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Implementing innovative farm management practices on dairy farms: a review of feeding systems

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Abstract: The Australian dairy industry relies primarily on pasture for its feed supply. However, the variability in rainfall negatively affects plant growth, leading to uncertainty in dryland feed supply, especially during periods of high milk price. New feeding (complementary) systems combining perennial ryegrass with another crop and/or pasture species may have the potential to mitigate this seasonal risk and improve productivity and profitability by providing off-season feed. To date, the majority of research studying the integration of alternative crops into pasture-based systems has focused on substitution and utilization of alternative feed sources. There has been little emphasis on the impacts of integration of forage crops into pasture-based systems. This review focuses on pasture-based feeding systems in southeastern Australia and how transitioning of systems contributes to improved productivity leading to improved profitability for dairy farmers.

Key words: Australia, dairy, double-cropping, feeding system, pasture-based, profitability

1. Introduction

In 2012 and 2013, dairy production in Australia was valued at 3.7 billion Australian dollars ($) farm-gate (1). Approximately 9.2 × 10^6 L of milk was produced, which ranked dairy as the third largest rural industry and one of the most leading agricultural exporters in Australia. This output was achieved by national dairy cow numbers of 1.7 million animals and around 6400 registered producers in 2013 (1).

The dairy industry was deregulated in 2000. Deregulation in 2000 led to all Australian milk prices being set by the world market rates with no price support from consumers (2). As a consequence, to remain competitive, dairy farmers expanded their businesses by increasing land value and/or increasing the productivity per unit of land (3), such as by increasing the herd size and stocking rates (4). Farmers in the industry adapted to deregulation by adopting new technologies and improving farm management practices. One consequence of these changes was an increased use of purchased feeds (1,5,6). Total productivity growth (total factor productivity), the ratio of total outputs to total inputs, of the Australian dairy industry was reported at 0.8% per year over the period between 1988–1989 and 2008–2009 (3). As a result of the improved farm management practices after deregulation, the Australian dairy industry has increased its outputs by 4.9% per year since 2000. However, the increased additional milk production in the dairy industry was a result of increased use of purchased feeds instead of improved productivity, which contributed to 4.1% increase in use of total inputs per year (3).

Although use of purchased feeds remains the main cost of production for most dairy farms, more recently this approach has been questioned (7). This has led to evaluation of the increased use of home-grown feeds in order to diminish the cost of milk production (8,9). This study critically reviews the pasture-based feeding systems supplemented with complementary forages during times when pasture is not available in southeastern Australia. It also provides insights into more productive and profitable farming systems by adopting complementary forage systems.

2. Australian feeding systems

Dairying in Australia is practiced in a number of regions. These regions, defined by differences in climatic and feed-

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base conditions, are subtropical/coastal, inland/irrigated, Mediterranean, and temperate/high-rainfall (>700 mm) regions. Victoria, producing around 65% of Australia's total milk production (1), is characterized by inland irrigated and temperate high-rainfall systems that allow substantial amounts of pasture to be grown, especially in spring (6,10). In southwestern Victoria, the seasonal production of pasture has led to the development of 5 feeding systems. According to Little (11), these systems are:

1) Pasture, other forages, and low grain/concentrate feeding in milking shed (less than 800 kg dry matter (DM) grain per year),
2) Pasture, other forages, and moderate-high grain/concentrate feeding in milking shed (800 kg to 1600 kg DM grain per year),
3) Pasture and partial mixed ration and/or grain/concentrate feeding system using feed pads or stand-off areas,
4) A hybrid system (pasture grazed for less than 9 months per year and partial mixed ration on feed pad and/or grain/concentrates), and
5) A total mixed ration system (zero grazing and cows are housed).

Managing feed costs is an important component of dairy-farm management and one of the keys to improve farm operating profits. It is important for dairy producers to ensure that feeds with high nutrient content are supplied at the least cost. This imperative has, in part, led to the producers in southwestern Victoria adopting Systems 1 and 2, and some producers still using System 3. While System 4 may be adopted in very wet seasons, System 5 is rarely practiced (4).

3. Pasture production in southwestern Victoria (feed supply)

Pasture availability is also known as pasture mass, herbage mass, pasture present, or pasture on offer. It is affected by herbage growth and grazing strategies (12). Plant growth consisting of vegetative growth, also known as tillering, occurs in autumn and winter, and reproductive growth, which involves stem elongation and the development of flowering head, occurs in spring and summer (13). The growth rate of pasture plants expressed as kg DM/day is determined by moisture and temperature (14), and the pastures in southwestern Victoria produce greater than 70 kg DM/ha per day (4).

Over half of the sown species' herbage accumulation is produced in spring (September, October, and November) and early summer (December). The growth rate declines considerably in late summer (January and February) and early autumn (March and April) and winter (June, July, and August) (4,15) (Figure 1) (16). High rates of pasture growth in spring can be attributed to the increased grass

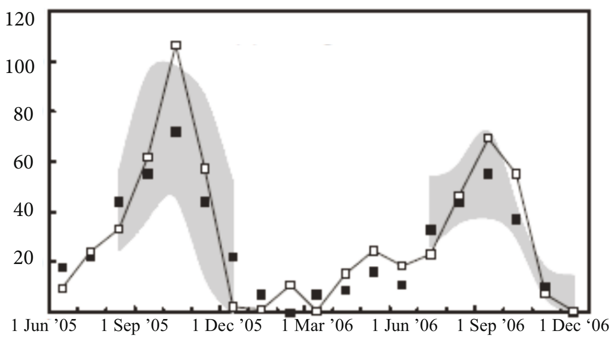

Figure 1. Measured and modelled monthly mean daily net herbage accumulation rates (kg DM/ha per d), including measured variability (gray-shaded) where available for Terang region (southwestern Victoria). Measured (■) and modelled (□). Source: Cullen et al. (16).

content of the sward, while low summer growth rates can manifest increases in dead material (17). While the restrictions in feed supply in winter are due mainly to the waterlogged soils, the restricted pasture production in summer can be the result of limited soil moisture (18).

In southwestern Victoria, the pasture plant species, corresponding nutritive values of pasture, and pasture growth pattern and availability vary according to season. The predominant sown grass in southwestern Victorian pastures is perennial pasture (*Lolium perenne* L.) (4), which is thought to be water-efficient, especially in deep soil structures (18). When supplemented with maize silage, this pasture can fulfill the requirements of the dairy cow to produce 20–25 L of milk per day for the majority of the lactation in systems where cows calve in late autumn (19). Typically, the white clover content of pastures in southwestern Victoria is around 10% (20), reflecting high N inputs and poor soil conditions for establishment. As well as perennial ryegrass and white clover, there are some other species of pasture plants that are adopted to fulfill the cow requirements during summer or to be used in pasture renovation. Some of these species are tall fescue, cocksfoot, red clover, brassicas, plantain, and chicory (21).

3.1. Nutritive characteristics of pasture plants

The factors determining the nutritive characteristics of pastures are their energy, protein, fiber, and mineral contents. Pasture digestibility, or DM digestibility (DMD), is often described as the proportion of feed not excreted in the feces and hence available for use by the animal (4). As the digestibility of a particular feed increases, the amount of energy it provides to the animal also increases. The DMD (and hence metabolizable energy (ME) content) varies with type of pasture and season. The ME refers to the amount of energy directly available to an animal for maintenance, activity, pregnancy, milk production, and live weight gain (4). These characteristics of feed types are important in the formulation of rations, especially for the contribution of supplementary feeds to the total ration (Table 1) (4,17,22,23).

In southwestern Victoria, the typical range in pasture energy (ME content) is 11.7 MJ/kg DM in autumn or spring to 8.4 MJ/kg DM in midsummer (4,17). The average ME content of perennial ryegrass is reported as 10.2 MJ/kg DM in autumn, 10.4 MJ/kg DM in spring, and 8.4 MJ/kg DM in summer. The DMD of perennial pasture is 72%, 73%, and 61% in autumn, spring, and summer, respectively (Figure 2) (4).

The crude protein (CP) content of pasture differs according to pasture species. Newly growing pastures, especially those receiving high levels of nitrogen (N) fertilizer, usually contain more CP compared to those where no fertilizer has been applied (4). The CP content of pasture ranges from 100 g/kg DM to 250 g/kg DM (winter and early spring, respectively) (17). Although it is useful to know the pasture production pattern and the options available to fill pasture gaps, the cow requirements need to be known for formulation of energy-balanced rations.

3.2. Principles of energy balance

In formulation of rations, in order to increase or support milk yield, the principles of energy balance should be applied. For instance, to achieve high profitability in pasture-based dairy systems, the yield and nutritive characteristics of pasture and demand of animals at a particular stage of lactation have to be matched. This information is necessary when making decisions about providing feed supplements and conserving feed surpluses (24). Where cow requirements are greater than the nutrient yield available for grazing, a deficit occurs, and therefore supplementation with home-grown or purchased forages, food industry by-products, and/or grains/concentrates becomes necessary. Pasture deficits for autumn-calved cows occur at the peak of lactation in winter, since the cow requirements at this stage exceed the pasture available. In contrast, for spring-calved cows, deficits of pasture usually take place during late lactation when the requirement and the intake of the cows are lower compared to the peak lactation (25).

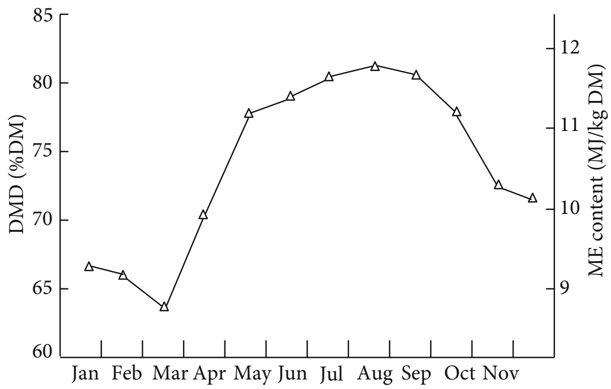

Figure 2. The DMD and ME content of perennial pastures in southwestern Victoria. Adapted from Doyle et al. (4).

Similarly, where the nutrient requirements of the animals are lower than those available at pasture, for instance in spring in southwestern Victoria, surplus pasture can be conserved as silage or hay. The utilization of these surpluses depends on the requirements and performance of the dairy business (stocking rate, milk production level, feed supply, cost of production, and knowledge of the farmer), and these may be carried forward to the next lactation for feeding, or sold (7,26). There may be an extra cost associated with conserving surplus feeds due to storage and wastage (27) since the pasture not utilized deteriorates and decays, resulting in wastage (12). The supply versus wastage risk can substantially reduce profitability (17).

The key principle in pasture-based dairy production systems is to achieve high milk production per unit of land area rather than high production per head that is dependent upon high inputs of purchased feeds (28). Therefore, increasing the use and efficiency of home-grown forages can increase the production per unit of land (25). This reflects, irrespective of calving season, more of the feed (kg DM) consumed by the cows being converted into milk solids (MS) (kg) in early lactation than late lactation. That is, feed conversion efficiency (kg MS/kg DM) is higher in early lactation (19).

Table 1. Estimated CP, ME, and DM values of the double-cropping systems.

Feed type	Period (H: harvested, G: grazing)	CP (g/kg DM)	ME (MJ/kg DM)	DM (t/ha)
Winter wheat	October (H)	110–140	8.5–9.5	8–10
Winter silage	October	150–250	9–11	10–15
Summer crop	January–March (G)	100–120	10–13	8–10

Sources: Dharma et al. (5), Jacobs et al. (17), Chapman et al. (22), and Jacobs et al. (23).

4. Pasture consumption (feed demand)

Factors affecting animal nutrient requirements include animal health and physiology, environment, and the production rate of the animal (14). Animal requirements vary with physiological stage, such as maintenance, pregnancy, and lactation, growth, (29). The intake of lactating cows is affected by cow size, milk yield, stage of lactation, and ME content of the ration offered (30). This is explained in Figure 3 (31).

Figure 3 illustrates that a lactating cow reaching her peak milk production 6–8 weeks after parturition requires more dietary energy and protein to maintain her increased milk production during this period. She also needs enough dietary energy during the late lactation when her milk production decreases in order to regain body condition. The energy required to maintain milk production in the first 12 weeks of calving is obtained from both the cow body tissues and the feed consumed. Using her body reserves during this period, the dairy cow achieves higher peak milk yield than she could using feed energy per se, but she also loses weight that was gained in the previous lactation (31).

The peak feed intake of a dairy cow occurs a few weeks after the peak milk production. Therefore, the regulation of pasture intake and the integration of supplements should be considered in relation to milk response and the stage of lactation (4). The desirable calving time is usually adjusted to 4–6 weeks before the spring pasture peak to meet the increasing cow requirements at that time (29). An example is provided in Table 2.

The voluntary feed intake at calving is almost half of the maximum peak intake due to the reduced rumen volume and the density and size of the rumen papillae during pregnancy. The energy requirement of the dairy cow usually exceeds the voluntary feed intake until week 12 and the milking cow gains her full appetite at 10–12 weeks into lactation (Figure 3) (31). Therefore, providing the milking cow with high energy feeds in early lactation is likely to result in increased milk production due to her restricted DM intake during this period. The voluntary feed intake gradually increases after the peak lactation. Although the milk production starts declining from mid- to late lactation, it is still important to provide the cow with an energy-balanced ration during this time to prepare

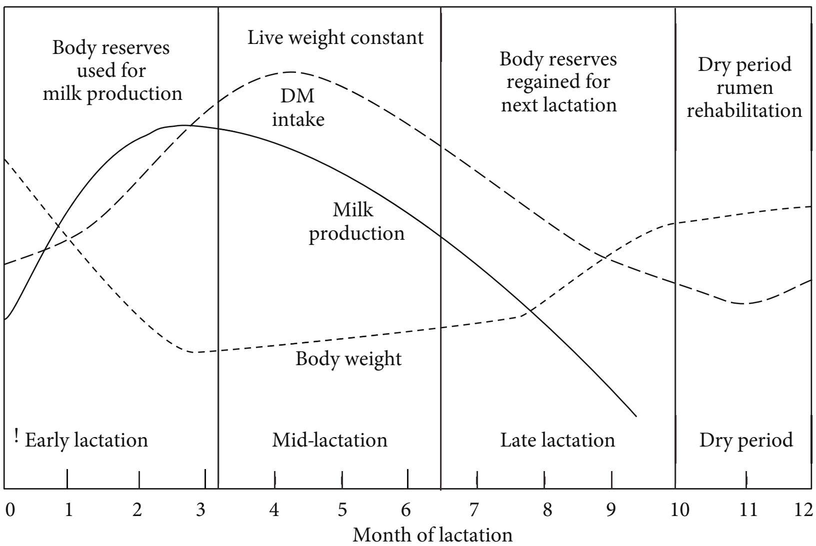

Figure 3. The relationship between cow milk production and DM intake. Source: Moran (31).

Table 2. Dry matter requirements of the lactating cows for different levels of milk production and different ME levels of feed. Source: Moran (31).

Milk production (L/day)	ME requirement (MJ/day)	DM requirement (kg DM/day)	
		8 MJ/kg DM	10 MJ/kg DM
13	125	15.6	12.5
17	146	18.2	14.6
20	161	20.1	16.1

her for pregnancy and to allow her to gain tissue reserves for the next lactation (31).

If sufficient nutrients are not provided in early lactation, cows of high genetic merit partition less energy into milk and more into body condition for the rest of the lactation, resulting in alleviated peak milk lactation (12) (Figure 4) (22).

Dry matter intake (DMI) of grazing cows is the main driver of productivity. It decreases as the supplementary feeds are increased. This is called substitution rate (kg pasture/kg supplementary feed) and is calculated as the difference between pasture DMI in unsupplemented feeding and pasture DMI in supplemented feeding divided by supplement DMI. A negative substitution rate signifies higher total DMI in the supplemented than the unsupplemented feed. Similarly, a large substitution rate reflects a low milk response due to the small increases in DMI in response to the increases in substitution rate (32). Since pasture is not available throughout the production period, the integration of complementary feeds into pasture should be considered.

5. Integration of complementary feeding systems into pasture-based feeding systems

Australian dairy systems are regarded as some of the most efficient dairy production systems in the world (4), reflecting their heavy reliance on low-cost home-grown pasture products, especially in southern Australia. The advantages of ryegrass pastures include easy establishment, high DM yield, and high nutritive values. However, their growth pattern is seasonal and they lack the ability to provide sufficient yield and nutrients throughout the whole production year (33). The inherent variability in rainfall has substantial negative effects on forage supply, leading to uncertainty in feed supply during periods of high milk price (summer and autumn) (34). This is also because pasture growth is challenged by wet winters and dry summers, land and labor requirements, water limitations (rainfall and irrigation water), and favored use of purchased feeds (33). This seasonal risk may be mitigated by developing complementary systems (35) or by changing farm management practices to increase DM production and reduce the impact of climate variability on feed supply (36). Most importantly, when the plant growth is restricted due to low rainfall events, combining perennial ryegrass with another crop and pasture species may improve the productivity (37).

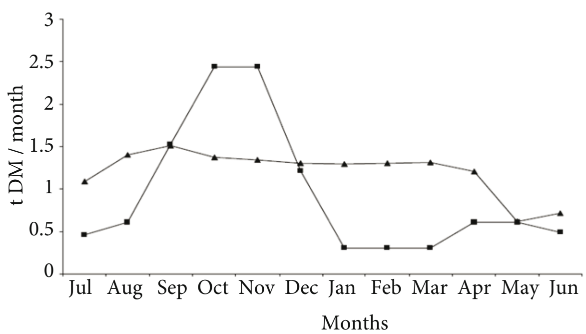

Figure 4. The relationship between the monthly feed requirements of cows stocked at 2.5 cows/ha (kg DM/month, (▲)) and the perennial ryegrass production (kg DM/ha per month, (■)) in southwestern Victoria. Source: Chapman et al. (22).

The principles underpinning the integration of supplementary feeds into pasture only systems are to offer extra DM when pasture availability is less than pasture required, to minimize wastage of both pasture and supplementary feed by developing management practices, and to ultimately maximize the total feed utilization in the system (38). Therefore, the amount of home-grown forage produced and consumed is an important factor for productivity improvements in the dairy industry (8,39). As perennial ryegrass is the main source of home-grown forage produced in southwestern Victoria, comparisons of different feeding systems need to be based on profitability gains associated with systems change (40).

There is a general agreement that summer-grown feeds have the potential to replace purchased feeds by producing off-season feed and reducing the cost associated with storing feed and wastage. Thus, practices should focus on how to fill summer and autumn gaps to further improve productivity (41). This also reflects the higher cost of feeding the dairy cows in autumn compared to spring (42). The additional contribution to farm income of off-season feed depends on when the extra feed is produced and reflects the efficiency of extra feed converted into milk. For example, in contrast to the excess pasture availability in spring, during summer, any extra feed produced is likely to be better utilized by the dairy cows (41), reflecting the amount of feed on offer and the stage of lactation (43). Typically, 95% of dairy producers in Australia purchase feeds to supplement the pasture deficits (average of 1.6 t of grain, grain mixes, or feed concentrates per cow) (1). In southwestern Victoria, grazed pasture contributes 46%–73% of the ME consumed. Total supplements consistute 38% of the ME consumed on the farm (44).

To date, the majority of research studying pasture-based systems has modelled growth patterns of pasture and pasture products (15,16,45,46) and studied the yield and nutritive characteristics of different feed types including pasture and pasture products (17,21,27,39,43) throughout a production year. There seems to be few studies reporting pasture surplus and deficit profiles of different pasture-based systems for subsequent lactations. Evaluation of pasture surpluses and deficits for subsequent lactations is necessary in order to discern how much of the feed that is intended to be produced is actually needed or how much of the surplus, if available, can be conserved and fed during lactation and carried forward to the next lactation for an extra feed supply.

5.1. Types of complementary forage systems available

Different combinations of pasture or fodder species may reduce restrictions in annual feed supply and produce more consistent forage production that better meets cow requirements. This is important in the development and selection of alternative feeding systems that are appropriate for southwestern Victorian climate conditions (15). Pasture-based systems complemented by alternative forages may provide higher total DM/ha compared to solely pasture-based systems only, but higher DM availability in these systems may not always lead to increased profitability. However, if successful, these systems may offer improved nutrient availability and improved N and water-use efficiency (4,15,39,47,48).

Jacobs and Woodward (36) suggest that increasing the use of legume forages such as white clover, lucerne, and lotus may supplement the pasture-based systems especially in late lactation due to their high forage quality and increased DM intake. Improved milk production as a result of the increased use of legumes in cow diets can be attributed to the higher CP content of white clover, reflecting higher intakes and higher excretion of N. Fodder crops, on the other hand, providing feed at critical times and being suitable to conserve, are commonly used supplementary feeds in dairy production systems. This is due to their potential to grow cereal crop during summer that can be used to fill a winter deficit (34).

Cereal silage is an alternative to fill winter gaps while brassicas provide extra DM in summer to fill summer feed deficits. Therefore, a combination of summer forages such as maize and winter forage crops may alleviate the limitations of perennial pasture-based systems (4). Winter cereal crops can also be fed to grazing cows as standing feed in early to mid-winter (43). Among winter cereals, oats, due to their fast recovery after grazing, and winter wheat and triticale, due to their high yield and price, are the most commonly used crops. Among brassicas, rape, kale, turnips, and swedes are used in cool temperate zones in Australia (49). Brassicas (especially turnip) are grown primarily for the purpose of pasture renovation. They also provide high nutritive value of feed in summer and early autumn (40). Brassica crops have the potential to reduce the reliance on seasonal pasture supply in pasture-based feeding systems by increasing forage production per ha in autumn and winter (50).

Sowing a winter-active cereal into a summer-active native perennial ryegrass (called pasture cropping) is a common strategy (35). Cereals grazed in early winter contain high estimated contents of ME and CP (43). Chapman et al. (37,51) suggest that there are 2 systems that can potentially improve profitability on a dairy farm: double-cropping, where winter cereal crop is grown for silage and followed by a summer grazing crop (turnip crop), and summer shoulder pastures based on tall fescue. These options are more capable of providing quality feed in summer and winter as long as the soil moisture is sufficient.

Double-cropping systems may produce higher DM than pasture-only systems. For instance, the higher nutritive value of forage rape in autumn makes it an important potential complement for pasture that has lower nutritive value in the same period. A complementary forage rotation (CFR) system of, for instance, maize, forage rape, and Persian clover is able to provide feed in autumn and early winter (39). Increased profitability from a CFR system can be achieved by ensuring maximum utilization of current pasture and being able to replace purchased feeds such as concentrates (8). In a scenario where an average autumn and a long spring are experienced, a double-cropping system practiced by the top 40% and top 10% farms could potentially conserve a total of 152 t and 32 t DM silage, respectively (51), which could then be carried forward and used in the next lactation. In contrast, short spring seasons are an obstacle to pasture conservation (51).

A recent approach adopted in southwestern Victoria is to use winter-sown cereals such as wheat and barley as part of a double-cropping system. The main characteristic of these annual crops is that they are grazed once before growth stage 3, the senescence of the oldest leaf (52), and regrowth is conserved as silage (19). After silage production, the land is reused to sow a summer-brassica crop (generally turnip or kale) for grazing in mid- to late summer. This is to support milk production when perennial ryegrass pasture is yielding no more than 5 kg to 10 kg DM/ha per day (4,26) (Table 3).

6. Increased profitability through increased use of home-grown forages

Australian dairy farmers may increase their profitability by increasing the use of home-grown feeds and utilizing pasture more efficiently. Efficient utilization of pasture can be achieved by adjusting stocking rate and management systems (9). In intensive dairy production systems, a combination of increased milk production and reduced purchased feed leads to increased operating profits in a 'good' pasture growth year. Inclusion of a moderate level of supplements such as mixture of forages and concentrates to fill the deficits in feed supply may overcome the limitations of 'pasture-only' systems (53). This may also lead to increased profitability through decreased reliance on pasture as main feed, higher stocking rates, and higher marginal response to concentrates (25). However, if not well planned, the inclusion of increased levels of purchased feeds, especially concentrates, may result in reduced profitability.

Table 3. The management of double-cropping options available. Source: Chapman et al. (26).

Option	Area sown	Date sown	Date grazed (G) or harvested (H)	Note
Winter crop	10% winter cereal crop (wheat)	1 April	July–September (G) Mid-October (H)	Harvested for whole crop silage, fed in early and late lactation
Summer crop	10% brassica crop (turnips)	1 October 21 November	1 January–end of February (G)	Sown twice, area returned to pasture grazing by mid-April

Pasture-based systems supplemented with high levels of concentrates are likely to produce higher returns (at a decreasing rate) than their alternatives such as partial or total mixed rations (54). However, the increased returns in a production system should be considered in relation to the variability in inputs or, in other words, risk. For instance, pasture-based systems with no extra supplementary feeding may carry higher risks. This is because pasture growth is dependent on rainfall, which is unpredictable (54). Similarly, those feeding forage and concentrate supplements to reduce the reliance on pasture may require more labor, as well as better management of climate and financial risk reflecting increased stocking rates (25). The supplement cost should always be considered regardless of the proportion of the ration that they form. Nevertheless, higher profits from pasture-based feeding systems are possible when early autumn rainfall and long springs are experienced, reflecting increased herbage production (51). Under Australian climate conditions, however, early autumn rainfall and long springs are relatively rare and, therefore, better management practices to supplement pasture are the cornerstone of profitability of the Australian dairy sector (4,38).

Average dairy farm business profit was reported by Dharma et al. (5) as approximately $106,000 per farm for year-round producers ($83,000 for seasonal producers) feeding more than 1.5 t/cow of purchased feed such as concentrates and by-products in 2010 and 2011. Chapman et al. (26) suggested that increased use of home-grown forages may increase the farm operating profits of southern Australian dairy farmers by 30% to 45%. Similarly, a study conducted by Alford et al. (8) showed that feeding systems based on home-grown forages can achieve around 8%–12% return on total assets while the systems based on only pasture and concentrates generate around 6% return on assets (9). Some of the alternative feeding systems to achieve increased return on assets are oversowing pastures with annual ryegrass, summer shoulder pastures (based on tall fescue), and double-cropping systems comprising a winter crop followed by a summer crop (26).

In these systems, an additional ton of home-grown feed consumption may generate around $70 and $100/ha additional return for the top 40% and 10% farms, respectively. Increasing the amount of supplements in pasture-based systems generates higher returns than relying purely on pasture, which may result in overgrazing of pasture and reduced milk production (55). However, there has been reluctance among producers to change from the traditional ryegrass-based system to complementary feeding. This may be due to the erroneous perception that complementary forage-based systems may carry a higher risk to production. This may also be due to the recent policy obligations regarding greenhouse gas emissions produced by dairy farm systems.

7. Conclusion

Australian dairy systems are considered as some of the most efficient dairy production systems in the world due to their heavy reliance on low-cost home-grown pasture products, especially in southern Australia. Because pasture is not available throughout the whole production period, the integration of complementary feeds into pasture should be considered. Managing feed costs is an important component of dairy-farm management and one of the keys to improve farm operating profits. It is important for dairy producers to ensure that feeds with high nutrient content are supplied at the lowest cost. The dairy farmers in Australia may increase their profitability by increasing the use of home-grown feeds and utilizing pasture more efficiently. Efficient utilization of pasture can be achieved by adjusting stocking rate and management systems. In formulation of rations in order to increase or support milk yield, the principles of energy balance should be considered. To achieve high profitability in pasture-based dairy systems, the yield and nutritive characteristics of pasture and demand of animals at a particular stage of lactation have to be matched. The principles underpinning the integration of supplementary feeds into pasture only systems are to offer extra DM when pasture availability is less than pasture required, to minimize wastage of both pasture and supplementary feed by developing management practices, and to ultimately maximize the total feed utilization in the system.

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