishing	6. S.I. Finishing Breeding	7. S.I. Intensive Finishing	8. S.I. Mixed Finishing
R DST_5 ($NZ/ha/yr)	$334	$334	$222	$210	$254	$302	$282	$285
R DST_3 ($NZ/ha/yr)	$173	$173	$111	$103	$132	$156	$157	$153
R DST_1 ($NZ/ha/yr)	$9	$9	-$4	-$6	$4	$3	$3	$4

Table 6. The benefit ($/year) of the decision support tool for each Farm Class and to New Zealand (DSTbenefit), based on the replacement cost method (R) for estimating trait economic weightings, and differences in cultivar star rating categories

	Farm Class (where S.I.=South Island and N.I.=North Island).								
Parameter (units)*	1. S.I. High Country	2. S.I. Hill Country	3. N.I. Hard Hill Country	4. N.I. Hill Country	5. N.I. Intensive Finishing	6. S.I. Finishing Breeding	7. S.I. Intensive Finishing	8. S.I. Mixed Finishing	9. All Classes NZ
R $DSTbenefit_{5-1}$ ($NZ/yr)	$528,163	$1,375,337	$438,203	$1,258,958	$1,406,197	$5,422,638	$1,395,856	$314,425	$12,139,777
% of total benefit for each Farm Class (R $DSTbenefit_{5-1}$)	4%	11%	4%	10%	12%	45%	11%	3%	100%
R $DSTbenefit_{5-3}$ ($NZ/yr)	$261,319	$680,475	$215,521	$625,179	$683,951	$2,635,394	$624,077	$147,513	$5,873,428
% of total benefit for each Farm Class (R $DSTbenefit_{5-3}$)	4%	12%	4%	11%	12%	45%	11%	3%	100%

*Where: R $DSTbenefit_{5-1}$= Value of sheep and beef farmers selecting 5 star cultivars instead of 1 star cultivars using replacement cost method, and, R $DSTbenefit_{5-3}$= benefit of sheep and beef farmers selecting 5 star cultivars instead of 3 star cultivars using replacement cost method.

Table 7. Net present value (NPV) and modified internal rate of return (MIRR) analysis of different cost and adoption scenarios for the decision support tool (DST) in scenarios[1] A, B and C, where the NPV and costs and benefits are expressed in $NZ million/year and benefits of the DST are based on the replacement cost method where farmers receive the benefit of 5 star rated cultivars compared with 3 star rated cultivars (R DSTbenefit$_{5\text{-}3}$ method)

Scenario[1]	Assumption	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	NPV	MIRR %
A	Cumulative adoption (%)[2]	0%	6%	28%	54%	72%	77%	80%	80%	80%	80%	80%		
	Benefits ($ million)	0.0	0.4	1.6	3.2	4.2	4.5	4.7	4.7	4.7	4.7	4.7		
	Costs ($ million)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5		
	Net benefit ($ million)	-0.5	-0.1	1.1	2.7	3.7	4.0	4.2	4.2	4.2	4.2	4.2	26.2	50%
B	Cumulative adoption (%)	0%	6%	28%	54%	72%	77%	80%	80%	80%	80%	80%		
	Benefits ($ million)	0.0	0.4	1.6	3.2	4.2	4.5	4.7	4.7	4.7	4.7	4.7		
	Costs ($ million)	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0		
	Net benefit ($ million)	-1.0	-0.6	0.6	2.2	3.2	3.5	3.7	3.7	3.7	3.7	3.7	21.5	34%
C	Cumulative adoption (%)	0%	4%	8%	12%	16%	20%	24%	28%	32%	36%	40%		
	Benefits ($ million)	0.0	0.2	0.5	0.7	0.9	1.2	1.4	1.6	1.9	2.1	2.3		
	Costs ($ million)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5		
	Net benefit ($ million)	-0.5	-0.3	0.0	0.2	0.4	0.7	0.9	1.1	1.4	1.6	1.8	5.8	27%

[1]Scenario A is the base scenario with estimated adoption rates and costs of implementing the DST. Scenario B is the same as scenario A except the costs of implementing the DST are doubled. Scenario C is the same as scenario A except full adoption is reduced from 80% to 40% and time to peak duration is extended from year 6 to year 10 . [2]Cumulative adoption of the decision support tool expressed as a percentage of farmers who are sowing perennial ryegrass each year who use the tool.

Table 8. Net present value (NPV) and modified internal rate of return (MIRR) analysis of different cost and adoption scenarios for the decision support tool (DST) in scenarios[1] A, B and C, where the NPV and costs and benefits are expressed in $NZ million/year and benefits of the DST are based on the replacement cost method where farmers receive the benefit of 5 star rated cultivars compared with 1 star rated cultivars (R $DSTbenefit_{5\text{-}1}$ method)

Scenario[1]	Assumption	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	NPV	MIRR %
A	Cumulative adoption (%)[2]	0%	6%	28%	54%	72%	77%	80%	80%	80%	80%	80%		
	Benefits ($ million)	0.0	0.6	2.6	5.1	6.7	7.2	7.5	7.5	7.5	7.5	7.5		
	Costs ($ million)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5		
	Net benefit ($ million)	-0.5	0.1	2.1	4.6	6.2	6.7	7.0	7.0	7.0	7.0	7.0	44.7	62%
B	Cumulative adoption (%)	0%	6%	28%	54%	72%	77%	80%	80%	80%	80%	80%		
	Benefits ($ million)	0.0	0.6	2.6	5.1	6.7	7.2	7.5	7.5	7.5	7.5	7.5		
	Costs ($ million)	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0		
	Net benefit ($ million)	-1.0	-0.4	1.6	4.1	5.7	6.2	6.5	6.5	6.5	6.5	6.5	39.9	44%
C	Cumulative adoption (%)	0%	4%	8%	12%	16%	20%	24%	28%	32%	36%	40%		
	Benefits ($ million)	0.0	0.4	0.7	1.1	1.5	1.9	2.2	2.6	3.0	3.4	3.7		
	Costs ($ million)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5		
	Net benefit ($ million)	-0.5	-0.1	0.2	0.6	1.0	1.4	1.7	2.1	2.5	2.9	3.2	12.0	39%

[1]Scenario A is the base scenario with estimated adoption rates and costs of implementing the DST. Scenario B is the same as scenario A except the costs of implementing the DST are doubled. Scenario C is the same as scenario A except full adoption is reduced from 80% to 40% and time to peak duration is extended from year 6 to year 10 . [2]Cumulative adoption of the decision support tool expressed as a percentage of farmers who are sowing perennial ryegrass each year who use the tool.

The total annual values of the DST were scaled by likely rates of adoption-informed by the ADOPT model (Kuehne et al., 2017) and likely annual costs of the DST to provide estimates of NPV and MIRR over a 10-year period. Rates of adoption of agricultural technology or practices are difficult to predict, but are necessary for forecasting potential value of new technologies or management practices, so they can be compared with alternative investments (Montes de Oca Munguia et al., 2021). To counter the uncertainty in predicting rates of adoption in this study, two adoption scenarios were examined.

This included the 'likely' adoption curve based on ADOPT. It also included a more conservative adoption curve where the assumption for number of years to peak adoption was delayed by 4 years to occur at year 10, and for peak adoption to reach half that estimated by ADOPT (from 80 to 40 per cent).

This allowed an assessment to be made as to whether the DST would still have positive economic benefits even under a conservative adoption scenario. It is reassuring that even under the scenario with a conservative adoption curve the DST was assessed to still have substantial benefits to the industry (with a $NZ6 million NPV, based on farmers changing from selecting 3 star cultivars to selecting 5 star rated cultivars). Across both adoption scenarios the introduction of a DST to the sheep and beef industry was estimated to result in positive NPV ($NZ6 million-$NZ45 million) and MIRR values (27-62 per cent). There was also estimated to be positive net annual benefits of the technology within a relatively short time period of its introduction (positive net annual benefits by year 1 to 2 depending on which scenario was used). The speed and scale of these investment analysis measures provides good supporting evidence that implementation of a DST will be of benefit to the sheep and beef industry.

The estimated annual values of the sheep and beef DST to the sheep and beef industry were lower than that estimated for the DairyNZ FVI, where benefits were in the order of $NZ160 million each year for the New Zealand dairy industry (DairyNZ, 2017). Sensitivity analysis in this study indicated that a major contributing factor to this difference in potential value between the New Zealand sheep and beef and dairy industry DST was because of the difference in annual rates of pasture renewal. Typically the New Zealand sheep and beef industry renews 2.3 per cent of its effective land area each year (B+LNZ, 2019). By comparison, the dairy industry renews approximately 9 per cent each year (Thomas et al., 2014). To put this into perspective, if the rate of pasture renewal in the sheep and beef industry were to increase to 9 per cent each year the value of the sheep and beef DST to the sheep and beef industry would increase 390 per cent. This highlights how sensitive the total value of the sheep and beef DST is to changes in pasture renewal rates, and generally how valuable increases in pasture renewal could be for the industry. However, pasture renewal rates in the New Zealand sheep and beef industry have changed little in the past 5 years. Introduction of an independent cultivar DST may provide farmers with more confidence in the value they may receive from renewing their pasture in new genetics, however other factors such as access to capital, risk aversion, environmental restrictions amongst others may restrict major increases in pasture renewal. Given pasture renewal was estimated as being 2.3 per cent of effective sheep and beef land area in 2015 (Morrison, 2017) an increase in pasture renewal to 9 per cent could be a very challenging target.

Analysis in this study was based on use of the replacement cost method for assessing the value of seasonal DM in pasture. One disadvantage of using the replacement cost method is that is does not necessarily reflect the inter-seasonal value of pasture DM well (Ludemann et al., 2013). This is most pronounced when only using barley as the replacement cost. However, estimates in this study were based on assessments of value of DM from a replacement cost method using barley and nitrogen as the reference costs. Inclusion of the nitrogen reference cost allowed to some degree an improvement in inter-seasonal variation of value in DM. This is because the nitrogen fertiliser component of the replacement cost method was based on a polynomial regression curve between pasture growth rates and pasture DM response to application of nitrogen fertiliser. Seasons with high pasture growth rates would have high pasture DM responses to nitrogen fertiliser. Greater responses of pasture DM to fertiliser nitrogen application dilute the cost of fertiliser application across more units of pasture DM. In essence this means the replacement cost of DM is lower in periods with high growth rates because in these periods it does not require much fertiliser nitrogen to 'replace' a kg of pasture DM. In this way inclusion of the nitrogen replacement cost component reflected lower economic values for pasture DM in seasons when there is more likely to be a surplus of pasture DM (in seasons with high pasture growth rates). When more data become available, more site-specific pasture DM responses could be used to improve accuracy of the replacement cost economic weights. This could for instance be based on more data using actual or predicted pasture growth rates on farm, and/or through machine learning technologies currently under development in New Zealand (Pylianidis et al., 2021). This could allow estimation of trait economic weightings across a wider range of farm systems - potentially farm specific - without onerous farm system modelling, as it would only require barley price and monthly pasture growth rate or meteorological data. These same methods could also be used to improve estimates of nitrogen response between cultivars which were simplistically assumed to remain the same between cultivars in this analysis.

Overall, this study provides information to the various stakeholders of the New Zealand sheep and beef industry for decision-making in regard to development of a sheep and beef DST. For farmers the relative values of 1, 3 and 5 star rated cultivars of perennial ryegrass quantified in this study may help improve their selection decisions and in particular toward those in the 5 star rated category. For pasture plant breeders focussed on the New Zealand sheep and beef industry the relative trait weightings estimated in this study could be used to account for relative differences in traits of perennial ryegrass for selection of parents in each round of cultivar improvement (Leddin et al., 2018). It therefore has the potential to improve breeding objectives of pasture plant breeding companies (Smith and Fennessy, 2011). For potential investors in a New Zealand sheep and beef DST, this study quantifies the magnitude of value of the DST to the industry as well as what Farm Classes are expected to receive the most benefit from this DST framework. These benefits were balanced against the potential costs of implementing a sheep and beef DST. What these costs amount to if the DST technology is adopted is uncertain. However the sheep and beef industry has the advantage that there is already an existing (DairyNZ) FVI framework that will allow synergies and benefits of scale to be captured if both industries collaborate in this space.

Conclusions

There appears to be substantial benefit to the New Zealand sheep and beef industry adopting a perennial ryegrass cultivar selection decision support tool (DST) based on the DairyNZ framework. Much of these benefits were estimated to go to the South Island Finishing Breeding, North Island Intensive Finishing, South Island Hill Country, North Island Hill Country and South Island Intensive Finishing Farm Classes. While the total value of a sheep and beef DST was estimated to be substantially less than that estimated for the DairyNZ FVI to the dairy industry, it was shown that differences in rates of pasture renewal between the two industries play a major role in this difference. Nevertheless, substantial NPV and MIRR were estimated in this study across the scenarios which had a wide range of assumptions for costs of the DST and rates of adoption of the technology. Information from this analysis can help inform farmers of the relative value of cultivars, plant breeders in the appropriate weighting of traits in their breeding objectives, and potential investors in the sheep and beef DST in the magnitude and distribution of potential benefit throughout the New Zealand sheep and beef industry for implementing the DST framework.

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Appendix 1. Assumptions used in ADOPT for estimating the time to near-peak adoption level and peak adoption rates for a sheep and beef cultivar decision support tool value

ADOPT variable	Question asked in ADOPT	Answer to ADOPT question
1. Profit orientation	What proportion of the target population has maximising profit as a strong motivation?	A majority have maximising profit as a strong motivation
2. Environmental orientation	What proportion of the target population has protecting the natural environment as a strong motivation?	A majority have protection of the environment as a strong motivation
3. Risk orientation	What proportion of the target population has risk minimization as a strong motivation?	About half have risk minimisation as a strong motivation
4. Enterprise scale	On what proportion of the target farms is there a major enterprise that could benefit from the practice?	A majority of the target farms have a major enterprise that could benefit
5. Management horizon	What proportion of the target population has a long-term (greater than 10 years) management horizon for their farm?	A majority have a long-term management horizon
6. Short-term constraints	What proportion of the target population is under conditions of severe short-term financial constraints?	A minority currently have a severe short-term financial constraint
7. Trialing ease	How easily can the practice (or significant components of it) be trialed on a limited basis before a decision is made to adopt it on a larger scale?	Very easily trialable
8. Practice complexity	Does the complexity of the practice allow the effects of its use to be easily evaluated when it is used?	Slightly difficult to evaluate effects of use due to complexity
9. Observability	To what extent would the practice be observable to farmers who are yet to adopt it when it is used in their district?	Difficult to observe
10. Advisory support	What proportion of the target population uses paid advisors capable of providing advice relevant to the practice?	A minority use a relevant advisor
11. Group involvement	What proportion of the target population participates in farmer-based groups that discuss farming?	A minority are involved with a group that discusses farming
12. Relevant existing skills & knowledge	What proportion of the target population will need to develop substantial new skills and knowledge to use the practice?	Almost none will need new skills or knowledge
13. Practice awareness	What proportion of the target population would be aware of the use or trialing of the practice in their district?	About half are aware that it has been used or trialed in their district
14. Relative upfront cost of the practice	What is the size of the up-front cost of the investment relative to the potential annual benefit from using the practice?	No initial investment required
15. Reversibility of the practice	To what extent is the adoption of the practice able to be reversed?	Very easily reversed
16. Profit benefit in years that it is used	To what extent is the use of the practice likely to affect the profitability of the farm business in the years that it is used?	Moderate profit advantage in years that it is used
17. Profit benefit in future	To what extent is the use of the practice likely to have additional effects on the future profitability of the farm business?	Moderate profit advantage in the future
18. Time for profit benefit to be realized	How long after the practice is first adopted would it take for effects on future profitability to be realized?	1 - 2 years
19. Environmental impact	To what extent would the use of the practice have net environmental benefits or costs?	No net environmental effects

ADOPT variable	Question asked in ADOPT	Answer to ADOPT question
20. Time for environmental impacts to be realized	How long after the practice is first adopted would it take for the expected environmental benefits or costs to be realized?	Not Applicable
21. Risk	To what extent would the use of the practice affect the net exposure of the farm business to risk?	No increase in risk
22. Ease and convenience	To what extent would the use of the practice affect the ease and convenience of the management of the farm in the years that it is used?	Small increase in ease and convenience

Appendix 2. Pasture growth rates for each Farm Class used in estimating cultivar decision support tool values using the replacement cost method (R DST)

Month	Mean pasture growth rate (kg DM/ha/day) for each Farm class (where S.I.=South Island and N.I.=North Island)*							
	1. S.I. High Country	2. S.I. Hill Country	3. N.I. Hard Hill Country	4. N.I. Hill Country	5. N.I. Intensive Finishing	6. S.I. Finishing Breeding	7. S.I. Intensive Finishing	8. S.I. Mixed Finishing
January	17	17	17	32	15	36	48	40
February	24	24	19	29	12	28	43	33
March	27	27	33	31	21	24	31	29
April	16	16	47	36	26	16	20	18
May	7	7	47	26	25	9	10	8
June	0	0	38	17	16	5	5	5
July	0	0	37	18	16	5	5	5
August	0	0	29	29	32	5	11	12
September	15	15	37	37	56	25	31	32
October	28	28	51	51	70	46	40	55
November	30	30	50	50	51	47	41	49
December	25	25	45	45	30	44	48	47

*From B+LNZ (2012).