Simple versus diverse pastures – opportunities and challenges in dairy systems

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ABSTRACT

For Australian and New Zealand dairy farms the primary source of home grown feed comes from grazed perennial pastures. The high consumption of perennial pasture is a key factor in the low cost of production of Australian and New Zealand dairy systems and hence their ability to maintain international competiveness. The major pasture species used are perennial ryegrass (*Lolium perenne* L.) and white clover (*Trifolium repens* L.), normally grown in a simple binary mixture. As pasture production has been further driven by increasing use of nitrogen fertilizer and irrigation, farms are getting closer to their economic optimum level of pasture consumption. Increasing inputs and intensification has also increased scrutiny on the environmental footprint of dairy production. Increasing the diversity of pasture species within dairy swards presents opportunities to further increase the productivity of the feedbase through additional forage production, extending the growing season, improving forage nutritive characteristics and ultimately increasing milk production per cow and/or per ha. Diverse pastures also present an opportunity to mitigate some of the environmental consequences associated with intensive pasture-based dairy systems. A consistent finding of experiments investigating diverse pastures is that their benefits are due to the attributes of the additional species, rather than increasing the number of species per se. Therefore the species that are best suited for inclusion into dairy pastures will be situation specific. Furthermore, the presence of additional species will generally require modification to the management principles of dairy pastures, particularly around nitrogen fertilizer and grazing, to ensure that the additional species remain productive and persistent.

Keywords: mixtures, monocultures, niche exploitation, forbs, herbs

INTRODUCTION

The Australian and New Zealand dairy industries produce a total of 28 billion litres of milk per year (Dairy Australia 2013; DairyNZ 2014a). Including downstream value adding, the value of the Australian industry is $13 billion, making it Australia's third largest rural industry (Dairy Australia 2013). The dairy industry is New Zealand's largest export earner with $12 billion dollars per year contributed to the New Zealand economy through the export of dairy products (DairyNZ 2014a). For both countries the supply of drinking milk and other short shelf-life products, while regionally important for some areas, is a relatively small segment of the industry. The major focus of both industries is the production and processing of milk to create long shelf-life/commodity products, i.e. milk powder, cheese and butter primarily for export (Dairy Australia 2013; DairyNZ 2014a). Ensuring a low cost of production is critical in enabling these industries to compete in a global market.

In Australia and New Zealand, the supply of feed for cows is by far the single largest component of dairy farm operational costs (ABARES 2014; DairyNZ 2014b). Consequently high consumption per ha of low cost 'home grown' feed by dairy cows is a key determining factor for dairy business success (Mitchell 1998, van Bysterveldt 2005). The low cost of production due to the efficient conversion of low cost 'home grown' forage into milk provides both countries a competitive advantage on the world dairy market (Dillon *et al.* 2005). To remain competitive in the face of rising currency values along with declining terms of trade for agriculture in general (1.6% per annum decline for Australian agriculture (Nossal and Sheng 2010)), dairy farmers are continually striving to make further efficiency gains in the production of feed and the conversion of home grown feed into milk.

Pasture grasses (namely ryegrass species, *Lolium* spp.) are the major forage source in the dairy regions New Zealand and Australia (Doyle *et al.* 2000, Holmes 2007). These species are responsive to inputs of nitrogen (N) fertilizers and supplementary irrigation. There has been increasing reliance on these inputs coupled with an increase in stocking rate to underpin profitability through increased forage consumption per ha (Mackinnon *et al.* 2010). However, intensification has brought with it environmental challenges, particularly N and phosphorus losses from farms (Monaghan *et al.* 2007). Furthermore, increasing inputs only moves the farm along the efficiency frontier rather than lifting the farm to a new level of efficiency (Bell *et al.* 2014). Farms that use increased inputs to achieve their economic optimum pasture production and utilisation face the challenge of identifying further efficiency gains for their feedbase. Making these gains (i.e. to change the efficiency frontier) will require a systems level change such as significant changes to the forage base.

In New Zealand and the southern regions of Australia, grass-legume pastures, particularly perennial ryegrass (*Lolium perenne* L.) and white clover (*Trifolium repens* L.) pastures, have a binomial supply of forage (Rawnsley *et al.* 2007). This manifests as a peak in accumulation rates in spring followed by a slowing of growth with increasing temperatures and soil water deficits (without irrigation) during summer and early autumn. If irrigation is used, pasture growth can be maintained through the summer period. In autumn, as temperatures decrease and rainfall increases, there is another smaller peak in growth rates followed by a slowing and near cessation of growth due to low winter temperatures, frosts and in some areas waterlogging. These periods of feed shortages and surpluses need to be managed (i.e. forage conservation, use of supplements) to meet animal requirements, prevent under and over grazing and ensure that the pasture base can continue to supply forage of suitable nutritive characteristics supportive of milk production. The constraints the pasture base places on the reliability of supply of a high nutritive value diet supportive of milk production has been long recognised (Jacobs and McKenzie 2003). Much research effort over the past decade has been directed at addressing this challenge through the integration of other forage species into a predominantly perennial ryegrass feedbase (Farina *et al.* 2011, Tharmaraj *et al.* 2014), or trying to improve the seasonality or total production of perennial ryegrass (Parsons *et al.* 2011, Chapman *et al.* 2014). A recent review of these activities (Rawnsley *et al.* 2013) identified that this strategy was most successful when the additional species/strategy was perennial focussed, directly grazeable and responsive to N fertilizer and irrigation inputs.

Dairy farms are highly complex systems with interactions between paddocks within the grazing rotation. Management decisions for one paddock can have consequences that flow through the entire system (Pembleton and Rawnsley 2011). The method promoted for the integration of new forage species within a dairy system has traditionally been as separate monocultures (Tharmaraj *et al.* 2014). This method of integration requires the development and management of two or more grazing platforms. While successful examples of this strategy exist (Woodward *et al.* 2008), the increased level of grazing management skills coupled with the grazing requirements of each platform periodically coming into conflict with each other, often results in the poor overall performance of at least one of the monocultures. This has limited the widespread adoption of such species.

An alternative is to add novel species to the already existing and relatively simple grass-legume binary mixture, effectively increasing the diversity in the pasture. Increasing species diversity should allow for the exploitation of specific benefits of additional species without creating additional management or input requirements. However, countering this, is a concern that increasing the diversity within a sward increases the management and inputs required to realise and maintain these benefits. This review will evaluate past research on diverse pastures as they pertain to dairy systems with an aim of exploring these two questions. In the interest of clarity we have defined diverse pastures as having three or more species components.

DRY MATTER AND ANIMAL PRODUCTION POTENTIAL OF DIVERSE VS SIMPLE PASTURES

The binomial distribution of forage dry matter (DM) production from simple binary pastures presents a challenge to maintaining high levels of milk production from a predominantly pasture-based diet (Rawnsley *et al.* 2007). Periods of over and undersupply of forage are typically addressed through forage conservation and the use of concentrate supplements. However, inefficiencies in forage conservation and feeding of conserved forage along with substitution of pasture with concentrates (Wales *et al.* 2006) means that these practices are less efficient than direct grazing and can reduce the total amount of pasture that can be consumed.

Improved pasture DM production from diverse pasture mixtures compared to simple pastures is commonly observed across a range of environments (e.g. high and low rainfall), production systems (cutting and grazing) and enterprises (dairy, beef and sheep grazing) (Dear *et al.* 2002, Tracy and Faulkner 2006, Picasso *et* *al.* 2011, Nobilly *et al.* 2013). Increasing species diversity within pastures allows each species to exploit niches. Niches could be spatial (i.e. caused by soil variation) or temporal (caused by seasonal weather patterns). Niches can also occur through one species not fully utilising a particular resource (i.e. space, water), allowing another species to exploit those resources (Sanderson *et al.* 2004). This particular form of niche exploitation may take several years to manifest (Tilman *et al.* 2001). There are also some instances where the presence of one plant improves the productivity and survival of another species (Garcia *et al.* 2007).

The design of past experiments has influenced the form of niche exploitation that have been observed. Small plots are less likely to capture spatial niche exploitation due to their scale. Furthermore, experiments with a high number of species present are more likely to identify increased productivity with increased diversity simply due to the increased chance of sampling a productive species. Termed the "sampling effect", this is a common criticism of older ecological studies investigating the increase in species diversity on plant community productivity (e.g. Huston (1997) commenting on the experiment reported by (Tilman *et al.* 1996)). There is also the issue of clipping/mowing potentially not being entirely representative of grazing by livestock in that it fails to account for either selective overgrazing as well as under grazing of specific species. Consequently the conclusions drawn from many past ecological investigations into species diversity may not be directly applicable to dairy pastures.

Recent experiments investigating the productivity of diverse and simple dairy pastures under grazing and at a scale and a level of inputs reflective of paddocks on dairy farms have identified a range of results from no increase (Woodward *et al.* 2013) to 43% increase (Sanderson *et al.* 2005) in pasture DM production. Results from Australian and New Zealand experiments suggest that in situations where a benefit will occur, it will be in the order of a 9 to 15% improvement (Table 1). However, all experiments have reported a seasonal effect on the results, either as an inter-year effect (wet versus dry years) or an intra-year effect (spring versus summer). Furthermore, there are no reports of a diverse pasture being less productive than the simple pasture to which it was compared. This DM yield benefit is an example of the exploitation of temporal niches. It is of little surprise that this form of niche exploitation is consistently observed for diverse pastures in dairy systems as the relatively small paddock sizes in dairy enterprises compared to other pastoral enterprises and the level of inputs (fertilizer, lime and irrigation water) will minimise the spatial variability present.

Interestingly, benefits in the productivity of diverse pastures in dairy systems have been observed with as little as three species (Table 1). (Sanderson *et al.* 2005) found that increasing the species diversity in cocksfoot (*Dactylis glomerata* L.) and white clover dairy pastures beyond three to either six or nine species by sequentially adding chicory (*Cichorium intybus* L.), tall fescue (*Festuca arundinacea* Schreb.), kentucky bluegrass (*Poa pratensis* L.), red clover (*Trifolium pratense* L.), birdsfoot trefoil (*Lotus corniculatus* L.), lucerne (*Medicago sativa* L.) and perennial ryegrass added little benefit in terms of annual pasture DM production. Similar results have also been recorded for beef pastures with a similar range of species (Tracy and Faulkner 2006). The identity of the plants contributing to the pasture appears to be a more important factor contributing to the increase in pasture DM yield rather than diversity itself. This is supported by the reports of New Zealand pastures containing perennial ryegrass, white clover, red clover, prairie grass (*Bromus willdenowii* Kunth), chicory, plantain (*Plantago lanceolata* L.) and lucerne (Nobilly *et al.* 2013, Woodward *et al.* 2013), south west Victorian pastures containing tall fescue, cocksfoot, white clover, red clover and chicory (Tharmaraj *et al.* 2008, 2014) and from perennial ryegrass, white clover and plantain pasture mixtures in Tasmania (K.G. Pembleton unpublished data). In all cases the increases in summer DM production were associated with increases in the proportion of deep rooted and heat tolerant species like chicory, lucerne and plantain. In associated work, Nobilly (2014) showed the effect of diversity on DM production was dependent on which species were added to pasture. Adding two grass species (prairie grass and timothy (*Phleum pratense* L.)) to a ryegrass-white clover pasture had little effect on DM yield, whereas adding additional forbs (chicory and plantain) or legumes (red clover and lucerne) increased DM yield. This was due to the adaptation of these species to summer water deficits.

Table 1: Recent examples of experiments comparing the dry matter (DM) production of simple and diverse pastures within pasture based dairy systems at the paddock level

Location	Study length (years)	Simple pasture species	No. of additional species in diverse pasture	Difference in annual DM production	Seasons improved production observed	Source
Waikato, New Zealand	3	Perennial ryegrass - white clover	4	None	Summer / autumn	(Woodward *et al.* 2013)
Canterbury plains, New Zealand	2	Perennial ryegrass - white clover	5	10% increase	Summer	(Nobilly *et al.* 2013)
North West Tas, Australia	1.5	Perennial ryegrass	2	12% increase	Summer	K.G. Pembleton Unpublished data
South West Vic, Australia	3	Perennial ryegrass - white clover	3	9% increase	Summer	(Tharmaraj *et al.* 2008)
South West Vic, Australia	3	Perennial ryegrass - white clover	2	15% increase	Summer/ Autumn	(Tharmaraj *et al.* 2014)
Pennsylvania, USA	2	Cocksfoot - white clover	1, 4 or 7	43% increase	Dry year	(Sanderson *et al.* 2005)

Increasing species diversity within a pasture is also associated with improved nutritive characteristics of the forage grown (Tharmaraj *et al.* 2008, Nobilly *et al.* 2013, Woodward *et al.* 2013), particularly lower neutral detergent fibre (NDF) concentrations and improved nutrient synchrony (Hall and Huntington 2008). However, this is an effect of the inclusion of species that have lower NDF contents or improved nutritive values (i.e. legumes and forbs), rather than an effect of the pasture diversity itself (Sanderson *et al.* 2006). (Nobilly *et al.* 2013) reported that irrigated diverse pastures had marginally lower estimated metabolisable energy (ME) than simple pastures (12.0 versus 12.2 MJ /kg DM), although the total ME produced per hectare was greater in diverse than simple pastures (202 versus 185 GJ /ha). Milk production from cows grazing diverse pasture has been observed to be greater than from cows grazing simple pastures (Totty *et al.* 2013, Woodward *et al.* 2013, K.G. Pembleton unpublished data). This has been observed across a range of levels of diversity with pastures containing from three species (perennial ryegrass, white clover and plantain) up to seven species (perennial ryegrass, white clover, tall fescue, prairie grass, chicory, plantain and lucerne). However, such increases are not consistently observed from season to season (Woodward *et al.* 2013). Evidence also exists for no increase in milk production from cows grazing a pasture containing cocksfoot, chicory, tall fescue, kentucky bluegrass, red clover, birdsfoot trefoil, lucerne and perennial ryegrass compared to cocksfoot and white clover (Soder *et al.* 2006). Importantly there are no reports of a decrease in milk production from cows grazing diverse pastures. While diverse pastures have been noted to have differences in sward structure (Sanderson *et al.* 2006), increased milk production when it has occurred, has been typically associated with a decrease in the NDF concentration of the diet associated with increasing proportions of legumes (red clover and lucerne) and forbs (chicory and plantain) (Chapman *et al.* 2008, Totty *et al.* 2013, Woodward *et al.* 2013). If diversity within the pastures allows the cows to preferentially select the best possible diet for themselves the effect would only be displayed at stocking rates/forage allocations that allow for such selection to occur. These stocking rates or allowances, that maximise production per cow, would be above those that allow for the efficient conversion of forage to milk on a per area basis. However, an examination of past experiments indicates that this is not the case (Figure 1). Experiments with forage allocations of 28 or 25 kg DM/cow/day above grazing height have noted no improvement in milk production through species diversity (Soder *et al.* 2006, Chapman *et al.* 2008) but in experiments with allocations between 20 and 16 kg DM/cow/day an increase was recorded (Totty *et al.* 2013, Woodward *et al.* 2013). This implies that under higher forage allowances, some level of dietary selection will occur which results in similar milk production between pasture options. However, at lower allowances where selection is restricted the improved nutritive value characteristics of some species in the diverse pasture leads to increases in milk production. This creates an allocation level/stocking rate and diversity interaction. Defining this interaction along with the effect of botanical composition will be important if the milk production potential from cows grazing diverse pastures is to be realised.

The incorporation of chicory, tall fescue, kentucky bluegrass, red clover, birdsfoot trefoil, lucerne and perennial ryegrass into dairy pastures containing cocksfoot and white clover has been demonstrated to change the fatty acid profile of the milk produced (Soder *et al.* 2006). (Greenwood *et al.* 2011) examined milk composition of cows fed perennial ryegrass-white clover pasture and those fed pasture also containing chicory, plantain and red clover. Inclusion of multiple plant species in a diverse pasture resulted in lower diet-derived long chain saturated fatty acids and higher amounts of linoleic and alpha-linolenic acids. In addition, there was a higher content of C4-15 fatty acids identified in the milk of cattle fed diverse pasture suggesting higher *de novo* synthesis. This has also been observed by feeding monocultures or binary pasture mixtures containing chicory (Muir *et al.* 2014). While this potential to value add milk will be important for small sub-sectors of the industry, the export commodity focus of the New Zealand and Australian dairy industries (Dairy Australia 2013; DairyNZ 2014a) is likely to limit the benefit to the industry overall in the short to medium term.

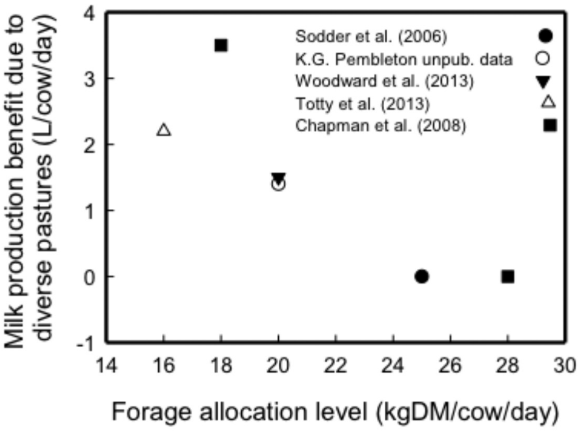

Figure 1: The increase in milk production measured in five recent experiments where dairy cows grazed diverse pastures compared to simple pastures plotted against the level of forage allocation used.

MANAGEMENT OF SIMPLE AND DIVERSE PASTURES

Increasing species diversity of a pasture involves the challenge of maintaining each additional component's presence within the pasture. Diverse pastures revert to simple grass dominant pastures over a period of three to four years (Sanderson *et al.* 2007). Repeated applications of N fertilizer has been associated with a reduction in the legume components of pasture (Bolland and Guthridge 2007). However, other reports have identified that when stocking rate was at levels that prevented competition between grasses and legumes the application of N fertilizer has a minimal effect on the persistence of legumes in pastures (Harris and Clark 1996, McKenzie *et al.* 2003). It is clear that reducing N applications favours the legume component of pastures (Turner *et al.* 2013). However, there is little comparative data on the performance of diverse and standard pastures in response to N fertilizer. (Van Rossum *et al.* 2013) compared DM production of simple grass-clover pastures and diverse pastures to N fertilizer and gibberellic acid application in autumn. The DM yield response to N fertilizer was similar for diverse and standard pastures; however the effect of gibberellic acid application was lower in diverse pastures that contained a high proportion of chicory and plantain.

Defoliation interval and intensity are also critical to maintaining the legume component in the sward with shorter defoliation intervals and lower post-defoliation residuals reducing the legume component of dairy pastures (Turner *et al.* 2013, Rawnsley *et al.* 2014). Unfortunately the grazing management requirements to optimise DM yield, persistence and nutritive value of many grasses, legumes and forbs (Sanderson *et al.* 2003, Labreveux *et al.* 2006, Turner *et al.* 2006, Lee *et al.* 2012) do not align with each other or align with perennial ryegrass and white clover. However, there are examples of some species combinations with aligning grazing management which could be components of diverse pastures (e.g. cocksfoot and lucerne: Casler (1988), cocksfoot and chicory: Parker and Kemp (1998), tall fescue and chicory: (Thamaraj *et al.* 2008)). To ensure their productivity and persistence the grazing management of diverse pastures will require compromises between the needs of each of the species present. However, it has been identified that some species may only have specific defoliation requirements at certain times of the year to ensure their persistence (e.g. lucerne, (Teixeira *et al.* 2007)). This means that grazing management could be tailored to the needs of each species during critical times of the year. Such tailoring will require an in-depth understanding of each individual species' physiology and its implementation will require skilled grazing management.

Diverse pastures based on perennial species tend to have a greater rooting depth than simple pastures (Skinner *et al.* 2006). This is most likely due to the rooting depth of species like lucerne and chicory. Species with deeper roots are better suited to deficit irrigation strategies that aim to increase the marginal water use efficiency, above what is possible with species with shallow roots (Pembleton *et al.* 2011). This benefit would be expected to translate to pasture mixtures that include these species. Furthermore, there is some evidence of diverse pastures improving the drought tolerance of shallow rooted species (Skinner *et al.* 2004) possibly via hydraulic lift or through niche separation.

Established diverse pastures in beef grazing systems in North America have considerable resilience to weed incursion compared to simpler binary pasture mixtures (Tracy and Faulkner 2006). Surveys of pastures in New Zealand have also confirmed this for beef and sheep pastures but not for the more intensively managed dairy pastures (Tozer *et al.* 2010). Similar to DM yield, resilience to weed incursion appears to be related to individual species identity rather than diversity itself (Sanderson *et al.* 2007, Soder *et al.* 2007). This is due to individual species occupying the same ecological niche as the weeds (Gitay and Noble 1997). Consequently weed incursion can still occur if such a species is absent or not able to fully compete (i.e. during establishment). Weed incursion can potentially be a challenge to the maintenance of species diversity, especially in pasture that contains the forbs plantain and chicory. While there is evidence of specific herbicides being safe for these species (Lockley and Wu 2008), few of these herbicides are registered for this purpose in either Australia or New Zealand. Conversely herbicides that are safe to use on the forbs, are damaging to other species likely to be present in a diverse pasture, particularly legumes. Recent developments in real time automated weed identification and spot spraying technology (McCarthy *et al.* 2010) in the sugar industry may provide a solution for controlling weeds in diverse pastures. Rope wick (wick wiper) applicators also have a role in the control of weed species whose upright growth habit suits this form of applicator (Moyo *et al.* 2006).

ENVIRONMENTAL CHALLENGES AND BENEFITS OF SIMPLE AND DIVERSE PASTURES

As pasture-based dairy systems intensify to improve the efficiency of home grown forage conversion into milk, the use of inputs of water and N fertilizer have increased (Mackinnon *et al.* 2010). Leaching losses of N from dairy systems (mainly from urine patches) are a concern in New Zealand (de Klein and Ledgard 2001) and Australia (Eckard *et al.* 2004) while emissions of nitrous oxide account for about a quarter of pre-farmgate greenhouse gas emissions of the dairy industry (Christie *et al.* 2011). Consequently expansion and further intensification of dairy farming, while economically attractive is being restricted due to environmental constraints. This is particularly true for the New Zealand industry.

Diverse pastures potentially offer a feedbase strategy to reduce the environmental footprint of dairy farming. Diverse pastures may reduce nitrate leaching through affecting the amount and concentration of N excreted in urine and through affecting the ability of plants to take up N from the soil once excreted in the urine patch. Initial approaches in the use of alternative plant species to reduce urinary N excretion focussed on the role of secondary plant compounds, particularly tannins in altering partitioning of N within the cow between urine and faeces. While the role of tannins has been clearly defined, they are often found in plant species (e.g. birdsfoot trefoil and *Lotus penduculatus* L.) that are poor competitors in mixtures and in addition, as legumes, are naturally high in N content. This poor competitive ability of species high in tannin content may limit the ability of the trait to be delivered in mixtures, with their use restricted to monocultures (Woodward *et al.* 2008).

In more recent work, the effect of including chicory and plantain in the diet on urinary N excretion has been examined. In a metabolism stall study, (Woodward *et al.* 2012) measured N partitioning in cows fed either perennial ryegrass-white clover forage or forage that also contained chicory, plantain and lucerne. Both urinary N concentration and urinary N output were lower (2.6 g versus 6.2 g N/L and 100 versus 200 g N/cow/day, respectively) from cows fed the diverse forage. A reduction in urinary concentration of 30 to 34% has been observed in New Zealand and Tasmanian grazing experiments (Totty *et al.* 2013, K. G. Pembleton unpublished data) with cows grazing diverse pastures containing chicory and/or plantain compared to standard ryegrass-white clover pastures. The exact reasons for the reduced concentration and amount of N excreted are unclear but it may not just reflect reduced N intake by cows (Totty *et al.* 2013). These species may also improve the nutrient synchrony of the pasture (with particular reference to the energy to N ratio), act as diuretics and with the lower DM% in these forages, water intake and hence urination may be higher. Regardless of the mechanism, the observed results represent an opportunity to increase the spread of urine patches within a pasture and in addition, lower the N concentration in each patch. The lower N concentration of urine patches should increase the amount of urinary N captured by the plants before it is leached or lost to the atmosphere (Di and Cameron 2007). Modelling the potential of diverse pastures to reduce leaching has shown a reduction in nitrate leaching at the farm scale of 11 and 19%, where 20 and 50% of the farm were sown to diverse pastures, respectively (Buekes *et al.* 2014).

Modelling has suggested that diverse pastures containing deeper rooted species have a greater potential to limit nitrate leaching (Snow *et al.* 2013). Again it was the individual species identity rather than the diversity of the pasture that was responsible for this. However, in a lysimeter based study nitrate leaching from urine patches with the same N loading was similar in perennial ryegrass-white clover pasture and pastures containing additional forbs (Malcolm *et al.* 2014). Although roots were found deeper in the soil profile in the diverse pasture, there was lower cool season growth of the chicory and plantain which limited the uptake of N from soil during winter. Mixtures based on plants species with greater cool season growth (e.g. Italian ryegrass; *Lolium multiflorum* Lam.) reduced nitrate leaching to a greater degree.

CAPTURING THE OPPORTUNITIES AND OVERCOMING THE CHALLENGES OF DIVERSE PASTURES

There are clear advantages of diverse pastures over simple binary pastures in terms of overall forage DM production, seasonal distribution of forage supply, pasture stability, nutritive value, animal production and environmental outcomes. These advantages are due to the identity of the additional pasture species rather than the diversity itself. Maintaining these additional species within the pasture will require compromises between the needs of individual species in terms of grazing management and N fertilizer use. Furthermore, efforts to control weeds can easily remove desirable species from the pasture. Maintaining diversity will require a re-evaluation and modification of the grazing, N fertilizer and weed control decision rules that are well established for simpler binary pastures (Rawnsley *et al.* 2014).

A consistent finding through past research is that the opportunities arising from diverse pastures are due to the individual species' identity rather than the diversity itself. If the addition of a single carefully selected species to the pasture mix is all that is required to achieve a benefit, diverse pastures become a much more attractive feedbase option. Adapting grazing and N management to suit a single additional species is conceptually a much simpler task than attempting to adapt management to compromise between an additional six or seven species. However, the ability of pastures based on only three species to achieve the benefits that diverse pastures offer will greatly depend on getting the initial species selection correct. Due to the interactions between climate, soil and farming system, this selection will be farm and paddock specific. However, tools are available to help guide this decision. Biophysical modelling platforms (e.g. DairyMod, APSIM) have been parameterised for many of the grass and legume species (Cullen *et al.* 2008, Li *et al.* 2011, Pembleton *et al.* 2011, Berger *et al.* 2014) that are used as components of diverse pastures. Furthermore, there are ongoing efforts in both Australia and New Zealand to expand the pasture species available in these platforms with particular focus on the forbs chicory and plantain (Figure 2). These tools could be cost effectively used to evaluate species for any given location and management, helping guide the decision of which species to combine to create diversity. As the benefits of the diversity within a pasture is due to species attributes the relative performance of the individual species throughout the year should provide a strong indication as to which species to include without the need to simulate pasture mixtures, even though both APSIM and DairyMod have this capacity (Snow *et al.* 2013).

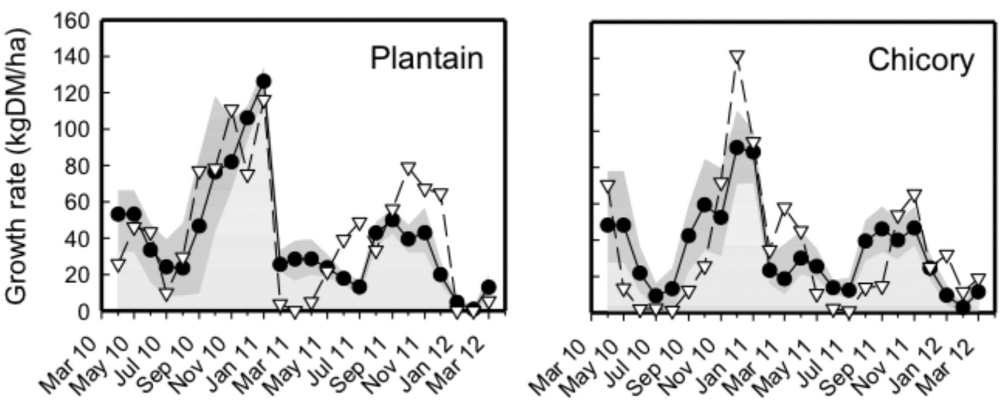

Figure 2: Comparison of modelled (△) and observed (●) mean monthly growth rates of plantain and chicory using the DairyMod biophysical model with parameters specific to these species (K.G. Pembleton Unpublished data). Observed values were drawn from experiments undertaken at Terang, Victoria (J. L. Jacobs Unpublished data). Grey areas indicate the range in observed values.

CONCLUSIONS

Diverse pastures offer opportunities to increase the productivity of pasture-based dairy systems while reducing their environmental footprint. As species identity is more important to achieving the potential advantages than diversity *per se*, capturing this opportunity will be contingent on identifying the right species to include in the diverse pasture. Diverse pastures provide both opportunities and challenges. The opportunity to achieve benefits through the addition of a single species is countered by the challenge of choosing and managing the situation-specific species. Biophysical modelling should assist in identifying the appropriate species for a given situation. Pasture management principles that have been developed for simple binary grass/ legume mixtures must be adjusted so diversity in the pasture can be maintained. This is going to require compromises between the needs of each species. Recent research has identified that species commonly included in diverse pastures might only have specific management requirements for relatively short periods of the year. Identifying these critical periods will be important in the development of management principles for diverse pastures.

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