Economic values of changes in energy concentration of pasture in contrasting temperate dairy regions in Australia

CI Ludemann[12], BR Cullen[1], B Malcolm[13] and KF Smith[12]
[1]Melbourne School of Land and Environment, University of Melbourne, Parkville, Vic, Australia.
[2]Dairy Futures CRC, AgriBio, Bundoora, Vic, Australia.
[3]Department of Environment and Primary Industries, Parkville, Vic, Australia.
Email: c.ludemann@student.unimelb.edu.au

Abstract

The estimated metabolisable energy (ME) concentration of pasture has a significant influence on the profit of farm systems that rely on pasture as a dietary component. However, breeders of pasture plants have traditionally focussed on improving herbage yield over nutritive characteristics or ultimately feeding value. Pasture intake from two contrasting dairy farm experiments in temperate Australia over multiple years was used to estimate the potential economic benefit of changes in the ME concentration of pasture consumed by lactating dairy cows. Barley prices were used to calculate the worth or 'replacement cost' of the ME within perennial ryegrass (*Lolium perenne* L.). The economic values for changes in ME concentration of pasture in each year of the experiments were estimated using a deterministic model. Then Monte Carlo (stochastic) simulation was conducted, incorporating distributions of changes in pasture intake, ME concentration and replacement cost of ME to derive a distribution of the economic benefits of an increase in ME concentration of pasture. The mean stochastic results of a one unit increase in ME concentration across the year for perennial ryegrass were AU$191/ha (Terang-'medium rainfall' in Victoria) and AU$459/ha (Elliott-'high rainfall' in Tasmania). In both farm experiments the largest seasonal contribution to the annual economic value was in the spring. In comparison, when economic values were estimated using changes in ME concentration achieved in experiments (1.74 MJ/kg DM higher in spring and 1.44 MJ/kg DM higher in summer), the economic values were AU$141/ha in spring and AU$74/ha in summer for Terang and AU$266/ha in spring and AU$187/ha in summer for Elliott. The economic values for changes in ME concentration of pasture provide an indication of potential feed cost savings for these farms. The savings estimated using Monte Carlo simulation for Terang was 9% of total variable costs for a one unit increase in ME concentration and 20% of total variable costs for Elliott.

The magnitude of the economic benefits that genetic improvement in the ME concentration of pasture plants could have on Australian dairy farms warrants consideration by plant breeders developing breeding programmes.

Keywords: farm profit, feeding value, high sugar, water soluble carbohydrates.

Introduction

Improvements to pasture production and utilisation through appropriate grazing management and renewal of poorly performing pasture can provide economic benefits to ruminant based farm systems that rely on pasture (Lewis *et al*. 2012). While quantity of herbage production is an important economic trait for farmers, less genetic progress has been made in traits that affect the nutritive characteristics of plants. That is, the chemical composition of plants grazed (Wheeler and Corbett 1989) which in turn could improve the quantity of product that grazing animals produce per unit of feed (feeding value)(Ulyatt 1973). Indecision over the most desirable characteristics of plants; the lack of demonstrable benefits to animal production in experiments; and the complexity of management, have all contributed to nutritive characteristics of plants receiving less attention than total dry matter yield (Lee *et al*. 2012). Unsurprisingly, the economic evaluation of grass traits has lagged behind those for livestock (DairyNZ 2011) that include a wider range of traits.

Greater interest is being directed toward traits that improve feeding value by modifying plant chemical composition. In particular the water soluble carbohydrate (WSC) component has been targeted. This can improve the estimated metabolisable energy (ME) concentration (MJ/kg DM) of herbage. A range of breeding programs for increasing WSC concentrations in perennial ryegrass (*Lolium perenne* L.) have been developed (Smith *et al*. 2007) because perennial ryegrass is a significant pasture plant species in temperate regions around the world (Bolaric *et al*. 2005). The first perennial ryegrass varieties bred in the United Kingdom for high WSC concentration used germplasm from around Europe (Humphreys 1989a, b, c; Smith *et al*. 2001). In the United Kingdom, positive production responses in ruminants fed perennial ryegrasses high in WSC were reported in dairy cattle in late lactation (Miller *et al*. 2001), and lambs (Lee *et al*. 2001).

However, there has been some inconsistency in the milk production responses to higher WSC grasses (Miller *et al*. 2001; Moorby *et al*. 2006; Cosgrove *et al*. 2007).

An important goal for efforts to improve genetics of pasture species is to improve farm profit (Chapman *et al*. 2012). Estimating the economic implications of various genetic improvements informs decisions about traits of economic concern and plants to select for improvement. Pasture species will differ in the performance of traits, yet the effect of these differences on farm profit is seldom analysed (Chapman *et al*. 2012).

Valuing grown pasture

The economic value of unit changes in pasture traits can be estimated without experimental data. The development of selection indices for animal breeding programmes are an example where modelling is used extensively to assess the likely economic consequences of changes in (animal) traits, eg. Amer and Fox (1992). In the absence of comprehensive experimental data, the marginal value product (MVP) of additional pasture can only be estimated within a range of values. This range was suggested by Johnson and Hardin (1955) as being higher than the net price obtained by disposing of the pasture off-farm (disposal value) and below the cost of achieving the same animal production through a non-pasture source (replacement cost).

The disposal value of pasture can be estimated based on the payment a farmer could obtain for selling grazing on the property. Alternatively, the value of pasture can be estimated using the payment a farmer might receive from selling pasture as standing hay or silage (Johnson and Hardin 1955). Valuing pasture using the replacement cost can be estimated using a range of substitute sources of feed that are equivalent in nutrient value, contributing the same animal production, as the pasture being valued. Logically the value of pasture cannot exceed the cost of obtaining the same production through alternative means. If this was the case, to maximise farm profit, the alternative feed source to pasture would be used instead of the pasture (Johnson and Hardin 1955).

The dairy industry in Australia depends highly on temperate pasture species as the major source of ME for milk production. Energy is generally the most limiting nutrient for Australian dairy cows during lactation (Cosgrove *et al*. 2007). Therefore dairy producers and consumers could benefit from adopting genetic improvement in temperate pasture species that improves the ME concentration of such species.

The replacement cost of utilisable ME can be used as one estimate of the MVP of an additional unit of pasture. Replacement cost could include the cost of obtaining utilisable ME on another farm through grazing (with the cost of animal delivery taken into account). Otherwise, the replacement cost could be estimated using the cost of utilisable ME from purchased hay, silage, grains or concentrates. In sum, where ME is the most limiting nutrient on a farm, the MVP of additional pasture will be a value in between the disposal value and replacement cost of utilisable ME.

In this study the potential economic values for changes in ME concentration of pasture is based on the replacement cost method. Data is used from a breeding program designed to develop perennial ryegrass plants with a greater concentration of WSC (referred to as 'high-energy ryegrass' herein) and two dairy research farm experiments (in temperate Australia) to provide context to this method of economic analysis.

Method

Approach

Data from two contrasting environments in temperate Australia were used to estimate the economic value of changes in ME concentration of perennial ryegrass consumed by dairy cows. These were the medium rainfall region of Terang, in south-west Victoria and the high rainfall region of Elliott, in northern Tasmania. The historic (1896-2011) mean annual rainfall for Terang for instance was 788mm compared to 1192mm for Elliott (data from 1915-2010) (Bureau of Meteorology 2011). Perennial ryegrass intake was limited to home-grown sources as either forage or silage. The replacement cost, method of benefit cost analysis (Sinden and Thampapillai 1995) was used to estimate the economic value of having more ME available on the farm through an increase in the concentration of ME in perennial ryegrass.

The value of pasture energy as hay or silage could be used as a proxy for the replacement cost of pasture energy. However, reliable data for hay and silage sales were limited. Furthermore, it is likely barley would have less variability in prices across regions and time. Barley makes up the majority of non-pasture based feed allocated to dairy cows in Australia (Coates *et al.* 2009). Therefore the price paid for ME in feed grains in the economy was used as a proxy for the value of ME for livestock regardless of the form in which that ME was delivered. Feed barley prices in AU$ per utilised megajoule of ME (MJ/kg DM) were used as an estimate of the cost of replacing ME derived from additional pasture energy.

In valuing the improved pasture species, the increase in concentration of ME in an improved perennial ryegrass was assumed to have no adverse effects on dry matter yield, pasture survival, or rumen function of dairy cows. Currently, data is lacking to support these simplistic assumptions, but experimentation by the Dairy Futures Cooperative Research Centre is being performed. It was also assumed there would be no additional costs incurred when the high-energy ryegrasses were grown as a full pasture seed mix instead of a 'standard' perennial ryegrass variety. No time-lag effects of adopting this technology were taken into account.

For each year of the two farm experiments deterministic economic values for changes in pasture ME were calculated. Then stochastic economic values using a Monte Carlo simulation was conducted using historic data including: perennial ryegrass intake per month (as forage and as silage); the change in energy concentration; and the equivalent value of barley energy. The @RISK program, version 6.1.1 (Palisade Corporation, Ithaca, NY, USA) was used to perform the Monte Carlo simulation.

Data

Six years (2005-2011) of 'Project 3030' 'Ryegrass Max' experimental data at the dryland DemoDairy site (S38°.24' E142 °.92') was used for Terang (Chapman *et al*. 2013). From June 2005 until April 2009 the 'Ryegrass Max' experiment consisted of 36 June-calving dairy cows grazing 16 ha of land. From May 2009 until March 2011 the same number of dairy cows was grazed in the experiment, except only 13.8 ha of grazing area was used, and calving was three weeks earlier.

Data from August 2003 until July 2007 was used from the Elliott farm irrigation experiment. This experiment was conducted by the Tasmanian Institute of Agriculture Dairy Centre, located at S41 °.08' E145 °.77' (TasDairy 2012). Over the four years of the Elliott irrigation experiment, 70 July-calving dairy cows were managed on 16 irrigated hectares.

In both experiments, stocking rates, pasture cover (in kg DM on offer per hectare), and protein and fat production were recorded. Total feed intake of cows was separated into grass consumed as forage and silage, and other sources of feed such as purchased hay, concentrates, or high quality lucerne hay. It was assumed pasture intake in the experiments was composed entirely of perennial ryegrass. These absolute pasture intake values were used for the deterministic economic values.

For each experiment, frequency distributions were derived for monthly pasture and silage intake values. Pearson's chi-squared test was used to determine the most appropriate distribution to fit each month's pasture intake distribution over the range of years available from the trials. A lower limit of 0 kg DM feed intake·ha^{-1} was assumed when fitting the distributions. These pasture intake distributions were used to estimate the stochastic economic values.

Cost of grain

For the deterministic economic values, the monthly feed barley prices (Table 1) were used as an estimate of the value of additional ME that would be available in the farm system if an improved perennial ryegrass with a trait for increased ME was grown. Prices for bulk feed barley ranged from $AU239 to AU$267·tonne^{-1} in Victoria and from $AU246 to AU$280·tonne^{-1} in Tasmania in the years of the experiments. For the stochastic estimation of economic values, the mean and standard deviation of the monthly barley prices for Victoria and Tasmania were used.

Conversion of the market price of barley into a cost per unit of utilized energy was calculated as follows:

$$\mathrm{B\$} = \frac{(\mathrm{MPB} + \mathrm{ABE})}{1000\mathrm{kg\_tonne}^{-1} \cdot \mathrm{Prop}_{\mathrm{DM}} \cdot \mathrm{EC} \cdot \mathrm{Prop}_{\mathrm{U}}} \quad [1]$$

where $\mathrm{B\$}$ is the cost of utilisable barley energy in Australian dollars per megajoule of ME (in AU$·MJME^{-1}); MPB is the market price of barley, in AU$·t^{-1} fresh weight; ABE is any additional barley expenses such as transport, repairs and maintenance on feeding equipment or any additional cost of labour for feeding out, in AU$·t^{-1} fresh weight; $1000\mathrm{kg\_tonne}^{-1}$ represents the kilogram to tonne conversion factor; $\mathrm{Prop}_{\mathrm{DM}}$ is the barley DM as a proportion of fresh weight (0.12); EC is the ME concentration of barley (12.5 MJ·kg DM^{-1}); and $\mathrm{Prop}_{\mathrm{U}}$ is the proportion of barley grain utilised by dairy cows (0.95). Equation 1 was used to convert the price of barley fresh weight into a cost per unit of utilised ME. This followed the premise made by McEvoy *et al*. (2011) that additional ME from perennial ryegrass can be substituted for other types of feed if done on an equivalent energy basis. The cost of barley in $AU·t^{-1} fresh weight was converted into a $AU·MJ^{-1} utilised by dairy cattle value (B$) for use in Equation 2.

The economic value calculation

The economic value for high-energy ryegrass ($\mathrm{HE\_EV}$) was calculated using:

$$\mathrm{HE\_EV} = \sum_{i=1}^{12} \mathrm{Month_i}\left(\left(\mathrm{DMI_P} + \mathrm{DMI_S}\right)\cdot \Delta\mathrm{E} \cdot \mathrm{B\$}\right) \quad [2]$$

where $\mathrm{HE\_EV}$ was in AU$·ha^{-1}, $\mathrm{Month_i}$ is the first month of the year; $\mathrm{DMI_P}$ is the dry matter intake of pasture, in kg dry matter per hectare per month; $\mathrm{DMI_S}$ is the dry matter intake for silage, in kg DM·ha·month^{-1}; and $\Delta\mathrm{E}$ is the change in ME concentration of perennial ryegrass, in MJ·kg DM^{-1} in each month.

The economic value for high-energy ryegrass across the lactation period was the sum of the monthly benefits. Farm benefits were calculated at the time when high-energy ryegrass forage or silage was consumed. An implication of this was that the benefits of improved ME concentration in silage were transferred from the time it was cut to the time it was consumed by dairy cows. The majority of silage in the experiment was consumed in the year it was made. This limits the transfer of benefits from changes in ME concentration of silage between years. Economic values were estimated for summer, autumn, winter and spring.

Scenarios

Five scenarios of an improved pasture for each experimental site were simulated. For Terang (T), this included 'TA', 'T0.5', 'T1.0', 'T1.5' and 'T2.0'. For Elliott (E) this included 'EA', 'E0.5', 'E1.0', 'E1.5' and 'E2.0'. The 'TA' and 'EA' scenarios represented changes made to the ME concentration in pasture in relation to values measured in actual field experiments. Experimental data were based on the difference in ME concentration between high-energy ryegrasses developed by the Dairy Futures Cooperative Research Centre and that of 'control' event plants with no selection for higher WSC concentration (Badenhorst, P. personal communication). The field experiments were located near Hamilton in south-west Victoria (S 37^{o} 49' E 142^{o} 04'). The high-energy ryegrass 'event' plants were on average 1.74 MJ·kg DM^{-1} higher in November and 1.44 MJ·kg DM^{-1} higher in February compared to the control plants. The standard error for the difference in ME concentrations in November was 0.26 MJ·kg DM^{-1} and for February was 0.53 MJ·kg DM^{-1}. Data of changes in ME concentration for November were used as an approximation for the improvement in ME concentration through genetic technology for the three months of spring. Data for February were used as an approximation for changes that would occur in the summer months. Experimental data were obtained from a site within 120 km of the Terang research experiment. The plant experiment was assumed to provide an adequate representation of what could happen at Terang. No equivalent field experimental data were available in Tasmania, so the Hamilton plant experimental values were also used for the EA scenario.

Scenarios for arbitrary differences in ME concentrations of pastures and their economic values were also simulated, including a 0.5, 1.0, 1.5 and 2.0 MJ·kg DM^{-1} change in ME concentration. The numbers in the titles of the scenario abbreviations indicate the arbitrary change in ME concentration of perennial ryegrass consumed across the whole year. No monthly variations to the change in ME concentration were made for the 'arbitrary' scenarios.

A further assumption was made that high-energy ryegrasses would produce the same marginal increase in ME concentration in grass consumed as silage as would be the case for ME consumed as forage. This assumption is based on high-energy grasses maintaining higher WSC concentrations compared to standard ryegrasses throughout the ensilage process (Davies *et al*. 2002; Merry *et al*. 2006).

Deterministic economic values for higher-energy pasture were estimated using the data from each year of the experiments. Stochastic economic values were estimated using distributions of pasture supply and barley costs from the six years of Project 3030 data from Terang and four years of Elliott data over 10,000 iterations of a Monte Carlo simulation.

Finally, the stochastic economic values were compared against the average total variable costs of producing milk in the regions the Terang (south-west Victoria) and Elliott (Tasmania) research farms were located (Red Sky Agricultural Pty Ltd 2012). Total variable costs included the following expenditure categories in the Red Sky benchmarking database: animal health; animal breeding and herd testing; dairy shed expenses; feeds/supplements, fertiliser, irrigation; repairs and maintenance, 10% of total standing charges (rates, insurance and levies) were directly attributable to the cows; vehicle expenses; and casual wages that were assumed to be 20% of the total labour expenditure. This was so that the proportionate change in costs of producing milk with the high-energy ryegrass could be related to the total costs of producing milk without this technology. The economic values on a per hectare basis were converted to an AU$ per litre of milk basis by dividing the per hectare economic value by the units of milk produced per hectare in each experiment. Then the economic values per unit of milk were related to the total variable costs per unit of milk to indicate what effect the unit changes in ME concentration could have on the cost structure of these experiments.

Results

Perennial ryegrass intake

A 1060 kg DM·ha·month^{-1} range in mean forage intakes at Terang was calculated following the Monte Carlo simulation (Table 2). October had the greatest forage intake (1060 kg DM·ha·month^{-1}) and April the least intake with 0 kg DM·ha·month^{-1}. A mean total forage intake of 6620 kg DM per annum was simulated across all months. There was a 1875 kg DM·ha^{-1} per annum standard deviation for Terang total annual forage intake, giving a coefficient of variation (CV%) of 28.3% for annual forage intake.

There was a 299 kg DM·ha·month^{-1} range in mean silage intakes at Terang with the greatest silage intake occurring in February and the least in April. A mean total silage intake of 1203 kg DM per annum was simulated across all months (Table 3).

There was a 1777 kg DM·ha·month^{-1} range in mean forage intakes for Elliott (Table 4). The greatest forage intake occurred in October and the least in July. Annual total forage intake at Elliott was 15434 kg DM·ha·month^{-1} as the mean. The standard deviation for total annual forage intake was 2763 kg DM·ha^{-1} for Elliott, giving a lower CV% than Terang of 18%.

A 445 kg DM·ha·month^{-1} range in mean silage intake was calculated for Elliott. The greatest silage intake was 445 kg DM·ha·month^{-1} in May, while October had no recorded silage intake (Table 5). Mean total annual silage intake was 1366 kg DM·ha^{-1} for Elliott. The standard deviation for total annual silage intake was 939 kg DM·ha^{-1}.

Deterministic economic values

The economic values of changes in ME concentration of pasture using historic data from the two experiments are shown in Table 6. The scenarios with changes in pasture ME concentration had mean economic values across all years of AU$223 for TA and AU$467 for EA. The CV% across years for the TA scenario was 33% and for the EA scenario was 29%. The CV% of the mean economic values across years for scenarios across the range of arbitrary changes in pasture ME concentration (0.5 to 2.0 ME) in Terang was 33% and for Elliott was 23%. Economic values were greater for scenarios with greater changes in pasture ME. For Terang, there was an AU$206·ha^{-1} increase in economic value for every 1 ME increase in pasture ME concentration. For the Elliott experiment, there was an AU$476·ha^{-1} increase in economic value for a 1 ME increase in pasture ME concentration. In the two year period from 2005 to 2007 when there was an overlap in experimental data available from both sites, the economic values per hectare for arbitrary changes in energy concentration at Terang were 28% that of Elliott. This compared to 43% when using the mean values across all years.

Stochastic seasonal economic values

Economic values (by season and per annum) following Monte Carlo simulation for scenarios with changes to ME concentration of pasture intake are shown in Table 7 for Terang and Elliott. Summer and autumn made the greatest contributions to the annual economic value of the high-energy trait when arbitrary changes to ME concentration were made year round. For Terang, in the scenario where actual plant trial changes in ME concentration were used (TA) 66% of the AU$215·ha^{-1} annual economic value came from spring and 34% from summer. In scenarios where arbitrary unit changes were made across the whole year (T0.5-T2.0) the contribution from spring at Terang was estimated as 43% compared to 27% from summer and 26% from winter.

In Elliott, 59% of the AU$453·ha^{-1} annual economic value came from spring and 41% from summer in the EA scenario. Where arbitrary unit changes across the year were made, spring contributed 33%, summer 28% and autumn 26% to the annual economic values.

Stochastic economic values in relation to total variable costs

The economic values for changes in ME concentration of pasture were compared with total variable costs of milk production and variability across 10,000 iterations of Monte Carlo simulation. Mean total variable costs for the south-west Victoria region (Table 8) between 2005 and 2011 was $AU0.13·L milk^{-1}. The economic value of a 1 MJME·kg DM^{-1} increase in ME concentration in Terang pasture was $AU0.01·L milk^{-1}. The economic value was therefore 0.09 proportion of total variable costs per litre of milk and 0.01 when actual plant trial changes in ME concentration were used. The CV% for the economic value of a one unit increase in ME concentration in Terang was 17% and 23% for the changes in plant ME concentration based on actual experimental data (TA).

Total variable costs in the Tasmania region (Table 9) were on average $AU0.11·L milk^{-1} for the period from 2003 to 2007. There was an economic value of AU$0.022·L milk^{-1} over the same period for a 1 MJME·kg DM^{-1} increase in ME concentration of pasture at Elliott. For actual experimental increases in ME concentration (EA), the economic value was slightly lower with AU$0.0217·L milk^{-1}. This meant the economic value of a unit increase in ME concentration was 0.20 as a proportion of total variable costs and plant trial increases in energy concentration were 0.197 as a proportion of total variable costs. The CV% for the economic value of a unit increase in ME concentration of pasture at Elliott was 9.10%. The CV% for the economic value of changes in ME concentration from experimental data at Elliott was 18.4%.

Discussion

In our study the economic value of high-energy ryegrass was estimated by isolating two main variables, pasture intake per hectare and grain prices. The Monte Carlo simulation indicated Elliott would have $AU268·ha^{-1} greater economic values than Terang from the inclusion of a high-energy ryegrass with one unit greater ME per kg DM. Elliott has greater rainfall (~400mm *per annum*) (Bureau of Meteorology 2011) as well as irrigation which allowed higher summer pasture production, utilisation and stocking rates compared to Terang. It is unsurprising then that Elliott had significantly greater pasture intake per hectare. Consequently, the greater pasture intake per hectare in Elliott contributed to significantly greater economic values per hectare per unit change in ME concentration.

Terang had economic values for the arbitrary changes (T0.5 to T2.0) in energy concentration that were 43% that of Elliott economic values (E0.5 to E2.0) across all available years. In the period from 2005 to 2007 when there was a two year overlap in experimental data available from both sites the economic values for arbitrary changes in energy concentration at Terang were 28% that of Elliott. Part of the difference in relative economic values between the years of overlap and all available years could be attributed to the use of different barley prices from the two locations (Elliott generally had barley prices greater than those in Terang) and due to different periods of time being used.

Spring had the greatest contribution to the overall economic value of high-energy ryegrass for both farms. The stochastic results ranged from $AU162·ha^{-1} for T2.0 to $AU41·ha^{-1} for T0.5 for Terang and $AU306·ha^{-1} for E2.0 to $AU76·ha^{-1} for E0.5 for Elliott. Spring had the greatest contribution to annual economic values due to the relatively favourable soil moisture and temperature in this season which facilitated high pasture growth rates for both Terang and Elliott. This is in agreement with Chapman *et al*. (2009) who concluded that moisture and temperature were the two most important factors that affect variability in herbage dry matter. The high growth rates in the two farm trials in spring would support high intake of perennial ryegrass per cow and per hectare.

Estimates of the economic value based on the reduction in feed costs assumed no additional costs were incurred by a farmer if they chose to sow a high-energy ryegrass instead of a 'normal' perennial ryegrass. The economic value to farmers estimated in this study would for example be eroded if seed retailers introduced a price premium on the high-energy ryegrass seed.

The smallest contributor to overall economic value for Terang was extra ME from pasture in autumn. In the T1.0 scenario for instance, autumn contributed 5% to the total annual economic value. Lower soil temperatures in Terang in autumn contributed to lower pasture growth rates and hence pasture intake. Winter contributed the least to Elliott's total annual economic value in the E1.0 scenario with a contribution of 12%. Soil temperature was a limiting factor that contributed to the reduction in pasture intake in Elliott in winter with slower growth and hence lower availability of herbage DM. Therefore the seasonal economic value of increasing ME concentration is strongly related to the quantity of pasture production and consumption in each month. This follows a conclusion by Lee *et al*. (2001) that in field trial conditions measuring lamb growth, high WSC grasses did not result in higher animal live weight gain if there was low herbage yield compared to the control.

Herd management was also a major contributor to variation in monthly pasture intake and hence the relative contribution of economic value from each season. The date dairy cows were stopped milking and taken off the trial for example limited pasture intake on both trials. Although there may have been some growth in the period when cows were taken off the trial, this was left ungrazed in order to provide adequate pasture herbage for the start of the next milking season. For Terang, dairy cows typically left the trial for up to 6-7 weeks in autumn (Chapman *et al*. 2013) whereas dairy cows were taken off the trial for a similar period in winter at Elliott.

The variation in economic values for changes in plant traits between seasons shown in this study supports results by McEvoy *et al.* (2011). McEvoy *et al*. (2011) estimated the economic value of a specific pasture 'quality' trait. They modelled a change in pasture digestibility for an Irish dairy farm. A one unit decrease in digestibility of perennial ryegrass dry matter was estimated to provide a range in economic values between -€0.006·kg dry matter yield^{-1} (September) and -€0.010·kg dry matter yield^{-1} (June) for the period between May and September. This supports the notion that higher WSC grasses may contribute positively to farm profits, as higher WSC grasses tend to have greater digestibility.

An interpretation of the results from this study on data from two Australian dairy experiments is that the economic value of high-energy ryegrass may represent the benefit of savings in total feed ME costs for the farm. For instance, it could represent a saving in grain feed costs as a result of the increased ME supplied from pasture. Economic value of the unit changes in ME concentration could therefore indicate the feed cost savings of these dairy farms. If this is so, then the cost savings of a one unit change in concentration of ME in pasture was shown to be significant in relation to total variable costs, ranging from 8.9% (Terang) to 20% (Elliott) of total variable costs. These estimates calculated through Monte Carlo simulation were based on a limited number of years (4-6 years) pasture intake data. However, there was a wide range in climatic conditions within those years. This included a year of drought and another year of very wet conditions. The Monte Carlo simulation therefore had both extremes of weather events in the iterations of estimating economic values.

Results of this study support statements by a number of authors who have highlighted the positive effect increasing the concentration of ME in pasture can have on farm profit (Lee *et al*. 2003; Lewis *et al*. 2012; Miller *et al*. 2001; van Bysterveldt 2007). In terms of data from an actual farm, Van Bysterveldt (2007) reported an increase in Economic Farm Surplus (EFS) when the ME concentration of pasture at the Lincoln University dairy farm (New Zealand) increased over a period of four years. The EFS calculation used the same (NZ$4/kg) milk solid payout price across years but was otherwise based on actual farm financial information. Because the analysis was performed on actual farm financial data, factors other than the concentration of ME in pasture may have contributed to the increase in EFS·ha^{-1}. It was therefore difficult to isolate the specific factors that contributed to the NZ$996·ha^{-1} improvement in EFS over the four year period. An inability to control specific parameters is a further limitation of data from actual farms. Nevertheless, it provides an indication of the potential financial benefit possible when the ME concentration of pasture increases on a commercial temperate dairy farm.

The deterministic economic values in this study gave a 'snap-shot' of the potential benefits in two regions of Australia. In contrast, the probabilities associated with the stochastic economic values could help decision-making by highlighting the likelihood of the ME concentration trait being of benefit to farmers in the long term.

Despite using a modelling technique to estimate economic values this study did not test a range of management practices to assess their effect on the economic value of ME concentration of pasture. This is because the analysis was based on historic data. Pursuing a wider range of scenarios in field experiments can be expensive and time consuming. It can also be difficult to ensure environmental variations do not overwhelm the differences between treatments for interpretation. Models of farm systems are an alternative method to using farm experiments as they can isolate changes in a system and be run over a greater number of years. They can also deliver general results to help narrow the focus of on-farm experiments (Hart *et al*. 1998).

Farm systems with changes to management or key parameters could be simulated using models to take this study further. Models are available to simulate pasture growth (Johnson *et al*. 2003) which could be used to identify the effect of changes in key parameters or management practices over a greater number of years. This would better take into account inter-annual variability which is marked in the temperate zone of Australia (Chapman *et al.* 2009).

Conclusions

This study provides a first look at the potential economic value of changes in ME concentration of a significant temperate pasture plant species. Use of the replacement cost method provides an approximation of the potential scale of benefit of changes in ME concentration in pasture. The Monte Carlo simulations provide a useful range of possible outcomes that included extreme possibilities not taken into account when fixed assumptions are used based on historic data.

The consequent results of the simulation indicate that there is significant potential economic value for an increase in ME concentration of perennial ryegrass. The scale of the values in this estimate justifies further research be carried out that moves beyond using historic field trial data and just the one management practice during the year. More dynamic models of pasture growth and farm systems could be used. These could facilitate analysis of how changes to management and other plant traits could affect the economic value of ME concentration in pasture.

If genetic progress for increasing ME concentration of pasture is made at a time of year when dairy cow pasture intake is regularly low due to management, soil temperatures or soil moisture, this would limit the overall economic benefit to the farmer. An implication for plant breeders is that they should consider seasons to target genetic progress in traits that improve the availability of ME in order to maximise economic value to dairy farmers.

Acknowledgements

Funding by the Dairy Futures Cooperative Research Centre and the University of Melbourne is gratefully acknowledged for this study that forms part of the lead author's PhD thesis. The authors also wish to thank Mark Freeman for providing data from the Tasmanian Institute of Agricultural Research Dairy Centre and answering subsequent questions, Joe Jacobs (Department of Environment and Primary Industries, Victoria), and the referees for their comments on this manuscript.

References

Amer PR and Fox GC 1992, 'Estimation of economic weights in genetic improvement using neoclassical production theory-an alternative to rescaling', *Animal Production,* 54: 341-350.

Bolaric S, Barth S, Melchinger AE, and Posselt UK 2005, 'Molecular characteristation of genetic diversity in European germplasm of perennial ryegrass', *Euphytica*, 146: pp.39-44.

Bureau of Meteorology 2011, *'Climate data online'*, [online], available: http://www.bom.gov.au/climate/data/ [accessed 12 December 2011].

Chapman DF, Bryant JR, McMillan WH and Khaembah EN 2012, 'Economic value for evaluating pasture plant traits', *Proceedings of the New Zealand Grasslands Association*, Gore, New Zealand, 76: pp.209-216.

Chapman DF, Cullen BR, Johnson IR and Beca D 2009, 'Interannual variation in pasture growth rate in Australian and New Zealand dairy regions and its consequences for system management', *Animal Production Science*, 49(12): 1071-1079.

Chapman DF, Hill J, Tharmaraj J, Beca D, Kenny SN and Jacobs JL 2013, 'Increasing home-grown forage consumption and profit in non-irrigated dairy systems. 1. Rationale, systems design and management', *Animal Production Science* In Press.

Coates S, Phillips C, Noble C and Roche D 2009, *Dairy moving forward: A national research, development and extension strategy*, Dairy Australia, Melbourne, VIC.

Cosgrove GP, Burke JL, Death AF, Hickey MJ, Pacheco D and Lane GA 2007, 'Ryegrasses with increased water soluble carbohydrate; evaluating the potential for grazing dairy cows in New Zealand', *Proceedings of the New Zealand Grasslands Association*, Wairakei, New Zealand, 69: pp.179-185.

Dairy Australia 2012, *'Dairy farm hay and grain report'*, [online], available: http://www.dairyaustralia.com.au/Statistics-and-markets/Farm-inputs-and-costs/Hay-and-grain.aspx [accessed 17 April 2012].

DairyNZ 2011, *'News archives: a rating system for grasses'*, [online], available: http://www.dairynz.co.nz/news/pageid/2145874405 [accessed 12 January 2012].

Davies DR, Leemans DK and Merry RJ 2002, 'Improving silage quality by ensiling perennial ryegrasses high in water soluble carbohydrate content either with or without different additives', in Gechie, L. M. and Thomas C (ed.) *Proceedings of the International Silage Conference XIII* Scottish Agricultural College, Auchincruive, Ayr: pp. 386-387.

Hart RPS, Larcombe MT, Sherlock RA and Smith LA 1998, 'Optimisation techniques for a computer simulation of a pastoral dairy farm', *Computers and Electronics in Agriculture*, 19(2): 129-153.

Humphreys MO 1989a, 'Water-soluble carbohydrates in perennial ryegrass breeding. I. Genetic differences among cultivars and hybrid progeny grown as spaced plants', *Grass & Forage Science*, 44(2): 231-236.

Humphreys MO 1989b, 'Water-soluble carbohydrates in perennial ryegrass breeding. II. Cultivar and hybrid progeny performance in cut plots', *Grass & Forage Science*, 44(2): 237-244.

Humphreys MO 1989c, 'Water-soluble carbohydrates in perennial ryegrass breeding. III. Relationships with herbage production, digestibility and crude protein content', *Grass & Forage Science*, 44(4): 423-429.

Johnson JL and Hardin LS 1955, *Economics of forage evaluation*, Station Bulletin 623, Lafayette, Indiana USA: Purdue University.

Johnson IR, Lodge GM and White RE 2003, 'The sustainable grazing systems pasture model: description, philosophy and application to the SGS National Experiment', *Australian Journal of Experimental Agriculture,* 43:711-728.

Lee JM, Matthew C, Thom ER and Chapman DF 2012, 'Perennial ryegrass breeding in New Zealand: a dairy industry perspective', *Crop and Pasture Science*, 63(2): 107-127.

Lee MRF, Jones EL, Moorby JM, Humphreys MO, Theodorou MK and Scollan ND 2001, 'Production responses from lambs grazed on Lolium perenne selected for an elevated water-soluble carbohydrate concentration', *Animal Research*, 50(6): 441-449.

Lee MRF, Merry RJ, Davies DR, Moorby JM, Humphreys MO, Theodorou MK, MacRae JC and Scollan ND 2003, 'Effect of increasing availability of water-soluble carbohydrates on in vitro rumen fermentation', *Animal Feed Science and Technology*, 104(1-4): 59-70.

Lewis C, Malcolm B, Farquharson B, Leury BJ, Behrendt R and Clark S 2012, 'Economic analysis of improved perennial pasture systems', *Australian Farm Business Management Journal*, 9(2): 37-56.

McEvoy M, O'Donovan M and Shalloo L 2011, 'Development and application of an economic ranking index for perennial ryegrass cultivars', *Journal of Dairy Science*, 94(3): 1627-1639.

Merry RJ, Lee MRF, Davies DR, Dewhurst RJ, Moorby JM, Scollan ND and Theodorou MK 2006, 'Effects of high-sugar ryegrass silage and mixtures with red clover silage on ruminant digestion. 1. In vitro and in vivo studies of nitrogen utilization', *Journal of Animal Science*, 84(11): 3049-3060.

Miller LA, Moorby JM, Davies DR, Humphreys MO, Scollan ND, MacRae JC and Theodorou MK 2001, 'Increased concentration of water-soluble carbohydrate in perennial ryegrass (Lolium perenne L.): milk production from late-lactation dairy cows', *Grass & Forage Science*, 56(4): 383-394.

Moorby JM, Evans RT, Scollan ND, MacRae JC and Theodorou MK 2006, 'Increased concentration of water-soluble carbohydrate in perennial ryegrass (*Lolium perenne* L.). Evaluation in dairy cows in early lactation', *Grass and Forage Science*, 61:52-59

Red Sky Agricultural Pty Ltd 2012, *'Red Sky Farm Performance Analysis*', [online], available: http://redskyagri.com/ [accessed 7 March 2013].

Sinden JA and Thampapillai DJ 1995, *Introduction to benefit-cost analysis*, Longman Australia Pty Ltd. Melbourne, Australia, p.262.

Smith KF, Simpson RJ, Culvenor RA, Humphreys, MO, Prud'homme MP and Oram R N 2001, 'The effects of ploidy and a phenotype conferring a high water-soluble carbohydrate concentration on carbohydrate accumulation, nutritive value and morphology of perennial ryegrass (Lolium perenne L.)', *The Journal of Agricultural Science*, 136(01): 65-74.

Smith KF, Stewart A and Spangenberg G 2007, 'Breeding high energy grasses for Australia and New Zealand', *Proceedings of the New Zealand Grasslands Association*, Wairakei, New Zealand, 69: pp.173-177.

TasDairy 2012, *'TasDairy research farm at Elliott: farm reports*', [online], available: http://tasdairyprojects.com.au/TDRFfarmreports.html [accessed 24 April, 2012].

Ulyatt MJ, 1973, 'The feeding value of herbage' in Butler GM and Bailey RW (ed.) *Chemistry and Biochemistry of Herbage,* Academic Press, London UK.

van Bysterveldt A 2007, 'LUDF -A commercial farm incorporating proven science', *South Island Dairy Event,* Lincoln, New Zealand: pp. 230-241.

Wheeler JL and Corbett JL 1989, 'Criteria for breeding forages of improved feeding value: results of a Delphi survey', *Grass & Forage Science*, 44(1): 77-83.

Appendix

Table 1. Monthly feed barley prices for Victoria and Tasmania, from Dairy Australia (2012).

	Victoria barley price (AU$/tonne fresh weight, 2005-11)		Tasmania barley price (AU$/tonne fresh weight, 2003-07)	
Month	**Mean**	**Standard deviation**	**Mean**	**Standard deviation**
May	241	77	280	84
June	244	83	268	53
July	245	84	260	49
August	251	73	246	40
September	261	87	253	52
October	267	95	270	77
November	244	77	273	78
December	239	83	269	89
January	239	82	267	87
February	242	78	264	84
March	240	82	265	75
April	239	82	268	78

Table 2. Monthly forage ryegrass intake from Terang with the mean, 10th and 90th percentile values based on the best fitting distribution equations according to Pearson's chi-squared test.

	Ryegrass intake as forage (in kg DM/ha/month)			
Month	**10th percentile**	**Mean**	**90th percentile**	**Standard deviation**
May	4	39	90	39
June	100	501	902	289
July	470	751	1083	250
August	642	889	1156	202
September	705	938	1151	174
October	952	1060	1171	86
November	691	859	951	121
December	347	679	1061	286
January	88	443	797	256
February	184	330	495	124
March	73	130	195	49
April	0	0	0	0
Annual total		6620		1875

Table 3. Monthly silage intake from Terang with the mean, 10th and 90th percentile values based on the best fitting distribution equations according to Pearson's chi-squared test.

Ryegrass intake as silage (in kg DM/ha/month)				
Month	**10th percentile**	**Mean**	**90th percentile**	**Standard deviation**
May	2	18	41	18
June	1	10	23	10
July	3	28	65	28
August	2	18	40	18
September	8	73	168	73
October	1	7	16	7
November	6	61	139	60
December	20	187	431	187
January	244	279	316	28
February	60	299	538	173
March	24	224	514	224
April	0	0	0	0
Annual total		1203		826

Table 4. Monthly forage ryegrass intake from Elliott with the mean, 10th and 90th percentile values based on the best fitting distribution equations according to Pearson's chi-squared test.

Ryegrass intake as forage (in kg DM/ha/month)				
Month	**10th percentile**	**Mean**	**90th percentile**	**Standard deviation**
May	862	1039	1225	142
June	87	436	786	252
July	26	245	564	245
August	213	1064	1915	614
September	1225	1541	1875	254
October	1911	2022	2135	88
November	1565	1808	2060	193
December	1398	1745	2112	280
January	1331	1597	1874	212
February	1249	1394	1544	115
March	1123	1400	1691	222
April	961	1142	1330	145
Annual total		15434		2763

Table 5. Monthly silage intake from Elliott with the mean, 10th and 90th percentile values based on the best fitting distribution equations according to Pearson's chi-squared test.

	Ryegrass intake as silage (in kg DM / ha / month)			
Month	**10th percentile**	**Mean**	**90th percentile**	**Standard deviation**
May	186	445	754	231
June	104	253	430	133
July	1	11	26	11
August	2	19	44	19
September	9	89	205	89
October	0	0	0	0
November	3	33	76	33
December	17	163	376	163
January	7	67	155	67
February	2	20	47	20
March	9	60	132	55
April	41	206	371	19
Annual total		1366		939

Table 6. Deterministic annual economic values for Terang (T) and Elliott (E) under scenarios with actual (A) field trial, 0.5, 1.0, 1.5 and 2.0 MJME/kg DM changes in energy concentration of perennial ryegrass using actual pasture intake data from each year of production[1].

Scenario	**Annual economic value (AU$·ha^{-1}) for respective year of production**								
	03-04	**04-05**	**05-06**	**06-07**	**07-08**	**08-09**	**09-10**	**10-11**	**Mean**
TA			*144*	*223*	*353*	*235*	*157*	*226*	*223*
T0.5			*61*	*90*	*160*	*116*	*86*	*104*	*103*
T1.0			*122*	*180*	*321*	*232*	*172*	*208*	*206*
T1.5			*182*	*270*	*481*	*348*	*258*	*311*	*309*
T2.0			*243*	*360*	*641*	*464*	*345*	*415*	*411*
EA	*439*	*386*	*375*	*669*					*467*
E0.5	*223*	*196*	*215*	*318*					*238*
E1.0	*446*	*393*	*429*	*636*					*476*
E1.5	*669*	*589*	*644*	*954*					*714*
E2.0	*892*	*786*	*859*	*1272*					*952*

---

[1] A complication which must be taken into account when comparing economic values between sites is that differences in barley prices due to geography and the periods of time used (for south west Victoria it was from 2005 to 2011, and Tasmania it was from 2003 to 2007) account for some of the variation in economic values between experimental sites.

Table 7. Stochastic seasonal economic values for Terang (T) and Elliott (E) under scenarios with actual (A) field trial, 0.5, 1.0, 1.5 and 2.0 MJME/kg DM changes in energy concentration of perennial ryegrass using 10,000 iterations of Monte Carlo simulation.

	Economic value (AU$/ha)							
Scenario	**Mean spring**	**Mean summer**	**Mean autumn**	**Mean winter**	**Total annual**	**σ** [1]	**10th** [2]	**90th** [3]
TA	141	74	0	0	215	45	162	274
T0.5	41	26	5	25	95	16	75	117
T1.0	81	51	9	49	191	32	151	233
T1.5	122	77	14	74	286	49	226	350
T2.0	162	102	19	98	382	65	301	467
EA	266	187	0	0	453	76	360	555
E0.5	76	65	61	27	230	24	200	260
E1.0	153	130	122	54	459	47	400	520
E1.5	229	195	182	82	689	71	600	781
E2.0	306	260	243	109	918	94	799	1041

[1] Standard deviation of annual mean; [2] is the 10th percentile for the annual mean; [3] is the 90th percentile for the annual mean

Table 8. Key production and price assumptions used for the stochastic economic analysis of high-energy ryegrass at the Terang research farm trial

Parameter	**Season**						**Mean**	**σ of means**[1]	**10th percentile of means**[2]
	05-06	**06-07**	**07-08**	**08-09**	**09-10**	**10-11**			
South west Victoria mean milk price ($/L milk)	0.33	0.32	0.48	0.41	0.36	0.43	0.39	N/A	N/A
South west Victoria mean TVC[3] ($/L milk)	0.19	0.23	0.29	0.29	0.25	0.26	0.13	N/A	N/A
Terang milk production (kg MS/ha)[4]	1145	1338	1426	1175	1329	1416	1305	N/A	N/A
Terang milk production (L/ha)	14699	15754	16809	15880	17271	19138	16592	N/A	N/A
Economic value of 1 unit increase in energy concentration of pasture ($/L milk)	0.013	0.012	0.011	0.012	0.011	0.010	0.012	0.002	0.009
Economic value of TA[5] increase in energy concentration of pasture ($/L milk)	0.015	0.014	0.013	0.014	0.012	0.011	0.013	0.003	0.010
Proportion of TVC as the economic value of a 1 MJME·kg DM^{-1} increase in energy concentration of pasture	0.100	0.093	0.087	0.093	0.085	0.077	0.089	0.015	0.070
Proportion of TVC as the economic value of a TA[5] increase in energy concentration of pasture	0.112	0.105	0.098	0.104	0.096	0.086	0.100	0.021	0.075

[1] Standard deviation of means calculated over 10 000 iterations using Monte Carlo simulation; [2] Tenth percentile of means calculated over 10 000 iterations using Monte Carlo simulation; [3] Total variable costs; [4] Milk solids (milk fat + protein); [5] 'Terang actual' change in energy concentration of pasture as seen in plant field trials in Hamilton, Victoria (1.74 MJME/kg DM spring and 1.44 MJME/kg DM summer).

Table 9. Key production and price assumptions used for the stochastic economic analysis of high-energy ryegrass at the Elliott research farm trial

Parameter	**Season**				**Mean**	**σ of means**[1]	**10th percentile of means**[2]
	03-04	**04-05**	**05-06**	**06-07**			
Tasmania mean milk price ($/L milk)	0.28	0.33	0.35	0.35	0.33	N/A	N/A
Tasmania mean TVC[3] ($/L milk)	0.15	0.17	0.18	0.20	0.11	N/A	N/A
Elliott milk production (kg MS/ha)[4]	1624	1583	1604	1598	1602	N/A	N/A
Elliott milk production (L/ha)	21195	21417	20434	20442	20872	N/A	N/A
Economic value of 1 unit increase in energy concentration of pasture ($/L milk)	0.022	0.021	0.022	0.022	0.0220	0.002	0.019
Economic value of EA[5] increase in energy concentration of pasture ($/L milk)	0.021	0.021	0.022	0.022	0.0217	0.004	0.017
Proportion of TVC as the economic value of a 1 $\text{MJME}\cdot\text{kg DM}^{-1}$ increase in energy concentration of pasture	0.197	0.195	0.204	0.204	0.200	0.021	0.174
Proportion of TVC as the economic value of a TA[5] increase in energy concentration of pasture	0.194	0.192	0.202	0.202	0.198	0.033	0.157

[1] Standard deviation of means calculated over 10 000 iterations using Monte Carlo simulation; [2] Tenth percentile of means calculated over 10 000 iterations using Monte Carlo simulation; [3] Total variable costs; [4] Milk solids (milk fat + protein); [5] 'Elliott actual' change in energy concentration of pasture as seen in plant field trials in Hamilton, Victoria (1.74 MJME/kg DM spring and 1.44 MJME/kg DM summer).