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Review

Defining the key attributes of resilience in mixed ration dairy systems

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Abstract. Dairy feeding systems in Australia and New Zealand have seen an increase in the use of mixed rations to manage variability in climate and market conditions and enable a certain degree of resilience in the operating environment. In this review, resilience was defined as the ability of the farm system to respond to challenges, optimise productivity and profitability for a given set of circumstances, and persist over time. Specific attributes of a dairy system that contribute to resilience were considered as flexibility, consistency, adaptation, sustainability and profitability. A flexible forage base that uses water efficient forage species provides a consistent supply of nutrients from home-grown forages across the year and is a key driver of resilience. Consistent milk production from purchased concentrates adds value to the forage base and will ensure that the system is profitable in the long term. Appropriate investment in infrastructure and careful management of debt has a positive impact on technical and financial efficiency and improves overall economic performance and resilience of the system. Nutrients, feed wastage, cow comfort and welfare were also identified as key areas to focus on for improved sustainability. Future research investigating the interaction between forages and concentrates, and the subsequent milk production response will be important for the future resilience of mixed ration systems. Adaptive management at a tactical and strategic level across several technical areas will further underpin the resilience of a mixed ration dairy system, and minimise the impact of climate and price variability. This will have flow on benefits to animal welfare and resource sustainability, which will have a positive impact of the public perception of these systems within the Australian and New Zealand dairy industries.

Additional keywords: flexible forage base, management, mixed ration feeding systems, production responses, profitable, resilience.

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Introduction

The use of mixed ration systems has increased in Australia and New Zealand over the past 10 years (Wales and Kolver 2017), primarily because of increased variability in rainfall and irrigation water availability and cost (Wales *et al*. 2013; Ho *et al*. 2015). Hence, feeding systems have changed to a forage base that is more water efficient, higher yielding and often lower in some quality parameters than temperate pastures (Neal *et al*. 2011*a*, 2011*b*, Rogers *et al*. 2017). Market forces have also played a role in the shift in feeding systems, with the increase in demand for domestic supply from milk processors, particularly in Australia, driving a requirement for flat-line and year-round production to meet domestic supply requirements. This has resulted in milk being produced at times of the year when the pasture base is limited in growth and quality, and conserved forages, concentrates and mixed rations are used to fill the gap, usually at a higher cost of production (García and Fulkerson 2005; Neal *et al*. 2007). Both partial mixed ration (PMR) and total mixed ration (TMR) systems have been implemented on farms in Australia and New Zealand over the past 10 years (Wales and Kolver 2017), as a way of managing this climate and market variability. To ensure longevity of the dairy business, mixed rations have provided more stability within the feeding system, ultimately attaining a certain degree of resilience across the whole farm system.

Resilience of ecological systems was defined by Holling (1973) as the properties of a system that allow it to absorb change in a range of variables and still persist. In the context of dairy feeding systems, resilience could then be defined as the ability of the system to respond to challenges, such as climate and market variability (Lin 2011), optimise productivity and financial outcomes for that given set of circumstances, and persist over time with repeated challenges. Resilience will also be characterised by the ability of farmers to manage volatility and risk associated with cost efficient production. Specific attributes of a dairy system that will define resilience include flexibility, consistency, adaptation, sustainability and profitability. The present paper reviews existing knowledge of these key attributes and their relationship with resilient mixed ration systems, with a primary focus on the forage base, milk production responses, the production: cost base and resource management. The paper also explores potential strategies to inform research, development and extension delivery over the next 10 years.

Flexible forage base

Feed costs comprise 44–55% (Murphy 2017; Department of Economic Development Jobs Transport and Resources 2018) of total milk income and a key long-term strategy to ensure that mixed ration systems are profitable and resilient must be to focus on reducing feed-related costs through increasing the intake of home-grown forages within the diet, assuming that home-grown forage is the cheapest and best quality feed source available.

With the shift in the feeding system to mixed rations, there has also been a change in the types of forages being used. Forages that are high in starch relative to pastures, such as cereal crops, are predominantly used for their higher yield and quality. The increase in starch concentration also results in a change in rumen fermentation, with a higher level of propionate being produced per kilogram dry matter (DM; Mills *et al*. 1999), resulting in higher milk yields and milk protein concentrations (Beever *et al*. 2001). However, with an increase to starch-based forages, typically, crude protein concentrations in the total diet decline (Garcia *et al*. 2008) and, therefore, protein requirements need to be met from purchased sources, increasing the diet cost relative to that of pasture-based systems.

Consistency of forage supply is critical for any dairy feeding system (Chapman *et al*. 2008). Where a mixed ration has been incorporated into a feeding system, a proportion of that forage supply will come from conserved forage sources such as silage and hay, either as home-grown or purchased. This will improve the consistency of the diet quality year round through appropriate diet formulation and feed budgeting; hence, TMR systems have the ability to manage both supply and quality better than pasture and PMR systems, resulting in a higher production per cow (Bargo *et al*. 2002). Variability in the forage supply in PMR systems, however, will result from seasonal changes in the quantity and quality of the pasture base (Auldist *et al*. 1998; Fulkerson *et al*. 1998). To smooth out the variability in the pasture base, or as a way of increasing herd size or stocking rate without increasing the area of pasture, PMR systems have evolved to utilise the existing pasture base without compromising production. Consistency of the pasture base in PMR systems will still be a vital management component of the system, as pasture will help control costs and improve forage quality, particularly in ryegrass-based systems (Garcia *et al*. 2008).

The advantage of using crops in mixed ration systems is the change in nutrient type (starch and protein), which offsets nutrients from purchased concentrates, and the improvement in water use efficiency due to higher DM yields. Neal *et al*. (2011*a*) demonstrated an increase in water use efficiency (WUE; kg/ha.mm of water) with cereal-based crops (26.7–42.9 kg/ha.mm) versus annual pastures (13.5–30.1 kg/ha.mm). With increased yields per unit of water applied, the forage cost will be reduced. Optimising year-on-year forage and nutrient yields relative to seasonal conditions will also be a key performance indicator of a consistent and flexible forage base.

Designing a forage base that meets a large proportion of the cow's nutrient requirements will decrease purchased feed costs and improve production consistency and efficiency (Garcia *et al*. 2008; Fariña *et al*. 2011). Some forages may be grown as a specific nutrient source or harvested at a stage of growth to optimise nutrient density within that forage. Garcia *et al*. (2008) demonstrated the benefits of a complimentary forage rotation (CFR) system to increase production and WUE of the forage base, with more than a 100% improvement in forage yield, nitrogen and WUE. Nutrient yield was also higher, with metabolisable energy and crude protein yield 2.3 and 0.7 times greater respectively, for the CFR than the pasture system. Fariña *et al*. (2011) also demonstrated in a whole farm study that over 26 t DM and 27 000 L of milk/ha.year can be achieved with a CFR system utilising pastures and crops as the home-grown forage supply; however, pasture intake was one of the main limiting factors for milk production. Finding the balance in terms of forage type and proportion within the diet is challenging; however, if achieved, it will allow the feeding system to be more consistent over time and increase the ability to deal with variability in weather and price.

Consistent production responses

In the dairying regions of south-eastern Australia, below average rainfall between 1997 and 2008 and a decline in the availability of pasture led to an increase in the average amount of supplements fed to cows and in the use of systems involving PMRs (Wales *et al*. 2013). In 2011, it was estimated that 11% of Australian dairy farmers employed PMR systems; in 2017, this number increased slightly to 12% (Dairy Australia, unpubl. data). Farmers presumably looked to these systems as a way of increasing the resilience of their farm businesses in the face of uncertain and varying contributions from home-grown forage.

It was recognised by some farmers and researchers that the traditional strategy of offering supplementary cereal grain in the dairy had reached its limit in terms of milk production responses. Milk production often increases when cereal grain is fed but the marginal milk response decreases as the amount of grain increases. Reductions in marginal milk responses have been observed when as little as 5 kg DM of grain is consumed (Kellaway and Harrington 2004; Stockdale *et al*. 1987); data from 2017 show that in response to reduced rainfall and pasture availability, ~40% of Australian dairy farmers were needing to feed more supplement than 5 kg DM (Dairy Australia, unpubl. data).

Despite an increase in the number of farmers switching to PMR systems from traditional systems, survey data have indicated that many were not getting an appropriate milk production response from doing so (National Dairy Farmer Survey, Dairy Australia 2011*a*). Herds switching from a system in which high amounts of grain were fed in the bail to a PMR system in which PMR was offered to cows on a feed pad in between bouts of grazing were only realising an extra 9 kg of milk solids per year (Fig. 1), despite the added expenditure of a mixer

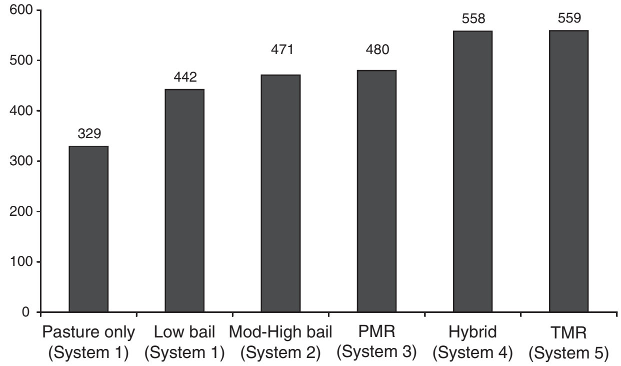

Fig. 1. Mean annual milk-solid production of Australian dairy farmers employing the five different feeding systems (from the National Dairy Farmer Survey (Dairy Australia 2011*a*)).

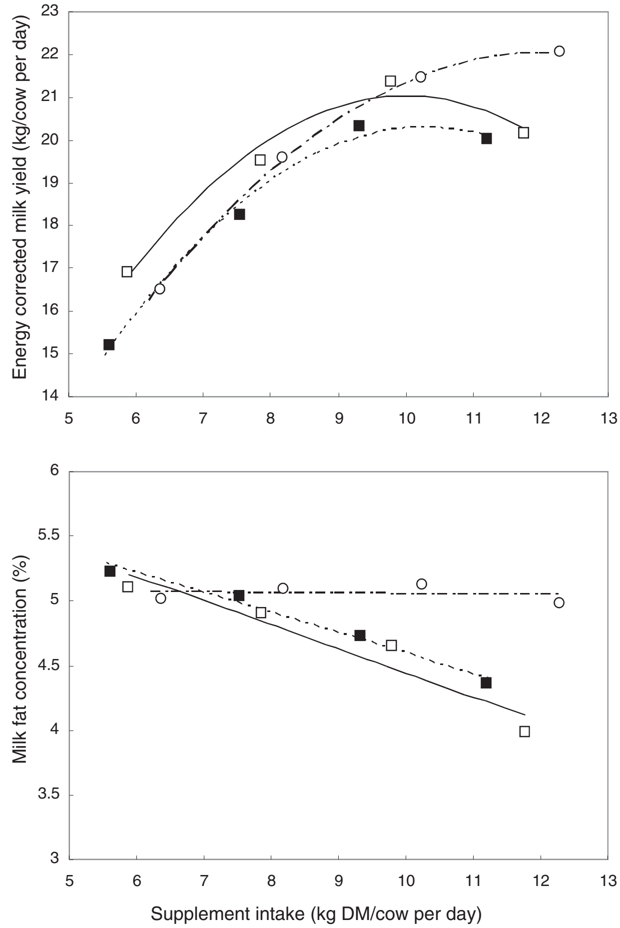

Fig. 2. Mean daily yields of energy-corrected milk (ECM), and concentrations of milk fat, for cows fed different amounts of supplements as cereal grain in the dairy and pasture silage in the paddock (□, solid line), a simple partial mixed ration (PMR) of barley grain and pasture silage (■, dotted line) or a PMR comprising barley grain, maize silage, maize grain and pasture silage (○, dashed line) feeding strategies. Data are means from the 11-day measurement period. Adapted from Auldist *et al*. (2013).

wagon and feedpad and a more complex management system. These data showed that PMR systems were not always resilient and pointed to an obvious research need to define the conditions under which PMRs could be used to produce consistent and profitable milk production responses.

A series of 11 experiments were conducted at Ellinbank over a 6-year period to address this research need. Early experiments showed that feeding a PMR containing maize grain, maize silage, barley grain and pasture silage on a feed pad could have energy-corrected milk (ECM) production benefits over feeding equivalent amounts of energy as cereal grain in the dairy and forage in the paddock when fed a perennial ryegrass pasture. However, this occurred only when the PMR was fed twice per day, and when at least 10 kg DM total supplement was fed/cow.day (Auldist *et al*. 2013; Fig. 2). Hence, farmers feeding less than this amount of supplement should carefully consider their need to adopt these types of systems.

These experiments also showed that it was the composition not the form of the diet that was important, with a mix of cereal grain and pasture silage fed on a feed pad having no measurable milk production benefits over the same components fed separately (Auldist *et al*. 2013; Fig. 1). In other words, the simple act of mixing the grain with the forage and allowing cows more time to consume it (and thereby moving away from 'slug feeding' in the dairy) did not improve milk production.

A very consistent effect of feeding PMR was that the concentration of milk fat remained stable as more supplement was fed, as opposed to the cows that were fed cereal grain, which exhibited a marked decline in milk fat concentration as grain intake increased (Auldist *et al*. 2013, 2016; Figs 2, 3). This was seen in all experiments and contributed to the ECM gains described previously (since calculating ECM involves the mathematical adjustment of milk yield to account for fat and protein concentrations).

Subsequent experiments demonstrated that the milk production benefits of PMR systems could be further increased by replacing some of the cereal grain in the ration with canola meal. The canola meal appeared to enhance cows' appetite and they, consequently, consumed more PMR (less refusals at high amounts offered) and grazed harder into the swards, increasing pasture utilisation and reducing pasture substitution (cows ate in the order of 1–2 kg DM more pasture per day). This intake effect was consistent with changes in the daily time budgets of cows, with cows consuming PMR containing canola meal spending ~30 min per day longer grazing than cows consuming PMR without canola (Wright *et al*. 2017). This was a major contributing factor to the milk production benefits of PMR systems.

Research showed that when high amounts of PMR were fed to grazing dairy cows, ECM production could be up to 5 kg/day more than for cows consuming equivalent amounts of energy as cereal grain in the dairy and forage in the paddock (Auldist *et al*. 2016; Fig. 1). This difference occurred because the milk yield of cows consuming cereal grain in the dairy did not increase further after intakes of 10 kg DM of total supplement were fed, while the milk yield of the PMR cows continued to increase until much higher intakes. In other words, the marginal response curve of the PMR cows was shifted to the right compared with traditional systems, such that the point of diminishing milk production

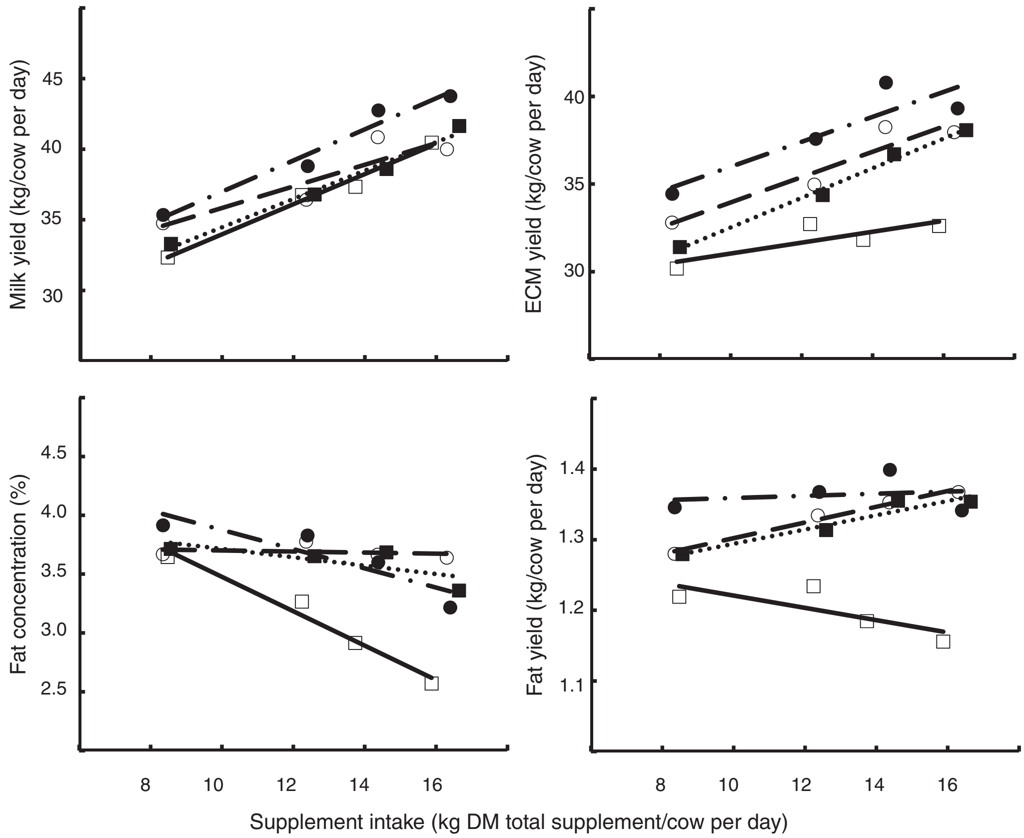

Fig. 3. Mean daily yields of milk and energy-corrected milk, and concentrations and yields of milk fat, for cows offered cereal grain in the dairy and forage in the paddock (□), a formulated grain mix of cereal grain, maize grain and canola meal in the dairy with hay in the paddock (■), a partial mixed ration (PMR) containing the same components as the formulated grain mix, plus hay in the paddock, and offered a low pasture allowance (○) or the same PMR with a high pasture allowance (●). Supplements were offered at nominal amounts of ~8, 12, 14 or 16 kg DM supplement/cow per day. Data are means from the 14-day measurement period. Adapted from Auldist *et al*. (2016).

occurred at a higher intake (Figs 2, 3). The same experiments showed that >75% (depending on level of intake) of the milk production benefits of PMR systems could be achieved feeding the main components through the dairy using existing infrastructure, thus removing the need to invest in a mixer wagon and feedpad (Fig. 3).

The mechanisms behind the milk production benefits of PMR systems are uncertain. It is possible that the appetite stimulating effects of canola meal are due to an increased, and more balanced, supply of amino acids, and that the subsequent increase in energy demand as a result of greater milk production induces greater intake (the 'pull' effect; Huhtanen *et al*. 2011). It is also possible that replacing some of the wheat in the ration with canola meal led to differences in the end products of digestion, specifically, in reduced amounts of propionate, which may have removed the satiety signals via the 'hepatic oxidation theory' (Allen *et al*. 2006).

The ruminal pH of cows consuming PMR is consistently higher and less variable, and spends less time below pH 6.0, than that of cows consuming cereal grain in the dairy (Greenwood *et al*. 2014; Fig. 4). This is presumably because maize is a more slowly digestible source of starch than is wheat grain, in combination with the buffering capacity of the additional protein provided by canola meal. This is possibly a contributing factor to the differences in milk fat concentrations, and, therefore, ECM, detailed above. Low and variable ruminal pH can cause a shift in the microbial population and altered lipid metabolism, leading to an increase in the amount of specific biohydrogenation intermediaries that have anti-lipogenic effects (Bauman and Griinari 2003). Lower, more variable ruminal pH in cows slug fed cereal grain is also known to compromise digestion in the rumen (Mould *et al*. 1983), although no differences in whole-tract digestibility were able to be demonstrated (Greenwood *et al*. 2014).

Profitable production: cost base

Mixed ration feeding systems that are resilient enable farm operators to meet their goals, stay in business and grow their wealth. To achieve this, farm managers need to make profitable short-term (weekly or monthly timeframe) and longer-term decisions. For short-term decisions, the capital and infrastructure are already available (costs sunk) and the marginal product, or the contribution to output of the last unit of input used, is the relevant measure to evaluate the economics

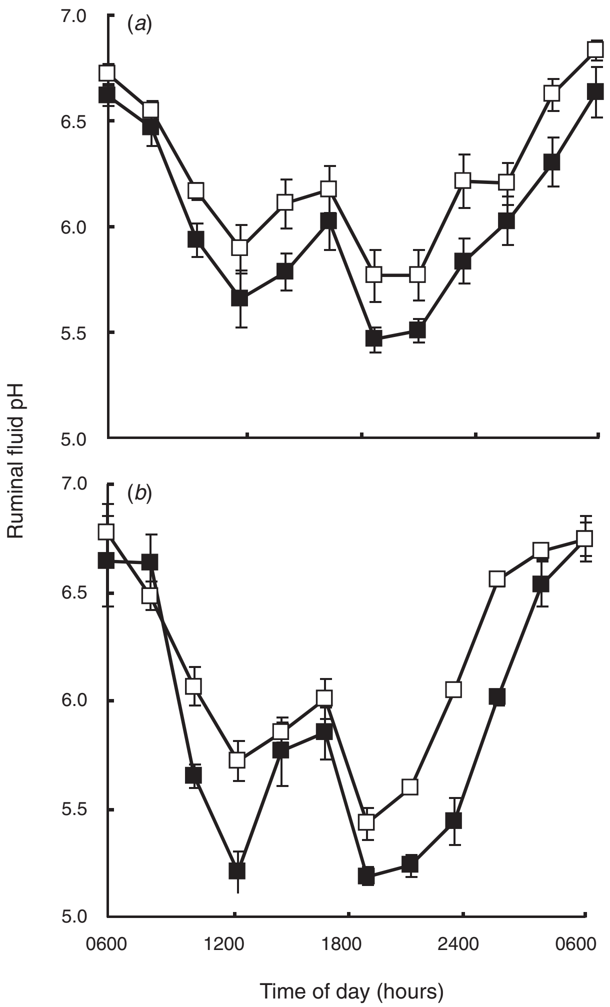

Fig. 4. Diurnal patterns of ruminal fluid pH for cows consuming fresh cut perennial ryegrass herbage and offered grain and silage either separately (■) or as a partial mixed ration (□). Data points represent means of seven cows per diet, measured approximately every 2 h over a 24-h period in (*a*) early lactation and (*b*) late lactation. Vertical brackets represent least significant differences of means ($P < 0.05$). Asterisks indicate sampling times at which there was a significant ($P < 0.05$) difference between treatment means. Adapted from Greenwood *et al*. (2014).

of a change on-farm. For example, feeding decisions should be assessed by estimating the margin of total milk income minus feed costs, where the profit-maximising amount of feed is given by the point where the marginal revenue from the milk produced just exceeds the marginal cost of the extra feed used (Barnard and Nix 1979; Eqn 1).

$$\text{Marginal revenue from milk} = \text{marginal cost of feed} \quad (1)$$

where marginal revenue from milk = price of extra milk × quantity of extra milk. Marginal cost of feed = price of extra feed × quantity of extra feed.

Determining the profit-maximising point requires knowing the price of the extra milk produced, the cost of feed and the likely amount of milk produced by the next kilogram of feed (Eqn 1). While prevailing prices can be used for the first two, robust data about the milk responses to mixed ration feeding have only recently become available (Auldist *et al*. 2013, 2014, 2016, 2017, 2018; Golder *et al*. 2014). These response functions are important for ensuring that inputs are used in the most profitable way for a given farm situation and have also been used by Ho *et al*. (2018) to examine the economics of short-term PMR feeding decisions. For a farm already equipped with a feed pad and mixer wagon, the benefits of feeding a mixed ration exceed the costs in early lactation. In late lactation, feeding a PMR or feeding cereal grain in the dairy and forage in the paddock made similar contributions to profit because of similar milk production. Milk responses to mixed ration feeding of cows in mid-lactation would be an area for future research, as this remains less well known.

For strategic decisions about investing in the infrastructure for mixed ration systems, appropriate measures of profitability and economic performance include modified internal rate of return (average earning rate over the life of the investment) and net present value (sum of profits adjusted to present-day dollars), which account for the opportunity cost of the farmer's capital. The infrastructure (e.g. feed pad, effluent system, feed storage) and equipment (e.g. mixer wagon, tractors) needed to establish mixed ration feeding systems can be costly, but Henty *et al*. (2017) showed that such investment can enable a dairy business to be more profitable than a traditional system where supplements are fed as grain in the dairy and forage in the paddock, particularly where herd size can also be increased. Key parameters affecting economic performance were the assumed milk response to mixed ration feeding and the reduction in wastage by using a feed pad rather than feeding out in the paddock. Decreased wastage reduces exposure to fluctuations in feed price; however, the components of a mixed ration can be more expensive than feeding grain in the dairy and forage in the paddock.

The impact of increased debt and financial risk should be an important consideration in the decision to implement a mixed ration system. Efficient use of borrowed capital enables a farmer to grow their business over time and at a faster rate than relying only on equity capital. But the principle of increasing risk means that, in years of poor seasonal conditions and prices, a business with higher debt will erode equity faster than a business with less or no debt, because debt-servicing payments still need to be made (Sinnett *et al*. 2017). Managing volatility in the operating environment within and between years as well as potential lag times in fully integrating changes into the existing farm system also create challenges for farmers making significant investments (Ho *et al*. 2013; Sinnett *et al*. 2017). The extent to which these factors affect the success and resilience of mixed ration systems warrants further investigation. Liquid reserves, having a portfolio of investments and forward contracting of input and output prices, may assist in managing the volatility of costs and returns, and increase the resilience of the whole farm business.

Measuring resilience in farm systems has been an on-going challenge, but Shadbolt *et al*. (2017) recently proposed the use of efficiency (technical and financial), liquidity and solvency as a proxy for describing overall resilience of a farm business. These measures were used to assess whether dairy farms in New Zealand from the DairyBase database were more or less resilient over a 5-year period that covered a range in price conditions. While the analysis by Shadbolt *et al*. (2017) was not specific for mixed ration systems, the findings would apply to all types of production systems. Efficiency was found to be the best indicator of resilience, with liquidity and solvency less useful for differentiating between farms, particularly within the group of more resilient farms. In general, the more resilient farms were more technically efficient (higher milk production per hectare, per cow and per labour unit), more financially efficient (higher return on assets and more profit per unit output), had greater liquidity (generated more discretionary cash for drawings and investment) and better managed debt-servicing obligations (lower ratio of debt to assets).

Over the 5-year period, System 3 and 4 farms, which were neither low input nor particularly high input farms, were also found to be more consistently resilient, and it was suggested these farm types could better respond to favourable and unfavourable conditions. This supports the analysis by Ho *et al*. (2013), which found that farms that had high performance over consecutive years had good, but not extreme, performance in a range of key areas. Optimising a single partial measure of technical performance is unlikely to lead to a consistently profitable business. Well managed mixed ration systems offer the flexibility to take advantage of favourable circumstances as well as manage poorer years.

Adaptive and sustainable resource management

System management is a key attribute that requires performance data and intuition to adapt management decisions to ensure that a system is resilient (Dairy Australia 2011*b*; Ho *et al*. 2013). This will include both strategic and tactical strategies to be planned for and decisions made on a continuous basis. Within mixed ration dairy feeding systems, management of the forage base and production responses will have the biggest impact on the financial performance and resilience of the system, given they are the most variable and often the highest cost. However, there are several other attributes, such as nutrient management, feeding and housing management of cows and management of public perceptions (social licence), that also need to be considered and managed appropriately to ensure that all management areas contribute to the overall resilience of the system.

Nutrient flow through the soil and into waterways is a real challenge faced by many dairy farms and is becoming a bigger community concern in both New Zealand and Australia, particularly in higher rainfall zones where movement of nutrients is more likely. In mixed ration systems, an excess or build-up of nutrients is likely to be the biggest challenge, with an excess of nutrients being used as an indicator of the environmental risk (Hutson *et al*. 1998). Management of nutrients in pasture-based systems can be difficult due to the spatial distribution of urine and faecal patches. Chataway *et al*. (2010) and Gourley *et al*. (2007) also found that nutrient surplus and distribution in pasture-based dairy systems in Australia was variable and was dependant on the level of purchased supplements imported on to the farm and stocking rate respectively. As dairy systems intensify to mixed ration systems, purchased supplements tend to increase and distribution of nutrients across the farm decrease. In a farmlet experiment conducted over 5 years in northern Australia, Chataway *et al*. (2010) found that a TMR system had a higher level of imported nutrients from supplementary feed and lower nutrient-use efficiency than pasture-based systems. However they identified an opportunity with intensive feeding systems to manage nutrients in specific areas and redistribute them more homogenously onto the forage base, with the potential to also export nutrients off farm to manage excesses within the whole farm system (Chataway *et al*. 2010). Mixed ration systems that use feedpads and housing infrastructure have the ability to strategically manage nutrient excesses and balances, resulting in a reduction in chemical fertiliser use and cost, and, hence, be more resilient to changes in nutrient loading policies implemented by government and community groups.

The move to mixed ration systems inevitably results in the use of specific infrastructure, such as feedpads and housing, to help manage feed losses and cow comfort and welfare. This is due to the higher feed costs (Murphy 2017) and production targets within that system, and the need to minimise feed wastage and the effect of short periods of heat stress or wet weather. Management and design of this infrastructure is critical for achieving DM intake (DMI) and production targets. The effect of mitigating heat loads with shade or cooling to reduce the impact on DMI has been well established (West 2003), with potential improvements of up to 2.8 kg DM/day when cows were exposed to thermo-neutral conditions and fed *ad libitum* compared with being under heat stress (>75 temperature humidity index) conditions (Cowley *et al*. 2015). The effect of heat stress on milk yield was over and above the reduction in DMI (Cowley *et al*. 2015), suggesting that there are other potential benefits on the physiological state of the animal that would improve the resilience of the system if heat stress mitigation strategies were implemented.

Improvements in cow comfort is another management strategy being implemented in mixed ration systems in Australia and New Zealand, which is a predominant feature in many freestall barn systems in the USA and Canada. A range of bedding options have been used to improve cow comfort and welfare (Haley *et al*. 2000; Tucker *et al*. 2003), with sand being the most popular from a management and cow health perspective. In northern Australia, compost sheds are being used as an alternative to a high cost freestall barn, which still allows for some grazing to occur in PMR systems without a large capital expenditure. Potential benefits in DMI have not been well documented in the literature; however, improvements in milk production have been seen with compost barns (Barberg *et al*. 2007). Other benefits on cow welfare, including hoof health, lying time and cow cleanliness, have also been recognised (Norring *et al*. 2008), which will add to the resilience of the feeding system. Return on investment is the biggest challenge and may be realised only over a longer period of time (>5–10 years).

Public perception of intensive animal production systems worldwide is poor, with grazing-based cattle production systems having a much greener feel from an animal welfare perspective. Freestall systems in the USA are continually under scrutiny from animal activist groups, regarding animal welfare issues around lameness, cow comfort and the inability for cows to roam and graze pastures (R. Patton, pers. comm.). This is a public perception that may be misguided from a scientific perspective; however, the impact of the general community on how dairy farm businesses are run in the future will increase. This is already being felt in New Zealand and Australia, with regulation around nutrient loading from dairy farms and the potential impact on natural resources. Mixed ration systems can be managed optimally from a technical perspective; however, if their public perception is low, then their ability to be resilient long term may be questioned. This is particularly so as differentiation of dairy products in the retail market increases. To counteract this, resilient mixed ration systems will need to be marketed by farmers and industry in a way that promotes the benefits to their communities. This will be underpinned by farms that are profitable, sustainable and resilient.

Resilient mixed ration systems in the future

There are several strategies that need to be explored in the future to underpin the resilience of mixed ration systems. These strategies are primarily focussed around feedbase management, as that will have the biggest financial outcome.

Alternative forage species that are higher yielding and more efficient in water use will be a necessity; however, understanding their characteristics and what nutrients they offer to the system relative to when they are required will be important. It may be an option to harvest specific parts of the plant to increase nutrient density, such as the seed head of wheat or sorghum, to provide a high starch forage source. The mix of forages used in the forage system will be dependent on nutrients required and climatic conditions that are suitable for individual forage types.

Increasing the forage proportion within the diet may be a strategic way of reducing feed-related costs, given that most forages sources (pastures and crops) are generally lower in cost per kg DM than are purchased concentrates. There are physical limitations to the amount of forage that a ruminant can consume before intake is maximised or decreased; therefore, understanding the forage-quality parameters that limit and or drive DMI will be important. In split herds, a strategic use of a higher forage diet in groups of late lactation cows may have minimal or no impact on milk production. Additionally, increasing the quality of forages through genetic selection or breeding could have a two-fold effect through an increase in nutrient density and DMI.

As the types of forages utilised within mixed ration systems increase, so will the number of forages within a single mixed ration diet, which will all provide their own individual nutrient profiles to the cow. Therefore, the interaction between nutrient types from a range of forages will be a key driver of production responses and the response to concentrates. Maximising forage intake and responses to forages will optimise the feed conversion efficiency and improve the marginal response to the total diet. Alternatively, tailoring diet formulation using a range of concentrates such as protein meal or by-products, may have an additive effect on pasture and forage intake and, therefore, improve marginal response to the total diet. This will be particularly important if the range in types of forages that are used in these systems is quite diverse. Also understanding the milk response to concentrates and forages within the whole diet for cows in mid-lactation will be important, as the average herd days in milk increases with year-round calving to meet domestic supply requirements.

Conclusions

To ensure resilience, dairy feeding systems require an adaptive approach across all key areas of the whole farm system. A flexible forage base that ensures a consistent supply of high quality feed to optimise year-on-year forage and nutrient yields relative to seasonal conditions will be a vital long-term key strategy to improve WUE and feed related costs. Consistent production responses will also be achieved through traditional supplementation of starch and protein-based concentrates, with additional milk yield and quality benefits achieved in mixed ration systems through higher feed intakes of a more balanced and consistent supply of nutrients to the rumen. The simple act of mixing concentrates with forages will not necessarily improve milk production; however, the investment of infrastructure in PMR systems will be beneficial long term to reduce feed wastage, mitigate heat load on cows through the provision of shade and cooling, increase herd size, enabling the farmer to grow their business over time and improve cow comfort. The implementation of these strategies along with the ability to adapt management decisions will be the key to managing resilient mixed ration systems to minimise the impact of climate and price variability. This will have flow-on benefits in animal welfare and resource sustainability, which will have a positive impact on the public perception of these systems within the Australian and New Zealand dairy industries. Further strategies to underpin the future resilience of mixed ration systems include the exploration of alternative forage species, increasing the proportion and nutrient density of tropical forages in the diet, and the interaction of these forages with different nutrient profiles.

Conflicts of interest

The authors declare no conflicts of interest.

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