A method to estimate the potential net benefits of trait improvements in pasture species: Transgenic white clover for livestock grazing systems

CD Lewis[1,4,7], B Malcolm[3,4], JL Jacobs[2,4,7] , G Spangenberg[5,6,7] and KF Smith[4,7]

[1]Agriculture Research, Department of Environment and Primary Industries, Ellinbank, Vic. 3821, Australia.
[2] Agriculture Research, Department of Environment and Primary Industries, Warrnambool, Vic. 3280, Australia.
[3] Agriculture Research, Department of Environment and Primary Industries, Carlton, Vic. 3053, Australia.
[4] Department of Agriculture and Food Systems, University of Melbourne, Parkville, Vic. 3010, Australia.
[5]Biosciences Research, Department of Environment and Primary Industries, AgriBio, Bundoora, Vic. 3083, Australia.
[6]School of Applied Systems Biology, La Trobe University, AgriBio, Bundoora, Vic. 3083, Australia.
[7]Dairy Futures Cooperative Research Centre, AgriBio, Bundoora, Vic. 3083, Australia.

Email: claire.lewis@dpi.vic.gov.au

Abstract

The potential net benefits of pasture species with enhanced genetic potential can be estimated using the acquisition value technique. This method values potential extra production of pasture dry matter (DM) as being equivalent to the market value of alternative sources of equivalent metabolisable energy (ME) and crude protein (CP). The market price of equivalent alternative sources of ME and CP gives an estimate of the maximum potential value of extra pasture DM produced on farm. In the work reported in this paper the improvement of two traits in white clover (*Trifolium repens* L.) are valued using the acquisition value technique. The traits are 1) alfalfa mosaic virus resistance (AMV Res.), and, 2) summer survival through delayed leaf senescence (SS). One hectare of pasture from two different environments in southern Australia was considered. Discounted cash flow budgeting was used to estimate the extra potential annual benefits minus the extra potential annual costs from growing a novel white clover compared to an existing common white clover cultivar over a 10 year period. Net present value (NPV) of the additional ME and CP was estimated using a real discount rate of 10% p.a. Probability distributions were developed and stochastic simulation was used to incorporate the effects of uncertain variables on the value of extra DM produced. Sensitivity testing of key parameters was conducted. The analysis presented here indicates there are potential net benefits from the genetic innovations, and these net benefits would be shared between suppliers and users. For the 'what if' scenarios explored, combining individual plant traits into a trait stack showed greater annual net benefit than individual trait improvements in white clover. For example, the 'AMV Res.' as a single trait improvement returned a mean annuity value of approximately $170/ha/yr for the 10 year period, with 68% of annuities calculated falling within approximately $80 of this mean, for the single hectare analysis of the high rainfall (1000 mm) using the market value of ME and CP. Comparatively, the trait stack option returned a mean annuity value of additional annual ME and CP of approximately $540/ha/yr for the 10 year period with a standard deviation of $275. Economic models applied to molecular breeding programs can produce information to help inform decisions on prioritisation of research and investment in new traits, and assists in determining the magnitude of improvements in trait efficiencies that is required to justify such investment. The approach presented here, based on the acquisition value technique to value extra annual DM from a hectare of pasture, represents an initial look at the question; such partial estimates are not the potential net benefits from trait improvements in pasture species that would occur at whole farm level, within years and over time. For this information, analysis at the whole farm scale is required to capture the impact on the complexity of the farm system from changes to the pasture base, as the next phase of this research will explore.

Keywords: forage, economics, genetic modification.

Introduction

Novel cultivars of pasture species are developed with the aim of improving the status quo of forage production for livestock grazing systems. These novel cultivars often result in significant changes to the quantity and timing of the dry matter (DM), energy, and protein supply of a given farm system (Smith *et al.* 2007). During the initial stages of plant breeding programs, investment decisions are required where information relating to response functions for novel cultivars are not well known (Graff *et al.* 2010).

Uncertainty, around technical response relationships fundamental to the processes of pasture growth and subsequent utilisation by grazing animals, makes the decision by plant breeders to invest in researching and developing novel pasture cultivars synonymous with agricultural decision making under risk and uncertainty (Hardaker 2004). The investor in plant breeding faces the added uncertainty about the precise characteristics that the novel cultivar will exhibit when grown under a range of environmental conditions. The relative balance that will occur between target traits increases this uncertainty (Smith *et al.* 1997; Smith and Fennessy 2011). Additionally, uncertainty surrounds the roles and management in different farm systems into which the plant will be placed and, in turn, has to perform in different market segments (Parsons *et al.* 2004; Francis *et al.* 2006; Graff *et al.* 2010).

Valuing changes in DM production from the introduction of novel pasture cultivars into a grazing farm system has its own set of complexities and challenges. Where estimates of pasture production and animal responses are available, this information can be used to inform appropriate economic analysis (Butler *et al.* 2012). This level of production information in the early stages of plant breeding efforts is rare. In animal breeding programs, the use of estimated breeding values (EBVs) to direct trait improvement is commonplace, with genomic selection more recently integrated at the commercial scale (Hayes *et al.* 2009; Goddard 2012). However, the application of breeding value approaches to analyse the value of multiple trait improvements is in its infancy in pasture breeding programs (McEvoy *et al.* 2011; Smith and Fennessy 2011; Chapman 2012).

Pasture DM is classified as an intermediate product in agricultural production – that is, it is used as an input for an animal production output (Abadi Ghadim and Morrison 1992). For sound economic analysis, a price must be placed on intermediate products (Anderson, 1967, Doyle and Elliott, 1983). Often the market for intermediate products used for agricultural production is poorly defined, or completely absent. This makes placing a dollar value on pasture DM inherently difficult (Anderson 1967; Doyle and Elliott 1983; Nelson *et al.* 1957). The methods of private Benefit-Cost Analysis (BCA) (Sinden and Thampapillai 1995) can inform judgement about investment in breeding and developing an improved pasture cultivar. Benefit cost analysts have long encountered difficult questions about how to value benefits and costs. The nature of some benefits and costs do not always lend themselves to easy valuation. An added challenge in BCA is to establish plausible estimates of benefits and costs in economically efficient ways. This requires developing new information that will add more value to decisions about the investment than the new information itself costs.

Understanding the potential net benefits of plant breeding opportunities is useful information before investment in large-scale experimentation and/or modelling proceeds. This is of particular relevance for investments in transgenic breeding, which often incur additional regulatory costs and restrictions in the creation of experimental data (Graff *et al.* 2010). Despite this, frameworks to estimate the potential net benefits of novel cultivars of pasture species, in economically efficient ways, are scarce in the literature.

A method to indirectly estimate the potential net benefits of novel cultivars of pasture species is required to inform subsequent investments in research, development and economic analysis. The acquisition value technique, from the BCA literature, values a benefit of a change in a system resulting from an innovation based on the cost of obtaining the equivalent services of the innovation from an alternative source. In the case of a pasture innovation, the acquisition value technique described by Hardin and Johnson (1955), and similarly by Sinden and Thampapillai (1995), can be applied to indirectly value DM production benefits. This is done by valuing the major production components of estimated metabolisable energy (ME) (MJ/kg DM) and crude protein (CP) (% DM) as priced in the supplementary feed market. To demonstrate this approach, a model was constructed to estimate the potential net benefits and risk profile of two transgenic trait improvements in white clover at two locations in southern Australia.

Transgenic white clovers (*Trifolium repens* L.) with alfalfa mosaic virus (AMV) resistance and delayed leaf senescence have been developed and are currently undergoing field evaluation with the aim of improving white clover DM production and persistence (Chu *et al.* 2005; Labandera *et al.* 2005; Lin *et al.* 2005; Panter *et al.* 2012; Forster *et al.* 2013). Alfalfa mosaic virus can cause reductions in white clover DM yield of approximately 30-50% (Gibson 1981; Johnstone and Chu 1993; Kalla *et al.* 2000). Incidence levels of 30-100% across pure white clover experimental swards and mixed pastures have been reported in Australia (Garrett 1991; McKirdy and Jones 1997; Smith *et al.* 2007; Forster *et al.* 2013). Transgenic white clover with field resistance to AMV infection has been demonstrated at two different locations in Australia (Panter *et al.* 2012). In glasshouse experiments, the delayed leaf senescence trait reduced plant death by approximately 50% compared to the control, and recorded a stolon death percentage of 5% compared to 25% under induced drought stress (Spangenberg, unpub.).

An investment decision under consideration is whether to deploy these two traits individually or together as a trait stack. The transgenic nature of the white clover technology precludes evaluation of the two traits in mixed pasture swards. This lack of data makes this technology an appropriate example to demonstrate how the acquisition value technique can be applied to indirectly value the potential net benefits of a pasture innovation where uncertainty regarding its on-farm performance is present. The physiological data from glasshouse and field experiments for these traits is used to construct 'what if' scenarios for the analysis. Information from plant breeders about the potential performance of the prospective novel pasture cultivar also informs the process.

Economic evaluation of new technology at the farm level requires more complex analysis than the approach proposed here. Whole farm analysis of improvements in the genetic potential of pasture species requires estimates of the likely changes in DM yield and nutritive value through the production year, and the subsequent effects on animal production, and hence the impacts on income, costs and risk profile (Malcolm *et al.* 2005; Bathgate *et al.* 2009). The whole farm approach aims to understand the complex interactions and response functions within the farm system, and appropriately requires substantial investment in both human resources and time (Malcolm *et al.* 2012).

The framework for indirectly valuing improved plant traits proposed does not replace the need for rigorous whole farm analysis; nor does it aim to elicit farm level net benefits. Rather the acquisition value approach based on limited data, expert opinion, and economic theory, represents an economically efficient way to conduct an initial look that complements the whole farm approach. It demonstrates how economic ways of thinking provide useful information to aid in the investment decisions required of pasture breeding programs where high levels of uncertainty are present.

Method

One hectare of a newly sown mixed pasture was considered in two locations for the analysis: (i) the high rainfall zone of southern Australia which is dominated by dairy production with an average annual rainfall of approximately 1000 mm; and (ii) the marginal white clover zone of south west Victoria which is dominated by sheep and wool production with an average annual rainfall of approximately 650 - 800 mm (Ward 1991).

The pasture reflects the common mixed sward used for livestock production in each location, and is termed the 'Base Case'. A 10 year period was selected for the analysis. Experience and farm evidence shows that white clover will decline over 10 years, often contributing less than 5% of the sward DM by year 10. The rate of white clover decline on an individual farm will depend on a range of factors including climatic conditions and management practices. It was assumed that the first full year of production occurred in the first year of the analysis period (Year 1), with the physical establishment of pasture assumed to have occurred prior to the commencement of the analysis.

White clover with the transgenic trait improvements is referred to as 'Novel' white clover. Expert opinion expects the alfalfa mosaic virus resistance ('AMV Res.') to eliminate the burden of this virus on white clover plants, and that the delayed leaf senescence trait infers increased survival of white clover plants over the summer period (summer survival 'SS'). These judgements and expectations are supported by the data from glasshouse and field-based experiments.

The objective was to estimate the potential net benefit of the 'Novel' white clover compared to the 'Base Case' situation in each location.

Base Case 1: High rainfall zone of southern Australia

It was assumed that 'Base Case 1' was a newly sown perennial ryegrass (*Lolium perenne* L.) and white clover sward. The current common cultivar present in the 'Base Case 1' pasture system is referred to as 'Current' white clover. Year 1 total pasture DM production was 14 t DM/ha (Jacobs *et al.* 1999; McKenzie *et al.* 2003a), with a white clover content of 25% of sward DM (McKenzie *et al.* 2003b). In the analysis, annual DM production of perennial ryegrass was constant at 10.5 t DM/ha for the 10 years.

The percentage of 'Current' white clover in the 'Base Case' pasture sward varies between years due to factors including environmental conditions and pasture management practices (Mason 1993; Chapman *et al.* 1996). As experimental data were limited, expert opinion of on-farm experience was sourced. It was assumed that white clover content could either increase or decrease from year to year, and would ultimately decline to contribute less than 5% of total sward DM by Year 10.

Potential of 'Novel' white clover for 'Base Case 1'

It was assumed that both traits resulted in a cumulative increase in white clover DM in the sward over time, as a greater proportion of white clover plants are anticipated to survive from one year to the next. In the model, this translated into a reduction in the 'Base Case 1' rate of decline seen for 'Current' white clover over the 10 year period, and hence additional white clover DM production over time.

Base Case 2: Marginal white clover zone of south west Victoria

It was assumed that the 'Base Case 2' pasture consisted of a newly sown perennial ryegrass and subterranean clover (*Trifolium subterraneum* L.) sward (Ward 1991; Saul *et al.* 2009). No white clover was present in the 'Base Case 2' pasture.

It was assumed that the newly sown 'Base Case 2' pasture DM yield remained constant at 9 t DM/ha per year for the 10 year analysis period. This assumed annual DM yield is consistent with reported figures for well managed perennial pastures in the south west region of Victoria, which range from around 6 to 15 t DM/ha year (Saul *et al.* 2009).

Potential of 'Novel' white clover for 'Base Case 2'

Survival of white clover stolons over summer is a key limitation to white clover performance in this region (Ward 1991; Fitzgerald and Clark 1993; Lane *et al.* 2000). There is the potential for white clover to contribute to mixed pasture swards in the marginal white clover zone. This could occur if the 'SS' allowed white clover stolons to survive the summer period (Clark and McFadden 1997), and subsequently respond to opening rains.

Introducing the 'Novel' white clover with improved summer survival to the 'Base Case 2' pasture system has the potential to alter the nature of the perennial ryegrass/subterranean clover sward, namely (i) white clover DM is produced in addition to current total sward DM production, (ii) white clover DM production displaces all subterranean clover DM production, or (iii) white clover DM production displaces a proportion of subterranean clover and/or perennial ryegrass DM production. The reality on farm may be one of these scenarios, or a situation beyond our current state of knowledge.

Rather than draw inference on what these interactions may be, it was assumed that 'Novel' white clover DM is produced in addition to current total sward DM production.

The Year 1 contribution of 'Novel' white clover with the 'SS' trait yield was 10% of total sward dry matter for 'Base Case 2', as it is expected that white clover production in this zone will be less than that seen for 'Base Case 1'. Over time, management influences are likely to negatively impact on 'Novel' white clover performance in the region. It was assumed that with the 'SS' white clover DM would fluctuate from year to year, and ultimately decline over time. This is consistent with the experience seen by Hutchinson *et al.* (1995) in the 30 year study of white clover persistence in pasture that was well fertilised and grazed by sheep in the Northern Tablelands of New South Wales.

It is unlikely that the 'AMV Res.' as a single trait improvement will be able to address the poor performance of white clover in 'Base Case 2' region due to dry summer conditions adversely impacting persistence of this species. A scenario was developed to explore the impact of introducing 'AMV Res.' as a trait stack with the 'SS'. This scenario assumed that including 'AMV Res.' would lead to a direct increase in white clover DM yield per annum, above what would be achieved with 'SS' as a single trait.

Net benefits framework

Discounted cash flow budget analysis was used to estimate the potential net present value (NPV) over the 10 year period. The

NPV at a particular discount rate is the value in present value terms of all future net benefits from an investment. This represents the potential addition to wealth above what could be earned from an investment that earned a return equivalent to the discount rate (Malcolm *et al.* 2005).

Real NPV was calculated after 15% tax on marginal income using a real discount rate of 10%. This discount rate was selected to allow for a risk premium due to the high level of uncertainty associated with the trait improvements. NPV was then converted to an annual basis using an annuity function. See Malcolm *et al.* (2005) for further details on NPV and annuity calculations.

The discounted cash flow approach compares the extra benefits and the extra costs from growing the 'Novel' white clover, compared to growing the 'Base Case' pasture sward.

Estimating the benefits of a pasture innovation

A frequently traded market exists for ME and CP in the form of supplements such as fodder, grain and concentrates. It is assumed that any extra ME and CP produced by an improved pasture cultivar has the same gross value as the equivalent amount of ME and CP supplied by purchased supplementary feed. The value of ME and CP is independent of the actual fate of ME and CP, whether it is used for livestock production or sold off-farm. This assumption is valid whether the extra ME and CP are achieved through DM yield improvements or through nutritive value improvements. The market price reflects the consumed value, with producers' willingness to pay for ME and CP from different supplementary feed sources accounting for feeding out wastage. Using the acquisition value technique provides the maximum potential value of a pasture innovation. If the DM is used in the farm system instead of being sold to other users, the maximum it could be worth is the market value of ME and CP. If it was worth more than the market value, then it would be used in an alternative way, and the cheaper market sources of ME and CP would be used in the farm system instead. Thus, the extra ME and CP produced is worth no more than the price the market is willing to provide it for (Hardin and Johnson 1955).

It was assumed that any additional 'Novel' white clover DM produced had an estimated ME value of 11 MJ/kg DM and a CP percentage of 25% (Stockdale 1999). The common supplementary sources of ME (barley) and CP (canola meal) used by the dairy industry were selected for 'Base Case 1', and those (ME, barley; CP, lupins) used by the sheep industry selected for 'Base Case 2'.

Equation 1 and Equation 2 were used to calculate the acquisition value of ME and CP.

Equation 1 Calculation of the value of 1 MJ ME

$$ME_{\$} = DM_{\$} / ME_{DM}$$

Where;

$ME_{\$}$ = value of 1 MJ ME pasture

$DM_{\$}$ = market value of 1 kg DM of supplementary feed

ME_{DM} = the average ME value per kg DM of supplementary feed

Equation 2 Calculation of the value of 1 g of CP

$$CP_{\$} = DM_{\$} / CP_{DM}$$

Where;

$CP_{\$}$ = value of 1 g CP pasture

$DM_{\$}$ = market value of 1 kg DM of supplementary feed

CP_{DM} = the average CP g per kg DM of supplementary feed

Estimating the costs of a pasture innovation

Two scenarios of cost of pasture establishment were explored. In the first instance it was assumed that establishment costs were equivalent for sowing the current common white clover cultivar and the 'Novel' white clover. A second scenario estimated how high the additional establishment cost would need to be for there to be no benefit from sowing the 'Novel' white clover (ie equivalent to a mean NPV of 0). This was done to account for any potential increases in the establishment cost of 'Novel' white clover; for example, higher seed costs.

The variable cost of additional P fertiliser for growing extra white clover DM was accounted for. It was assumed that the P soil fertility of both 'Base Case' pasture systems was at non-limiting levels for pasture production based on the findings of Weaver and Wong (2011), with only maintenance application of P required. The P that was required to grow the extra white clover DM was based on the approach outlined by Syers *et al.* (2008). It is recognised that this approach doesn't account for all factors including leaching, runoff and sorption in the calculation of total P maintenance requirement (Weaver and Wong 2011). The additional P fertiliser required was assumed to be 3.5 kg P per tonne of additional white clover DM grown. This was based on the mean total P content of white clover of approximately 3,500 mg/kg dry weight shoot (McDowell *et al* 2011). The price of P fertiliser was $550/t for triple super phosphate (TSP) (20.7% P).

Risk analysis

Stochastic Monte Carlo simulation was undertaken using @Risk (Palisade Corporation 2012). This add-in package to Microsoft Excel allows uncertainty to be described by probability distributions. The uncertainty was the volatility of levels of key input variables, and unknown or uncertain relations between technical elements of the innovation.

In this analysis, the uncertain variables were supplementary feed prices, white clover annual DM yield, trait potential benefit, and trait stack multiplication factor. The trait stack multiplication factor reflects the phenomenon that when traits are stacked, the total impact of the traits together will differ from the sum of the traits as individual improvements. For instance, in the absence of the ‘AMV Res.’ trait, the on-farm expression of the value of the ‘SS’ trait may be reduced in leaves affected by the symptoms of AMV. Conversely, remediating AMV through the ‘AMV Res.’ trait could cover part of the benefit that would be ascribed to ‘SS’.

Probability distributions for these inputs were included in the model (Table 1 and Table 2). Whilst the assumption of the maintenance P fertiliser requirement per kg of additional white clover DM grown is an uncertain variable, this parameter was considered static in the model, as NPV results were largely insensitive to changes in this parameter. For example, a 50% increase in P requirement decreased NPV by approximately 1% across all scenarios.

Monte Carlo simulation randomly selects sets of input parameters based on their specified probability distributions. A potential value is then estimated based on the discounted cash flow budget analysis. Each outcome from a random set of inputs is termed an ‘iteration’. A large number of iterations were compiled to form a distribution of NPVs. The results reported in this analysis for ‘Novel’ white clover are based on 10,000 iterations, or 10,000 runs of 10 years.

Distribution type describes the shape of each distribution used in the analysis. In the absence of long term yield data on white clover production in the ‘Base Case 1’ environment, distribution A (see Table 1) was constructed. Distribution A allows for annual increases (up to 15%) and decreases (up to 65%) in white clover content, from the initial contribution in Year 1, over the 10 year period (Mason 1993; Chapman *et al.* 1996; Jacobs *et al.* 1999; McKenzie *et al.* 2003a). A Weibull distribution was selected as it is flexible enough to allow the distribution to be skewed to reflect the ultimate decline in white clover expected in this environment over the 10 year period.

The parameters used for distribution A were also used for ‘Base Case 2’, to reflect the expected decline in the ‘SS’ white clover over time (Table 2, distribution E).

Uniform distributions were used for the trait potential benefits (distribution B, C, and F) and trait stack multiplication factor (distribution D and G). Every value across the range of the uniform distribution has an equal likelihood of occurrence, making it appropriate to use for variables where there is little or no knowledge (Palisade Corporation 2012).

Historical price data, adjusted to current dollar values, and expert opinion regarding future price expectations were used to develop expected feed price distributions (distributions H, I and J in Table 3) for the future production period (Coffey 2005; Malcolm *et al.* 2005; Armstrong *et al.* 2010; Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES) 2011). Gamma and Weibull distribution types were selected for the price distributions, as they were each deemed the best fit for the relevant historical price data based on the Anderson-Darling goodness of fit test (Palisade Corporation, 2012).

Sensitivity testing

Sensitivity testing was used in combination with the stochastic Monte Carlo simulation to test explicit scenarios. For ‘Base Case 1’, the contribution of white clover to total sward DM in Year 1 was initially set at 25%, and was sensitivity tested at 10% and 15%. When the ‘Novel’ white clover with the ‘SS’ trait was introduced to ‘Base Case 2’, the

Year 1 contribution of white clover was initially set at 10%, and was sensitivity tested at 5% and 15% of total sward DM for the purpose of this study.

It is unrealistic to assume that all of the extra ‘Novel’ white clover DM is consumed by grazing animals or sold as fodder. The potential NPV of the improved white clover was analysed at 100%, 80%, 60% and 40% pasture utilisation. The utilisation of pastures is about 40% to 60% in sheep systems and 50% to 60% in dairy systems (Andrews *et al.* 1992; Warn *et al.* 2006; Meat and Livestock Australia (MLA) 2009). However, utilisation can also vary between seasons (Andrews *et al.* 1992; Moore *et al.* 2009). Eighty per cent utilisation was also analysed as white clover is likely to be the dominant pasture species available during the summer months, where other species may be in limited supply.

The real NPV discount rate was sensitivity tested at 5% and 20%.

The model

‘Base Case 1’ annual white clover production

Equation 3 was used to calculate the annual white clover DM production for ‘Base Case 1’ from Year 2 to Year 10.

Equation 3 Calculation of ‘Current’ white clover DM yield for Year 2 to Year 10 (t DM/ha/year) for ‘Base Case 1’.

$$C_t = C_{t-1} * (1+C_{\%})$$

Where;

C_t = ‘Current’ white clover DM production in current year (kg DM/ha/year)

C_{t-1} = ‘Current’ white clover DM production in previous year (kg DM/ha/year)

$C_{\%}$ = Percentage of C_{t-1} available in current year (Table 1, Distribution A)

For ‘Base Case 1’, the effects of individual trait improvements on white clover DM production (t DM/ha/year) were calculated using Equation 4.

Equation 4 Calculation of ‘Novel’ white clover DM yield for Year 2 to Year 10 (t DM/ha/year) with individual trait for ‘Base Case 1’.

$$1N_t = 1N_{t-1} * (1+(1N_{\%} \pm (1N_{t-1} * \triangle_{\%})))$$

Where;

$1N_t$ = ‘Novel’ white clover DM production in current year (kg DM/ha/year) with individual trait

$1N_{t-1}$ = ‘Novel’ white clover DM production in previous year (kg DM/ha/year) with individual trait

$1N_{\%}$ = Percentage of $1N_{t-1}$ available in current year (Table 1, Distribution A)

$\triangle_{\%}$ = Percentage change in $1N_{t-1}$ due to individual trait (Table 1, Distribution B or Distribution C depending on trait of interest)

For ‘Base Case 1’ the effect of the trait stack on white clover DM production (t DM/ha/year) was calculated using Equation 5.

Equation 5 Calculation of ‘Novel’ white clover DM yield for Year 2 to Year 10 (t DM/ha/year) with trait stack for ‘Base Case 1’.

$$2N_t = 2N_{t-1} * (1+(2N_{\%} \pm (2N_{\%} * ((\triangle_{\%AMVres} + \triangle_{\%SS} * 2N_f))))$$

Where;

$2N_t$ = ‘Novel’ white clover DM production in current year (kg DM/ha/year) with trait stack

$2N_{t-1}$ = ‘Novel’ white clover DM production in previous year (kg DM/ha/year) with trait stack

$2N_{\%}$ = Percentage of $2N_{t-1}$ white clover DM yield available in current year (Table 1, Distribution A)

$\triangle_{\%AMVres}$ = Percentage change in $2N_{\%}$ due to ‘AMV Res.’ trait (Table 1, Distribution B)

$\triangle_{\%SS}$ = Percentage change in $2N_{\%}$ due to ‘SS’ trait (Table 1, Distribution C)

$2N_f$ = Trait stack multiplication factor (Table 1, Distribution D)

‘Base Case 2’ annual white clover production

Equation 6 was used to calculate the DM yield of the ‘SS’ white clover from Year 2 to Year 10. Year 1 white clover content was set at 10% of total pasture sward DM production, and subsequently sensitivity tested at 5% and 25%.

Equation 6 Calculation of ‘Novel’ white clover DM yield for Year 2 to Year 10 (t DM/ha/year) with ‘SS’ trait for ‘Base Case 2’.

$$SS_t = SS_{t-1} * (1+ SS_{\%})$$

Where;

SS_t = ‘Novel’ white clover DM production in current year with ‘SS’ trait (kg DM/ha/year)

SS_{t-1} = ‘Novel’ white clover DM production in previous year with ‘SS’ trait (kg DM/ha/year)

$SS_{\%}$ = Percentage of SS_{t-1}available in current year (Table 2, Distribution E)

Equation 7 Calculation of 'Novel' white clover DM yield for Year 2 to Year 10 (t DM/ha/year) with trait stack for 'Base Case 2'.

$$2N_t = SS^f_t * (1+\triangle_{\%AMVres}*2N_f)$$

Given that, if $SS_{\%}$ is positive;
$SS^f_t = SS^f_{t-1} * (1+ SS_{\%}*2N_f)$

If $SS_{\%}$ is negative;
$SS^f_t = SS^f_{t-1} * (1+ SS_{\%}/2N_f)$

Where;
$2N_t$ = 'Novel' white clover DM production in current year (kg DM/ha/year) with trait stack

SS^f_t = 'Novel' white clover DM production in current year with 'SS' trait, adjusted for $2N_f$ (kg DM/ha/year)

SS^f_{t-1} = 'Novel' white clover DM production in previous year with 'SS' trait, adjusted for $2N_f$ (kg DM/ha/year)

$SS_{\%}$ = Percentage of SS_{t-1} available in current year (Table 2, Distribution E)

$\triangle_{\%AMVres}$ = Percentage change in SS^f_t white clover yield due to 'AMV Res.' trait (Table 2, Distribution F)

$2N_f$ = Trait stack multiplication factor (Table 2, Distribution G)

Annual net benefits

Annual net benefits were calculated using Equation 8 for Year 1 to Year 10.

Equation 8 Calculation of annual net benefit of growing novel white clover over current white clover for Year 1 to Year 10.

$$\$_t = ((N_t-C_t)*U_{\%})*(ME_{DM}* ME_{\$}+ CP_{DM}* CP_{\$}-P_{\$}))$$

Where;
$\$_t$ = Annual net benefit of novel white clover (\$/ha/year)

N_t = Novel white clover DM production in current year (kg DM/ha/year) with trait/s

C_t = Current white clover DM production in current year (kg DM/ha/year)

$U_{\%}$ = utilisation rate (% of total DM/ha)

$ME_{\$}$ = value of 1 MJ ME pasture (see Equation 1)

ME_{DM} = the average ME value per kg DM of supplementary feed

$CP_{\$}$ = value of 1 g CP pasture (see Equation 2)

CP_{DM} = the average CP g per kg DM of supplementary feed

$P_{\$}$ = phosphorus fertiliser requirement ($ kg/DM)

Results

The mean potential net benefit was greater when traits were stacked compared to single traits for both the 'Base Case 1' high rainfall zone scenario and the 'Base Case 2' marginal white clover zone scenario, when using the acquisition value technique as a one hectare improvement. All scenarios returned positive mean NPV's as shown in Table 4 and Table 5.

The variability of NPV increased with increasing mean NPV. A single trait improvement returned a mean annuity of value of extra ME and CP of approximately $174/ha/yr over the 10 year life of the pasture, with 68% of annuities calculated falling within $82 of this mean for 'Base Case 1'. Comparatively, the trait stack option returned a mean annuity value of additional ME and CP of approximately $543/ha/yr for the 10 year period with a standard deviation of $275. The 'SS' trait alone returned a mean annuity value of $218/ha/yr for the 10 year period with a standard deviation of $67 for the 'Base Case 2' scenario. The 'Base Case 2' trait stack had an increased mean annuity value of $256/ha/yr for the 10 year period with a standard deviation of $85 compared to the 'SS' single trait improvement.

Sensitivity testing indicated that the discount rate used to estimate NPV did not affect the ranking of the scenarios tested, with mean NPV figures remaining positive at the highest discount rate tested of 20%. Sensitivity testing of the Year 1 white clover content had a substantial effect on the NPV results. For example, the mean NPV for the 'Base Case 1' trait stack scenario decreased by 47% for a white clover content of 15%, and by 67% with a 10% white clover content, when compared to the initial Year 1 assumption of 25% of total sward DM production.

The amount the annualised establishment costs for the improved clover plants would need to increase to make the mean NPV equal 0, and hence provide no extra net benefit from growing the 'Novel' white clover, ranged from around $190-$580/ha/yr for 'Base Case 1', and $230-

$270/ha/yr for 'Base Case 2', depending on the trait scenario being considered. This suggests there are substantial net benefits available to be shared between suppliers and users of the genetically improved plants. The complete results are shown in Table 6.

The assumptions about the pasture utilisation have a large impact on the NPV estimated, and the variability of NPV, for both systems as shown in Figure 1 and Figure 2.

Discussion

The mean net benefit and risk from deploying the 'AMV Res.' and 'SS' trait improvements in white clover have been estimated. The method outlined in this paper allows risk and return to be estimated, and sensitivity testing of key parameters. Decisions about investing in plant development, and adopting innovative pasture plants on farms, have great uncertainty surrounding the success of the scientific processes and the performance of the plants in managed mixed pastures and farm systems (Graff *et al.* 2010). The acquisition value technique provides an initial indication of the potential net benefits the trait improvement scenarios in white clover. The use of the market price to value pasture provides the maximum potential value of the additional ME and CP produced (Hardin and Johnson 1955).

The net benefits of 'Novel' white clover provide an initial indication of the maximum potential net benefit of trait improvements, with all scenarios investigated returning positive NPV. The higher the estimated mean potential net benefit, the greater the variability of potential net benefit for both 'Base Case 1' and 'Base Case 2'. This increase in variability is consistent with economic theory regarding concomitant increasing risk and return (Hardaker 2004; Malcolm *et al.* 2005). Based on this analysis there appears to be considerable scope for changes in establishment costs per hectare before 'Novel' white clover returns zero net benefit; benefits which will be shared between suppliers of the genetic material and the farmer users of it.

The assumptions about Year 1 white clover content and DM utilisation substantially affect the NPV of the investment. For example, the mean return for 'Base Case 1' have the potential to vary by over $300/ha/yr depending on how much of the extra 'Novel' white clover DM is used. If additional costs are required for the establishment of 'Novel' white clover, the expected utilisation will also affect whether the investment is likely to remain profitable. The results of the sensitivity analysis have highlighted the importance of the Year 1 white clover percentage and utilisation parameters in the estimated NPV results. This is valuable information for future whole farm economic analysis of the trait improvements in white clover and will assist in allocating research resources.

All potential net benefit results are a direct product of the 'what if' assumptions used. The annual net benefit and risk estimates are suggestive of potential. Real-world factors, both technical and economic, plant and system, will rein in the size of these estimates of net benefits (Hardin and Johnson 1955; Dillon and Burley 1961; Davidson and Martin 1965). The results, however, suggest further, more detailed investigation is warranted. For instance, precise timing of supply of extra DM has implications for its value in farm systems. The next stage will require detailed whole farm system analysis to obtain improved estimates of the net benefits from including the 'Novel' white clover in farm systems.

For 'Base Case 1', located in a dairying region, further considerations include, but are not limited to, the following: the impact of additional white clover on the ryegrass proportion of the sward (Chapman *et al.* 1996) and the implications for biological N fixation (Care 1996; Ledgard *et al.* 2001; Denny and Guy 2009; Panter *et al.* 2012). Trait-specific considerations include the nature of the spread and decay caused by the AMV over time (McKirdy and Jones 1995, 1997; Denny and Guy 2009; Panter *et al.* 2012), and the impact of 'SS' on the seasonal nutritive value of white clover. Performance of novel plants in pastures over a range of seasonal conditions over time is critical to the true net benefits and risks of such innovations. Other impacts to the dairy system that may result from introducing the 'Novel' white clover include changes in grazing rotation to maximize 'Novel' white clover DM production, DM intake, milk production and composition, and altered supplementary feed strategies as a result of increased white clover content in the diet. Fertiliser requirements may also be influenced by potentially increased N fixation in the system.

It was assumed that 'Base Case 2' was located in the marginal white clover zone of south west Victoria. This raises questions regarding the appropriateness of the analysis approach because white clover does not currently persist in mixed pastures in this region. There was an optimistic assumption made that the 'Novel' white clover DM was produced in addition to the current DM production of the perennial ryegrass-subterranean clover mixed pasture sward. Further investigation is required to understand how the introduction of 'Novel' white clover is likely to have an impact on the dynamics of mixed pasture swards in this region. It may also be appropriate to consider these two traits in an alternative perennial legume, more suited to the environment of 'Base Case 2'.

There are likely to be within-year benefits from including white clover in the 'Base Case 2' pasture system. White clover is a perennial species, and has the ability to respond to summer rainfall and extend the growing season compared to the annual subterranean clover of the 'Base Case 2' pasture (Ward 1991). If this situation occurs, there are likely to be adjustments to the nutritive value of the sward throughout the year, changing the feed supply curve of the farm system. As a result, opportunities for small adjustments to the system on a seasonal basis may occur such as shifts in the pattern of supplementary feeding. Larger decisions for the farm system including lambing time and turn-off practices are also likely to be influenced. These changes to the seasonal pasture supply curve within year may provide significant benefit to prime lamb producers.

Both traits investigated in this analysis are stress-alleviating traits such that the benefits of the traits are only realised when summer stress conditions prevail, or when the AMV virus is present in the pasture sward. It will be important for future whole farm work to consider the physical distribution and impact of these stresses when valuing the trait improvements (Shakya *et al.* 2012).

Using farm economic ways of thinking about molecular breeding programs can inform the investment decisions about prioritisation of traits deployed and also assist in determining required trait efficiencies. The analysis provides an initial indication of the maximum potential net benefits of two trait improvements in white clover; both individually and as a trait stack. The results provide information that is useful for investment decision making in an environment of scarce data and great uncertainty, and highlight key factors to focus on in future, using whole farm analysis. The whole farm approach is the only analytical framework available to capture comprehensively the impacts on the complexity of the farm system of introducing 'Novel' white clover (Malcolm *et al.* 2005).

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Table 1

Summary of the probability distributions used for 'Base Case 1'. The 2nd percentile (P2), the median (P50) and the 98th percentile (P98) for each continuous skewed distribution are described, and the minimum (Min) and maximum (Max) values for each Uniform distribution. Distribution type (W) = Weibull, (U) = Uniform, (G) = Gamma.

Dist.	Dist. Description (type)	P2 / Min	P50	P98 / Max
'Current' white clover production				
A	White clover annual DM yield for Year 2 to Year 10 (% of previous year) (W)	15	- 25	- 65
'Novel' white clover production				
B	Change in 'Distribution A' due to 'AMV Res.' (%) (U)	10	20	40
C	Change in 'Distribution A' due to 'SS' (%) (U)	10	30	60
D	Trait stack multiplication factor (of individual trait effects) (U)	0.8	1.0	1.2

Table 2

Summary of the probability distributions used for 'Base Case 2'. The 2nd percentile (P2), the median (P50) and the 98th percentile (P98) for each continuous skewed distribution are described, and the minimum (Min) and maximum (Max) values for each Uniform distribution. Distribution type (W) = Weibull, (U) = Uniform, (G) = Gamma.

Dist.	Dist. Description (type)	P2 / Min	P50	P98 / Max
'Novel' white clover production				
E	White clover with 'SS' annual DM yield for Year 2 to Year 10 (% of previous year) (W)	15	- 25	- 65
F	Change in 'SS' annual DM yield due to 'AMV Res.' (%) (U)	10	20	40
G	Trait stack multiplication factor (of individual trait effects) (U)	0.8	1.0	1.2

Table 3

Summary of the price probability distributions used. The 2nd percentile (P2), the median (P50) and the 98th percentile (P98) for each continuous skewed distribution are described, and the minimum (Min) and maximum (Max) values for each Uniform distribution. Distribution type (W) = Weibull, (U) = Uniform, (G) = Gamma.

Dist.	Dist. Description (type)	P2 / Min	P50	P98 / Max
H	Feed barley price - $/t as fed ($/t DM) (G)	165 (183)	280 (311)	480 (533)
I	Canola meal price - $/t as fed ($/t DM) (G)	265 (294)	390 (433)	580 (644)
J	Lupin prices - $/t as fed ($/t DM) (W)	172 (191)	258 (287)	384 (427)

Table 4

Mean annuity of NPV after tax for the 10 year period ($/ one ha) (± standard deviation) replacement value for each trait option for 'Base Case 1'. The static values for each parameter are highlighted in **bold** i.e. when Year 1 white clover yield was sensitivity tested the discount rate was set at 10%.

	Value	'AMV Res.'	'SS'	'SS' + 'AMV'
Discount rate (% real)	5	216 (186)	332 (186)	688 (353)
	10	174 (82)	266 (147)	543 (275)
	20	180 (99)	180 (99)	360 (179)
Year 1 current white clover content (%) (t DM/ha)	10	58 (27)	88 (49)	181 (92)
	15	92 (44)	141 (78)	287 (146)
	25	174 (82)	266 (147)	543 (275)

Table 5

Mean annuity of NPV after tax for the 10 year period ($/ one ha) (± standard deviation) replacement value for each trait option for 'Base Case 2'. The static values for each parameter are highlighted in **bold** i.e. when Year 1 white clover yield was sensitivity tested the discount rate was set at 10%.

	Value	'AMV Res.'	'SS'	'SS' + 'AMV'
Discount rate (% real)	5	-	240 (78)	284 (99)
	10	**-**	218 (67)	256 (85)
	20	-	187 (53)	217 (66)
Year 1 'SS' white clover content (%) (t DM/ha)	5	-	109 (34)	128 (42)
	10		218 (67)	256 (85)
	25	**-**	655 (202)	769 (255)

Table 6

Extra establishment cost for no benefit from trait improvements (ie. to return a mean NPV equivalent to $0). Results are presented as the extra annualised establishment cost occurring in each year of the 10 years, or alternatively, as the equivalent present day single lump sum extra establishment cost.

	'AMV Res.'	'SS'	'SS' + 'AMV'
Base Case 1			
Extra annualised establishment cost for 10 years ($/one ha/year)	186	285	582
Extra lump sum establishment cost ($/one ha)	1143	1751	3576
Base Case 2			
Extra annualised establishment cost for 10 years ($/one ha/year)	-	233	273
Extra lump sum establishment cost ($/one ha)		1432	1677

Figure 1

Mean and key percentiles for annuity of NPV at 10% real over the 10 year period for the 'AMV Res' + 'SS' trait stack option for 'Base Case 1'. Results are shown for four utilisation assumptions; 100 %, 80 %, 60 % and 40%.

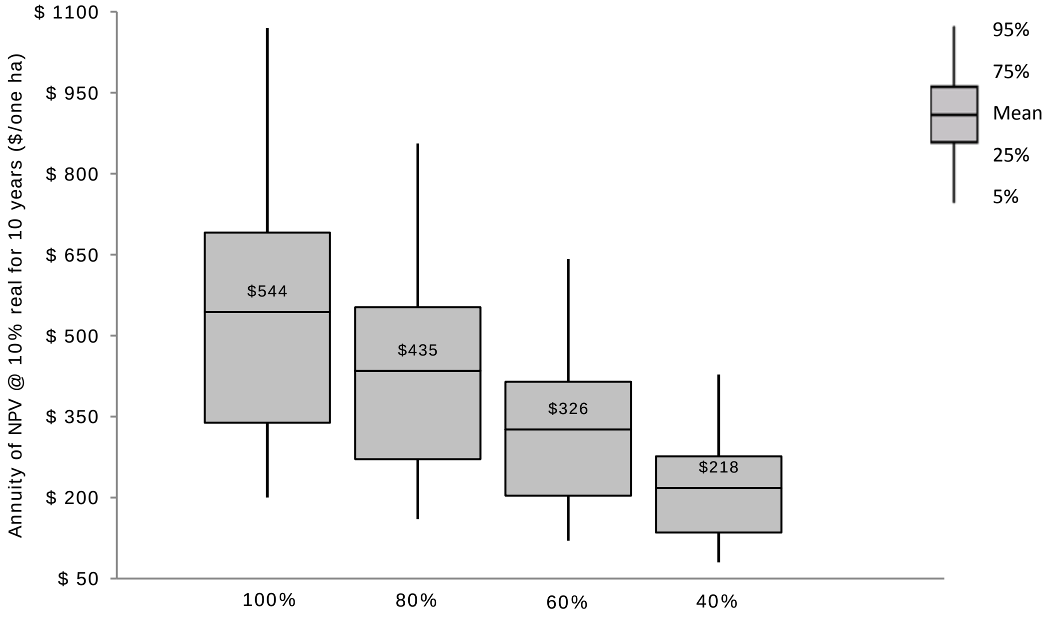

Figure 2

Mean and key percentiles for annuity of NPV at 10% real over the 10 year period for the 'AMV Res' + 'SS' trait stack option for 'Base Case 2'. Results are shown for four utilisation assumptions; 100 %, 80 %, 60 % and 40%.