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Review

Complementary forages – integration at a whole-farm level

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Abstract. A high proportion of the Australian and New Zealand dairy industry is based on a relatively simple, low input and low cost pasture feedbase. These factors enable this type of production system to remain internationally competitive. However, a key limitation of pasture-based dairy systems is periodic imbalances between herd intake requirements and pasture DM production, caused by strong seasonality and high inter-annual variation in feed supply. This disparity can be moderated to a certain degree through the strategic management of the herd through altering calving dates and stocking rates, and the feedbase by conserving excess forage and irrigating to flatten seasonal forage availability. Australasian dairy systems are experiencing emerging market and environmental challenges, which includes increased competition for land and water resources, decreasing terms of trade, a changing and variable climate, an increasing environmental focus that requires improved nutrient and water-use efficiency and lower greenhouse gas emissions. The integration of complementary forages has long been viewed as a means to manipulate the home-grown feed supply, to improve the nutritive value and DM intake of the diet, and to increase the efficiency of inputs utilised. Only recently has integrating complementary forages at the whole-farm system level received the significant attention and investment required to examine their potential benefit. Recent whole-of-farm research undertaken in both Australia and New Zealand has highlighted the importance of understanding the challenges of the current feedbase and the level of complementarity between forage types required to improve profit, manage risk and/or alleviate/mitigate against adverse outcomes. This paper reviews the most recent systems-level research into complementary forages, discusses approaches to modelling their integration at the whole-farm level and highlights the potential of complementary forages to address the major challenges currently facing pasture-based dairy systems.

Additional keywords: dairy farming systems, modelling, pastures.

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Introduction

The Australian dairy industry production has a current value of AU$3.9 billion and is the country's third largest rural industry behind beef and wheat, producing 9.1 billion litres of milk and exporting $2.75 billion of product in 2010–11 (Dairy Australia 2011*a*). The New Zealand dairy industry produced 17.3 billion litres of milk valued at NZ$10 billion in 2010–11(DairyNZ 2011), making it the country's largest export earner. The major competitive advantage of both the Australian and New Zealand dairy industries, relative to other countries in the developed world, is the efficient production of milk from a relatively cheap feed source; the home-grown feedbase (Dillon *et al*. 2005).

Pasture grasses are the dominant forage source throughout each of the dairy regions of Australia and New Zealand (Doyle *et al*. 2000; Holmes 2007). Home-grown forage consumption is a key determinant in dairy business success (Mitchell 1998; van Bysterveldt 2005). However, as farms move closer to achieving a ceiling level of production from their current feedbase and natural resource base, the question that is often proposed is, 'Where is the next major gain in the feedbase?' Intensifying the farm system to achieve a higher level of pasture consumption from a business that is currently using over 70% of its pasture production potential often comes with substantial additional costs and risk. Additional increases in home-grown forage consumption do not always achieve the predicted improvements in profit. In some regions it is often considered more effective to purchase more land than intensify the current enterprises, especially if the land is not suited to further increases in stocking rate. Unfortunately, the opportunity to purchase additional land in many regions is limited because of encroaching urbanisation and increasing land prices. Consequently, dairy businesses are seeking new and complementary pasture species, conserved forages and novel concentrates/by-products to supplement their pasture-based systems (Clark *et al*. 2007).

The use of forage species to complement the feedbase with respect to quantity, nutritive value or seasonality of feed produced (from here on referred to as complementary forages) is not a novel idea. Complementary forages have been adopted successfully across dairy farming systems in Australia and New Zealand for many years. Forage sources that potentially complement the perennial ryegrass (*Lolium perenne* L.) feedbase include annual forage species, legumes (both pastures and crops), forbs, and other perennial grasses. These complementary forages have received greater research, development and extension focus in recent years to increase forage DM production potential (both grazed and conserved), manipulate nutritive value, achieve greater productivity gains, increase farm profitability, lower business risk and to compensate declining terms of trade.

This paper briefly reviews the strengths and weaknesses of the current dairy feedbase system throughout Australia and New Zealand and examines the current adoption of complementary forages. The paper also examines the external pressure of decreasing land and water availability and reviews the most recent systems-level research into complementary forages. The key factors influencing the success of integrating complementary forages are discussed. The paper also details modelling complementary forages and explores how challenges such as a changing and variable climate and a carbon constrained economy may influence the feedbase and the role that complementary forage may play in alleviating these challenges.

Managing the feedbase

Due to varying climates, availability and cost of land, water and feed, milk payment schedules, personal preferences and knowledge base, a wide spectrum of dairy production systems has evolved in both Australia and New Zealand (Table 1). In Australia, dairy farms are categorised into five varying farming systems (Dairy Australia 2011*b*). According to national farm survey results (Dairy Australia 2011*b*), 30% of Australian dairy farms are classified as farming system 1 (grazed pasture and other forages with <1.0 t grain/concentrates fed in bail), 50% in system 2 (grazed pasture and other forages with >1.0 t grain/concentrates fed in bail), 11% in system 3 (pasture grazed for most or all of year with a partial mixed ration on feed pad with or without grain/concentrates fed in bail), 5% in systems 4 (pasture grazed for less than 9 months per year with partial mixed ration on feed pad with or without grain/concentrates fed in bail) and 2% in system 5 (zero grazing, cows housed and fed total mixed ration). In New Zealand, in the past 15 years, systems have changed such that they now range from 100% pasture systems through to systems where 50% or more of feed is imported from outside the pasture area (Macdonald *et al*. 2010). There are also five classes of dairy systems in New Zealand, based on the proportion of total feed consumed comprised by imported feed, and whether imported feed is used for dry cows, lactating cows or both (Kolver and Hedley 2006). Imported feed is defined as any feed used for dairy cows that is not grown on the milking platform area (area directly utilised by lactating dairy cows). This includes silage conserved on support land (areas of land not directly utilised by lactating dairy cows) or crops grown on support land fed to dairy cows either while milking, or during the non-lactating period. It also includes feed purchased from outside the farm business. In 2010–11, 13% of New Zealand dairy farm were classified as system 1 (no imported feed), 30% in system 2 (between 4 and 14% feed imported, which is used for dry cows only), 35% in system 3 (10–20% of feed imported, which is used for dry cows and to extend lactation), and 22% in systems 4 and 5 (>20% feed imported, with some imported feed used all year round for lactating cows in system 5) (Clark *et al*. 2012).

The major competitive advantage of grazed pasture-based dairy systems is the ability to produce milk at a low cost (Dillon *et al*. 2005). Pasture-based dairy systems, in particular those utilising perennial ryegrass, also possess a range of other positive attributes including a relatively high forage nutritive value, ease of pasture establishment, responsiveness to nitrogen (N) fertiliser, perenniality in conducive environments and a vast body of knowledge relating to their management (Holmes *et al*. 2002). However, in most of the temperate regions, under rain-fed conditions, there is a bimodal distribution of pasture growth with the majority of growth occurring in spring and a secondary peak occurring in autumn (Rawnsley *et al*. 2007*b*). This results in substantial periods of undersupply (feed gaps) along with periods of oversupply throughout the year (Fig. 1). In the northern dairy regions of subtropical Australia, the combination of warm-season and cool-season pastures, with conserved forages, grains and by-products, is used to support milk production throughout the year (Callow *et al*. 2005). Producers have to manage the feedbase to provide feed of adequate quantity and nutritive value as feeds are often higher in fibre content and lower in digestibility (viz. C_4 summer grasses) compared with C_3 grasses (Garcia *et al*. 2008; Fariña *et al*. 2011*b*).

The constraints associated with the seasonality of forage supply and nutritive value has long been recognised. Jacobs and McKenzie (2003) recommended prioritising feedbase research to explore the integration of other forage species with varying seasonal growth patterns to even out forage supply and to develop cropping combinations that achieve high DM yields of high nutritive value. This has led to a strong focus on the integration of complementary forage across dairy systems in both Australia and New Zealand.

Dairy producers have long recognised the limitations associated with seasonality of pasture supply and large year-to-year variations in annual pasture production. They have adapted strategic management responses such as calving date, stocking rate, use of irrigation, and forage conservation to lessen these influences and improve the balance between feed demand and supply. One of the most common uses of complementary forages is to even out the supply of forage throughout the year and to reduce the reliance on conserved feed and concentrates to fill feed gaps (Pritchard *et al*. 1991). Examples of this include the use of alternative pasture grasses that extend the growing season into summer, e.g. tall fescue (*Festuca arundinacea* Schreb.) in south-west Victoria (Chapman *et al*. 2008*b*) and in the Waikato region of New Zealand (Clark *et al*. 2010) or growing

Table 1. The regional milk supply, climatic zone, main feed source and farming system for each of the major dairy regions of Australia and New Zealand
Australia milk production by region for 2010–11, sourced from Dairy Australia (2012). Major feed source for Australian zones and farming system adapted from (Barlow 2008) and Dairy Australia (2011*b*). Feed source for New Zealand farm system types for 2010–11 from DairyBase (DairyNZ, Diane Sutton, pers. comm.)

Australian region	% of milk supply	Australian climatic zone	Main feed source and farming system (FS)
Gippsland regions of Victoria	24%	Temperate: no dry season warm summer	Non-irrigated perennial ryegrass/white clover pasture, (39% FS 1, 53%, FS 2, 8% FS 3)
South-west Victoria	23%	Temperate: distinctly dry (and warm) summer	Non-irrigated perennial ryegrass/white clover pasture, (41% FS 1, 47%, FS 2, 8% FS 3, 2% FS 4, 2% FS 5)
Northern irrigation and north-east regions of Victoria, Riverina and upper Murray region of New South Wales	20%	Grassland: warm persistently dry	Irrigated perennial ryegrass (19% FS 1, 48% FS 2, 15% FS 3, 15% FS 4, 2% FS 5)
Tasmania	8%	Temperate: no dry season, mild summer	Irrigated and non-irrigated perennial ryegrass/white clover pasture (66% FS 1, 26% FS 2, 6% FS 3)
Eastern New South Wales	8%	Temperate: no dry season, hot summer	Irrigated and non-irrigated temperate and subtropical annual and perennial grasses (15% FS 1, 51% FS 2, 15% FS 3, 15% FS 4, 4% FS 5)
Northern New South Wales to Far North Queensland	7%	Subtropical to tropical, Warm winters, hot summers, summer dominant rainfall	Irrigated and non-irrigated annual grass and legume pasture, subtropical grasses (14% FS 1, 49% FS 2, 20% FS 3, 5% FS 4, 8% FS 5)
South Australia	6%	Temperate: moderately dry winter warm summer	Irrigated and non-irrigated perennial ryegrass/white clover pasture, annual grasses and legumes (20% FS 1, 58% FS 2, 12 FS 3%, 3% FS 4, 7% FS 5)
South-west Western Australia	4%	Mediterranean: distinctly dry (and hot) summer	Non-irrigated annual grasses, irrigated perennial grasses, subtropical pastures (19% FS 1, 60% FS 2, 8% FS 3, 10 FS 4%)
New Zealand region	% of milk supply	New Zealand climatic zone	Main feed source and farming system (FS)
Waikato/Bay of Plenty/Central Plateau	33%	Temperate, high rainfall: often dry summer	Non-irrigated perennial ryegrass/white clover pasture; maize silage; some maize grain (5% FS 1; 27% FS 2; 38% FS 3; 24% FS 4 and 7% FS 5)
Lower North Island including Taranaki	19%	Temperate, high rainfall: occasional dry summer	Non-irrigated perennial ryegrass/white clover pasture; maize silage (9% FS 1; 26% FS 2; 37% FS 3; 18% FS 4, and 10% FS 5)
North and South Canterbury	17%	Cool-temperate high rainfall: cold winter, irrigated in summer	Irrigated perennial ryegrass/white clover pasture; kale (grazed) for winter feed on support land; increasing use of cereal grain (1% FS 1; 5% FS 2; 45% FS 3; 38% FS 4, and 10% FS 5)
Otago/Southland	17%	Cool-temperate high rainfall: cold winter, rarely dry summer	Non-irrigated perennial ryegrass/white clover pasture; kale (grazed) and swedes (grazed) for winter feed on milking platform or support land (7% FS 1; 26% FS 2; 40% FS 3; 24% FS 4, and 3% FS 5)
Northland/Auckland	7%	Temperate, high rainfall: frequently dry (and warm) summer	Non-irrigated perennial ryegrass/white clover pasture, often with significant presence of kikuyu (volunteer); maize silage (10% FS 1; 35% FS 2; 32% FS 3; 16% FS 4, and 6% FS 5)
West Coast/Tasman/Marlborough	4%	Temperate, high rainfall: rarely dry summer	Non-irrigated perennial ryegrass/white clover pasture (15% FS 1; 40% FS 2; 35% FS 3; 9% FS 4) and 1% FS 5)

summer forage crops (namely forage brassicas) in southern Australia and New Zealand to provide late summer–early autumn forage (Clark *et al*. 1996; Jacobs *et al*. 2001). In this situation, forages are often grown as part of the pasture renovation cycle so that the cost of the renovation is offset against the extra forage grown by the crop (Notman 1994). Use of winter cereals in the South Island of New Zealand (de Ruiter *et al*. 2002) and in southern Australia (Jacobs *et al*. 2009) has the potential to provide additional highly digestible forage in early to mid winter, a period when growth rates of perennial grasses are low. The use of single-graze winter cereals, such as forage oats (*Avena sativa* L.) and Doubletake triticale (*x Triticosecale*), on the south Island of New Zealand, yield up to 5.5 t DM/ha by mid July after a March sowing (de Ruiter *et al*. 2002). Likewise, multiple grazing of Doubletake triticale through winter provides a flexible forage source with the potential for a further 13.5 t DM/ha harvested for silage in late spring (de Ruiter *et al*. 2002).

Complementary forages can be used to manipulate seasonal feed supply on the milking platform and milking support areas. The use of brassica crops such as kale (*Brassica oleracea* var. *acephala*) or swedes (*Brassica napus* var. *napobrassica*), along with fodder beet (*Beta vulgaris* L.) for winter feed on dairy

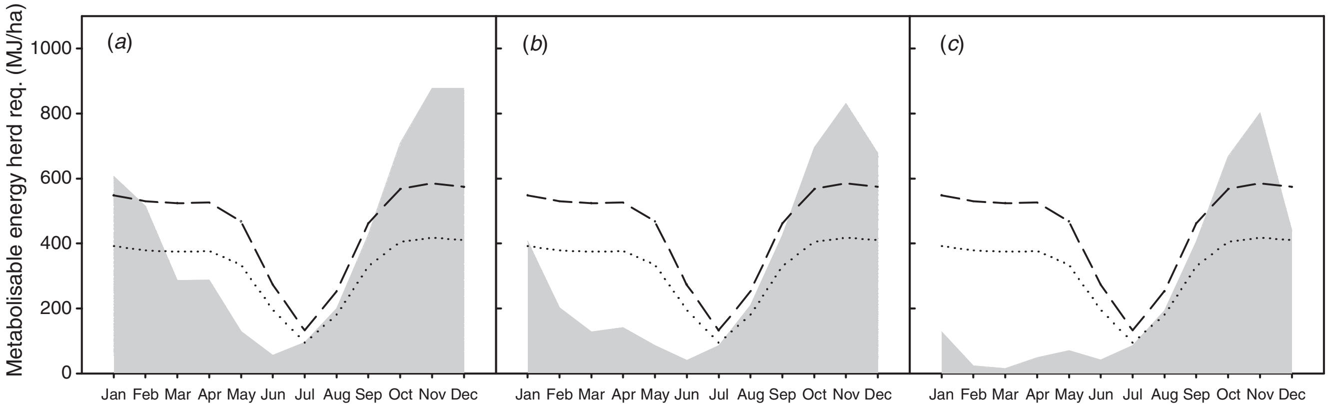

Fig. 1. The daily metabolisable energy (MJ) supply from pasture (shaded area) per ha for the temperate region of north-west Tasmania, for a top 10% forage production year (*a*), an average forage production year (*b*), and a bottom 10% forage production year (*c*) and herd requirements stocked at 2.5 (dotted line) and 3.5 (dashed line) cows per ha, calving in early spring and producing 400 kg MS/cow.lactation (R. P. Rawnsley, unpubl. data).

support land in the South Island of New Zealand is an example of this strategy. This allows higher stocking rates to be sustained on the milking platform than would otherwise be possible due to low winter pasture growth rates (Judson *et al*. 2010) and also allows farm pasture cover (average kg of DM measured across the farm) to increase to target levels for the start of calving in early spring. Common practice is to plant these crops on support areas in mid spring (generally mid October to early November), and feed them in winter at allowances of 10–14 kg DM per cow per day (plus forage supplement, such as silage or straw) for 50–70 days before cows return to the milking platform for calving. Crop yields of 12–18 t DM/ha for kale and swedes, or 20 t DM/ha for fodder beet are commonly achieved in Canterbury and Southland (Judson and Edwards 2008; Judson *et al*. 2010). While there are some health concerns with forage brassica- or fodder beet-based diets (e.g. nitrate poisoning, acidosis) these can be effectively managed by adapting cows onto crops through a transition period and by the use of fibre supplements (Judson *et al*. 2010). This complementary forage strategy, largely developed by dairy farmers, has helped facilitate a doubling of cow numbers in the Canterbury and Southland region over the past 10 years (Anonymous 2002; DairyNZ 2011).

Complementary forages have been used to improve and balance the nutritive value of the diet being offered to dairy cows. Maize (*Zea mays* L.) silage has been successfully integrated into dairy systems both in Australia and New Zealand (Pritchard *et al*. 1989). Maize is high in starch and fibre and low in protein. Maize complements a diet that is low in fibre and high in protein, which describes a typical perennial ryegrass-based pasture in winter and early spring. The use of forage brassicas over summer and early autumn in southern Australia enables the addition of a high energy, low fibre feed during a period where available pasture and conserved hay or silage are all high in fibre (Fariña *et al*. 2011*a*).

Complementary forage options have also been adopted to gain more from a limited resource base. Forage crops can be up to 250% more water-use efficient than shallow rooted pasture species such as perennial ryegrass and the DM yield potential of forage crops often exceeds that of a pasture over the same period. In Victoria, the water-use efficiency for total water received (irrigation plus rainfall) of turnips (*Brassica rapa* L.) was 48.0 kg DM/mm (Jacobs and Ward 2003) and millet (*Echinochloa utilis* cv. Ohwi and Yabuno) was 28.1 kg DM/mm compared with 22.2 kg/DM mm for perennial ryegrass (Jacobs *et al*. 2004). Similarly in subtropical south-east Queensland, the water-use efficiency for maize for total water received was 46 kg DM/mm, which was 2–3 times higher than for annual ryegrass (Callow and Kenman 2004). In New South Wales under non-limiting N and water conditions, irrigation and total water-use efficiency of maize ranged from 61 to 70 and from 36 to 42 kg DM/mm, in paddock- and plot-scale experiments, respectively (Garcia *et al*. 2008; Islam and Garcia 2012*b*). Irrigation-use efficiency of forage rape (*Brassica napus* L. cv. Goliath) ranged from 47 kg DM/mm (Garcia *et al*. 2008) to 80 kg DM/mm (Islam and Garcia 2012*a*). Total water-use efficiency of forage rape was 29 kg DM/mm (Garcia *et al*. 2008). Clearly, integrating forage crops in a farming system can be viewed as a way to maximise water-use efficiency (t DM produced per ML of irrigation water applied) and land yield potential (t DM produced/ha of available land). However, the decision to grow a forage crop should not be based on such metrics alone but on how the crop complements the whole-farm system including both farm profit and risk. This requires a detailed understanding and analysis of the whole system.

Integrating complementary forages at the whole-of-system level

García and Fulkerson (2005) highlighted the need to develop dairy systems with greater productivity to alleviate the increased competition for agricultural land and water in New South Wales, and also to offset the long-term declining terms of trade. This led to detailed component and farm system experimentation examining the potential of complementary forage rotations (CFR) under irrigation. In a 3-year field study Garcia *et al*. (2008) produced 42 t DM/ha.year from a CFR comprising of an annual sequence of maize, forage rape and a legume (Persian clover, *Trifolium repesinatum* L. or maple pea, *Pisum sativum* L.). This was compared with the pasture (control) treatment [kikuyu grass (*Pennisetum clandestinum*) over-sown with short-rotation ryegrass (*Lolium multiflorum* L.)], which yielded 17 t DM/ha.year. A CF system was also established in which the CFR and pasture on the farmlet area were proportioned at a ratio of 35 : 65. Consumption of forage from the CFS was over 26 t DM/ha.year and resulted in 2159 kg milksolids (MS)/ha from home-grown feed (Fariña *et al.* 2011*a*). The 2-year physical dataset generated in this study was used as a basis of a comprehensive modelling study that included the combination of biophysical models [Agricultural Production Systems Simulator (APSIM), DairyMod and Farmax Dairy Pro], budgeting software (New South Wales Department of Primary Industries Milk Biz Whole-Farm Budgeting Program version 3.2.1) and risk analysis software (@Risk version 4.0.5, Palisade Corporation, Newfield, NY, USA). The study compared the economic impact and potential risks (associated with climatic and feed price variability) of the CF system and a pasture plus concentrate system. On average the CF system achieved over 30% more operating profit/ha than the pasture plus concentrate system (S. R. Farina, unpubl. data). The CF system was also less sensitive to variability in both climate (due to higher and more uniform responses to irrigation water used in summer for high-yielding forage crops) and feed price (due to lower dependence on bought-in feed) than the pasture plus concentrate system. The study demonstrated the economic sustainability of intensification options based on increasing home-grown feed through better use of complementary forages.

Chapman *et al.* (2006) also identified the need for continued productivity gains on-farm to counter declining terms of trade. In southern Australia it was clear that top producers are already achieving close to the ceiling of pasture production potential from the traditional perennial ryegrass base. While the CFR and CF system work proposed by García and Fulkerson (2005) addressed the limitations of land and water availability (Garcia *et al.* 2008; Fariña *et al.* 2011*a*), further work in southern Australia addressed the strong seasonality associated with perennial ryegrass in a non-irrigated environment, the high inter-annual variation in pasture production and the limited pasture persistence (Chapman *et al.* 2006, 2008*a*). Chapman *et al.* (2008*a*) proposed for the non-irrigated dairy regions of southern Australia that home-grown forage consumption could be increased by 30%, by integrating other pasture species and forage crops into the perennial ryegrass pasture base. It was hypothesised that a 30% improvement in consumption of home-grown forage would lead to a 30% improvement in return on assets. Initial modelling by Chapman *et al.* (2008*b*) identified that the 30% improvement in production could be obtained through the inclusion of a double crop (winter forage cereal and summer brassica) and a more active summer pasture (tall fescue) system (also termed complementary forage system) compared with a perennial ryegrass-only system (RM). They also concluded that the herbage accumulation in the CF system was more consistent across years than RM system. It was suggested that the CF system would provide farmers with a more predictable operating profit from year to year (Chapman *et al.* 2008*c*). When tested within a 4-year farmlet experiment, the increase in DM production was confirmed with on average 31% more home-grown forage being consumed per ha in the CF system compared with the RM system (Cullen *et al.* 2012*a*). However, this only translated into a 3% higher return on assets, much less than expected because of the strong performance and profitability of the perennial ryegrass-based farmlet, generally low DM yields of summer brassica crops related to drier-than-average climatic conditions, lower than expected consumption rates and nutritive value of whole crop silage made from winter-grown cereals, and failure of tall fescue-based pastures to improve the seasonal distribution of pasture supply (Cullen *et al.* 2012*a*). Compared with the RM system, the profitability of the CF system fluctuated more in the face of year-to-year variability in climatic conditions and milk price, and therefore carried a higher business risk. Subsequently, these farmlets were modified and continued for a further 2 years. Key modifications included a higher stocking rate in the RM system and for the CF system, a focus on high rates of perennial ryegrass renovation using grazeable forage options, thus reducing the reliance that the CF system previously had on high amounts of conserved forage from winter cereals. Results from the second year of this revised experimental design (first year was considered a transition year) showed that 16% more home-grown forage was consumed from the new CF system and this resulted in a 10% increase in return on assets (Cullen *et al.* 2012*a*).

While the initial CF system was capable of growing more feed and resulting in greater consumption of home-grown feed per ha, the additional costs associated with forage conservation, feeding out and DM losses through this process, coupled with greater exposure to poor seasons (short springs and dry summers) meant that this did not translate to significantly greater profit. Furthermore, the perennial ryegrass system performed above expectation and highlighted that there is further opportunity for many producers to exploit this potential. When the CF system was re-designed and focussed on producing more feed for direct grazing, associated costs were reduced and the system became more profitable and offers potential for the future.

Compared with southern Australia and New Zealand, the feedbase systems utilised within the subtropical dairy regions of northern Australia are more varied. A relatively common and simple feeding system in northern Australia is grazed tropical grasses during summer, grazed temperate pasture during winter, conserved feed fed out in autumn and grain based concentrate fed during milking throughout the year, with cows batch-calved during autumn and spring. More complex partial mixed ration systems calve all year and use detailed ration formulation and feed-out systems, with varying amounts of crops and pastures for grazing and conservation, usually with some irrigation (Chataway *et al.* 2010*a*). In 2000, milk producers in northern Australia were required to make rapid adjustments to their production systems to enable them to compete in a newly deregulated market. Studies were initiated to evaluate the effect of intensifying dairy production on profitability in the context of the whole-farm system. Five different production systems considered to have relevance to northern Australia were modelled. Four of these systems maintained a grazed forage base and had the potential to increase milk output 3-fold by increasing milking cow numbers and level of purchased supplementary feed without having to expand the land area. The fifth system was a feedlot system and involved feeding a total mixed ration comprised of grain, maize silage, barley silage, and lucerne hay (Callow *et al.* 2005). A field evaluation of the modelled milk production systems was conducted over 4 years with five farmlets established in a subtropical environment of south-east Queensland (Chataway *et al*. 2010*b*). For the grazed systems, mean annual milk yield per ha ranged from 866 kg MS (1.9 cows/ha) for a system based on rain-fed tropical pastures to 1619 kg MS (3.0 cows/ha) where cows were fed temperate and tropical irrigated forages. For the feedlot herd, annual milk yield of 2924 kg MS/ha (4.3 cows/ha) was achieved through the use of high levels of concentrates (~3 t DM/cow). Decreased forage DM production caused by adverse environmental conditions with below average rainfall and restrictions on irrigation were offset by purchasing conserved fodder ranging from 0.3 to 1.5 t DM/animal. While these farmlets showed that it was relatively simple to achieve high milk production from intensifying farming systems (Chataway *et al*. 2010*b*), it was difficult to define the appropriate phasing and sizing for each dairy system to match labour and budgetary constraints. Unpredictable environmental conditions, poor seasonal growth and uncertainty in milk price increase the risk of business failure particularly during periods of rapid intensification (Walker *et al*. 2007).

In the Waikato region of New Zealand, a ‘Super Productivity’ system was operated for 3 years, with the aim of lifting total annual milk production to 1750 kg MS/ha, compared with the 1500 kg MS/ha (including off-farm area used for growing maize silage), deemed to represent the upper level of production achieved in the New Zealand dairy industry up to 2006–07 (Glassey 2009). The forage plan for the system sought to provide all the feed needed for this production from within the milking platform area of the farm. The forage plan was based on replacing old pasture with new perennial ryegrass and white clover (*Trifolium repens* L.) cultivars; and growing forage crops (predominantly maize, followed by annual ryegrass) on 25% of the farm area, which were expected to yield a minimum of 29 t DM/ha.year (Glassey 2009). Compared with a benchmark all-grass farm system, the Super Productivity farm aimed for an additional 3.8 t DM/ha consumed to support higher per cow production and an additional 0.5 cow/ha. Over the 3 years of the study, estimated DM and feed energy production were within 1% of target, but production per cow fell 11% below target due to fewer than expected days in milk resulting from failure to shift the seasonal pattern of feed production sufficiently to extend lactation into late autumn. An additional 2.8 t DM/ha was grown on the Super Productivity farmlet compared with the benchmark farmlet, of which 2.0 t DM/ha came from increased pasture herbage accumulation (partly explained by an additional 33 kg N fertiliser per ha per year), and 0.8 t DM/ha from the crops grown. While the Super Productivity system resulted in an additional 340 kg MS/ha, costs of production were higher ($3.08 versus $2.65/kg MS in benchmark), operating expenses were $1297/ha greater, and mean return on assets was 7.3 versus 6.0% per annum in the benchmark system. Glassey (2009) concluded that the Super Productivity farmlet ‘required both consistently higher payouts and improved feed production for it to be reliably superior in profitability to the benchmark farm’.

In examining the performance of perennial ryegrass in relation to that of alternative forage systems in south-west Victoria, Chapman *et al*. (2008*c*) found that in good years (defined as having early autumn and long spring growth), integrating complementary forages into the feedbase could not exceed the profitability of the perennial ryegrass only feedbase. However, in average or poor years (e.g. shorter growing seasons), integrating complementary forages could match and exceed the profitability of a perennial ryegrass-only feedbase. In the cool temperate growing regions of Tasmania where perennial ryegrass has been shown to yield in excess of 20 t DM/ha under irrigation (Rawnsley *et al*. 2007*b*) and also under rain-fed conditions in the high rainfall (>1000 mm/year) regions (Cotching and Burkitt 2011), replacing a productive perennial base with an annual forage crop is rarely economically viable. In this environment, annual forage crops are more effective when integrated as either part of a renovation cycle or used to improve the utilisation of support land (Rawnsley *et al*. 2007*a*; Pembleton and Rawnsley 2011).

While most of the studies described so far have concentrated on manipulating feed supply (quantity), feed nutritive value and DM intake can also limit milk production especially in summer and autumn in the absence of irrigation. Woodward *et al*. (2008) extended the idea of complementarity by designing a system based largely on legumes to deliver forage of higher nutritive value (mimicking a forage ‘total mixed ration’, FMR), and comparing production and profit with a system based on conventional perennial ryegrass-white clover pasture. Each system was represented by a farmlet located in the Waikato region, New Zealand. The FMR system, which included lotus (*Lotus corniculatus* L.), lucerne (*Medicago sativa* L.), white clover and red clover (*Trifolium pratense* L.), resulted in lower total DM yield than the ryegrass/white clover control (mean over 2 years of 15.5 and 18.7 t DM/ha per year, respectively), but higher milk production (+7.7% per cow and per ha), most of which was captured in the late summer–autumn period due to higher nutritional value of the diet. Averaged across the 2 years of the trial, the FMR system increased economic farm surplus by 11%. However, Woodward *et al*. (2008) noted that the finding of higher profitability in FMR should be treated cautiously, since the experiment was conducted for only 2 years, and the true persistence of some of the species used (and, hence, costs of pasture maintenance) was not fully tested. On the positive side for the FMR system, the legume-dominant forage base (including lotus, a tannin-containing species) could offer environmental benefits such as reduced methane emissions (Woodward *et al*. 2004) and a higher proportion of excreted N being partitioned to faeces compared with urine which should reduce the risk of N leaching from urine patches (Haynes and Williams 1993; Fraser *et al*. 1994). However, these benefits have been difficult to capture in pasture legume mixtures, where the legumes have had poor agronomic performance and associated low abundance and persistence (Edwards *et al*. 2008).

The collection of complementary forage work undertaken across both Australia and New Zealand highlights the importance of understanding the challenges of the current feedbase and level of complementarity that is needed to improve profit and/or alleviate/mitigate against adverse outcomes. The work undertaken in south-west Victoria by Chapman *et al*. (2008*a*) suggested that a greater financial return may be possible from perennial ryegrass-based systems than previously recognised and there was little evidence to support the idea of moving substantially away from the perennial ryegrass base in pursuit of greater profits. However, Cullen *et al*. (2012*a*) highlighted that if the focus of the complementary forages is to provide additional grazeable feed and this is integrated into the system as part of a proactive renovation program then there may be opportunity for such options to improve profitability of dairy systems.

We consider that a key feature driving the positive relationship between farm profitability and home-grown forage use across Australia and New Zealand is the perenniality and grazeable nature of the current feedbase. Alternative grazed perennial forage species within the family Poaceae (grasses) and from families other than Poaceae should be further explored to address limitations of the current feed base. Edwards and Bryant (2011) highlighted that, in New Zealand, the identification of the appropriate perennial ryegrass ecotypes or combination of ecotypes for a dairy farm is an important decision to improve pasture production, persistence and nutritive value. Current cultivars have a range of flowering times of ~6 weeks and there is a strong relationship between early spring growth and early flowering (Kemp and Culvenor 1994). Edwards and Bryant (2011) suggested that sowing paddocks of ryegrasses with different flowering dates on farm will help improve early spring and late spring growth and assist in maintaining pasture nutritive value and DM intakes throughout spring and into summer. While the breeding of perennial ryegrass has focussed on improved annual herbage production and it is suggested that this has achieved genetic gains of ~0.5% per annum (Woodfield 1999), seasonal distribution of the feed supply and better matching this supply with feed demand during key periods, is also considered desirable (Easton *et al.* 2002).

Nie *et al.* (2004) compared deeper rooted perennial grasses [tall fescue, phalaris (*Phalaris aquatica* L.) and cocksfoot (*Dactylis glomerata* L.)] with perennial ryegrass for 4 years in south-west Victoria and observed less inter-annual variability in total herbage accumulation and growth rates for these alternative perennial pastures. Similarly, Christie *et al.* (2005) found that when dairy cows grazed pasture swards dominated by either prairie grass (*Bromus willdenowii* Kunth.) or cocksfoot, there was no difference in milk production compared with perennial ryegrass-dominant swards. The ability to combine differing species and/or cultivars across the milking platform with varying distributions of feed supply and/or nutritive characteristics, whilst maintaining the grazeable nature and perenniality of the feedbase might have been somewhat overlooked in the pursuit of more substantial gains in total annual forage production.

Modelling complementary forages

Lee *et al.* (2012) highlighted that substantial value could be gained by using growth rate data in a modelling approach, followed by on-farm validation experiments to quantify and extend the potential benefits of combining species on farm. The majority of modelling associated with complementary forages has been undertaken at a biophysical level where observed DM yields have been compared with simulated DM yields. For ryegrass pastures the biophysical model DairyMod (Johnson *et al.* 2008) has been shown to satisfactorily simulate pasture DM yields across dairy regions of Australia and New Zealand (Cullen *et al.* 2008) and also under varying management inputs such as irrigation (Rawnsley *et al.* 2009). There is a paucity of modelling information relating to the production of complementary forages and a clear gap exists in the current range of models available to the dairy industry to investigate and predict the interactions between forage crops and other system components. APSIM (Keating *et al.* 2003) is a biophysical model that was developed to explore interactions between soil, climate, crops and management practices within the Australian broadacre cropping industries and is now used worldwide across a range of agricultural systems. Recent evaluations of the accuracy of APSIM in simulating DM yield, phenology and nutritive characteristics of forage crops grown in the dairy regions of south-eastern Australia (K. G. Pembleton, unpubl. data) concluded that APSIM can be used with confidence to explore the influence of crop management and environment on forage crop DM yield and phenology (Fig. 2). However, the ability to simulate herbage nutritive characteristics was somewhat limited and should be the focus of future research and model development.

Developing and validating models for simulating the growth of complementary forages provides a cost effective approach to the evaluation of inter-annual performance and the influence of agronomic management on production (e.g. Pembleton *et al.* 2011), while also providing a means to evaluate the performance of a broad range of crops under future climate scenarios. However, as stated by Jacobs and Woodward (2010), when scaling up from both modelling and component studies there needs to be consideration given for reductions in realised DM yields due to a range of factors including increases in spatial variation and the ability to impose consistent and timely management as the scale of operation increases. In addition, it is important to evaluate model capacity to capture the complementarity that can exist at the soil and plant level when simulating CFR. Garcia *et al.* (2007) provided a list of soil–plant complementarity interactions. While forage rotations can be productive in terms of total biomass production, they can also create unforeseen problems, for example, greater soil disturbance than a permanent pasture, a potential decreases in organic matter content and a more difficult environment in which to control weeds (Stevenson *et al.* 1997; Houlbrooke *et al.* 2009). Potential positive outcomes can include greater N capture (Kristensen and Thorup-Kristensen 2004), improved nutrient utilisation (Merrill *et al.* 2002) and increased development and distribution of biopores and microbial communities (Ball *et al.* 2005). It is therefore critical that our current evaluation of biophysical models not only considers the ability to simulate DM yields but also the interacting components.

The future for complementary forages

Although the majority of work on complementary forages has focussed on increasing the total biomass grown and the conversion of additional home-grown forage into milk, other external and/or future pressures should be considered in deciding whether to integrate complementary forages into the feedbase. An emerging challenge for the Australian dairy industry is to develop productive and profitable systems that are adapted to a warmer and possibly drier climate, rely less on irrigation and minimise greenhouse gas (GHG) emissions per unit of production. Indeed, Cullen *et al.* (2012*b*) and

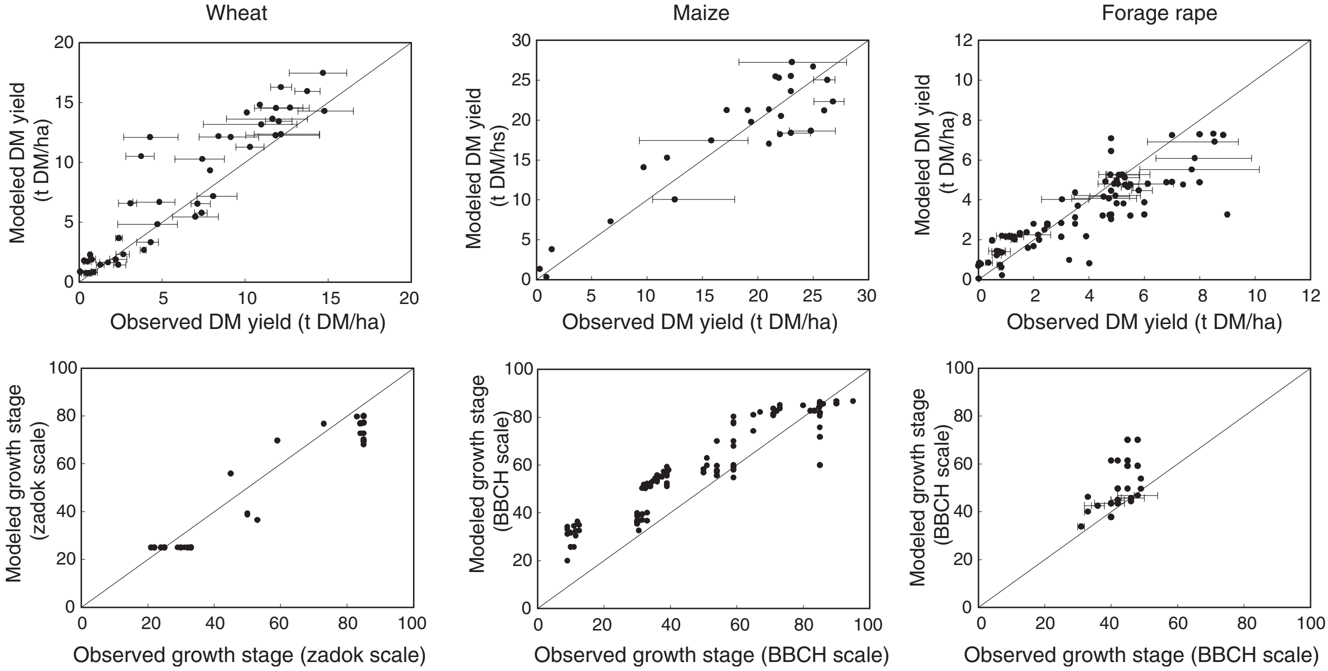

Fig. 2. An example of the ability of the Agricultural Production System Simulator (APSIM) to predict DM yield and phenology of annual forage crops (shown as scatter plots of observed values vs. modelled values) grown in the south-east Australian dairy regions. Error bars represent the range in observations where more than one observation made up a data point. Source K. G. Pembleton (unpubl. data).

Cullen *et al*. (2009) showed that the annual DM production of perennial ryegrass in temperate regions such as southern Victoria is likely to decline with more than 2°C warming, especially if this is associated with lower rainfall and shorter growing seasons. In contrast, in cooler temperate regions like north-west Tasmania, warming with associated increases in atmospheric carbon dioxide concentration are expected to increase perennial ryegrass production (Holz *et al*. 2010; Cullen *et al*. 2012*b*). There is an emerging body of evidence to suggest that alternative forage species will play an important role in complementing perennial ryegrass as the main forage source for dairy production in future warmer and drier climates. Desirable traits in perennial species include deeper roots, increased summer activity or tolerance for high temperatures and higher water-use efficiency (Cullen *et al*. 2009; White and Snow 2012).

Biophysical modelling with APSIM was undertaken to compare the production potential of double cropping forage options to that of rain-fed perennial ryegrass under future climate scenarios (K. G. Pembleton, unpubl. data). Historical climate data from north-west Tasmanian and south-west Victoria along with two warmer and drier future climate scenarios were used. The warmer and drier climate scenarios were created by scaling the historical weather data by a 1 or 2°C increase in mean air temperature, with a corresponding 10% ('+1/–10' scenario) or 20% ('+2/–20' scenario) decline in rainfall, with atmospheric carbon dioxide concentrations of 435 and 535 ppm, respectively. The +1/–10 and +2/–20 climate scenario represent possible climates in 2030 and 2050, respectively (IPCC 2000; CSIRO and BoM 2007). This modelling suggests that in the cool temperate climate of north-west Tasmania, there appears to be no benefit in shifting away from a perennial ryegrass base to a double cropping system, although in the relatively warmer and drier climate of south-west Victoria the potential DM yield benefits of moving to a complementary forage system appear likely to increase under a future climate scenario (Fig. 3 upper panels). While there was only between a 0 and 2.5% increase in the risk of crop failure between the baseline and future climate scenarios for the forage systems shown in Fig. 3, some other forage systems investigated (data not shown), which involved later sowings of the spring–summer crops had up to a 25% increase in the risk of crop failures. One of the major limitations to the success of double and triple cropping systems is the limited time window to establish successive crops (García and Fulkerson 2005).

The biophysical modelling data presented in Fig. 3 (upper panels) were then used within the dairy farm system model Dairy Predict (Walker and Simpson 2006) to explore the inclusion of the annual forage system on 20% (selected as intermediate level between 10 and 30%) of the milking area within a perennial ryegrass based system for a north-west Tasmanian and a south-west Victorian dairy farm (B. R. Cullen, unpubl. data). The inclusion of an annual forage cropping system into the perennial pasture base reduced the gross margin of the north-west Tasmanian dairy farm under both the current and future climate scenarios (Fig. 3 lower panels). In contrast, the gross margin of the south-west Victorian dairy farm remained steady when an annual forage system was included under the baseline scenario, and increased with the inclusion of the annual forage cropping system under both future climate scenarios. This highlights that while in some environments under current climatic conditions, complementing

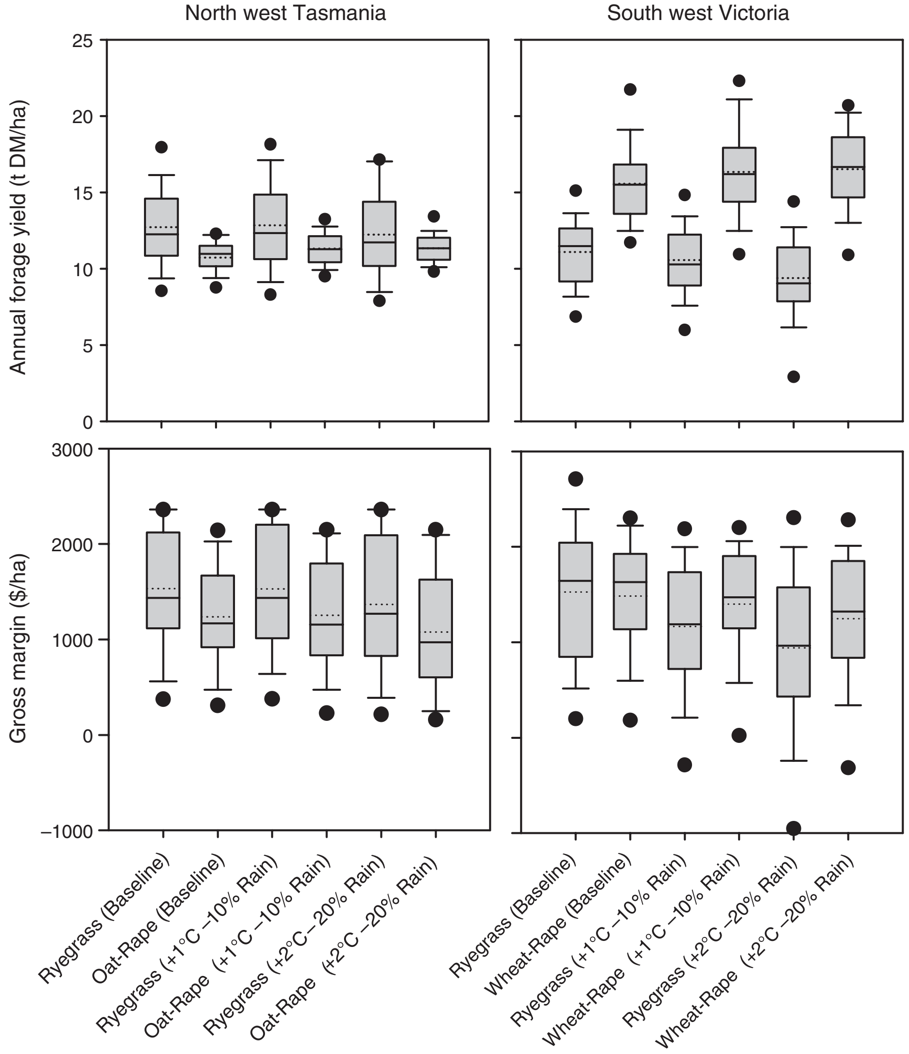

Fig. 3. Box-plots (5th, 10th, 25th, 50th, 75th, 90th, and 95th percentile, with dotted mean line) of the annual forage yield of perennial ryegrass pastures and forage cropping systems (upper panels) and the gross margin of pasture-based dairy farms incorporating annual forage crops onto 20% of the milking area under current (baseline), 2030 (+1°C –10% Rain) and 2050 (+2°C –20% Rain) climate scenarios (lower panels). Source K. G. Pembleton (unpubl. data) and B. R. Cullen (unpubl. data).

temperate pastures with annual forage crops may only be marginally economically viable, their inclusion in the future may assist to mitigate some of the negative consequences of climate change on farm profitability.

The farm systems described in Fig. 3 were assessed for their GHG emission profiles using the industry recognised greenhouse accounting tool Dairy Greenhouse gas Abatement Strategies Calculator (Christie *et al.* 2011). This assessment showed that there was little difference in the GHG emission intensity of milk production (kg carbon dioxide equivalents/kg MS) between the feedbase options and the climate scenarios, indicating limited potential to manipulate the forage base to mitigate the emissions associated with milk production (B. R. Cullen, unpubl. data). However, it is important to note that the emission estimates are based on current GHG inventory methods only, and that future research quantifying GHG emissions associated with differing complementary forage systems may potentially lead to changes in the inventory calculations. For example, Woodward *et al.* (2004) found lower methane emissions per unit of MS when animals were fed diets based on *Lotus corniculatus* compared with those fed perennial ryegrass. While perennial pasture species lend themselves to low input systems of production, the increased pasture DM yield required to support modern dairy production has reduced their nutrient-use efficiency (particularly N-use efficiency). Garcia *et al.* (2008) identified that a CFR based on maize, forage rape and Persian clover (*Trifolium resupinatum* L.) had over a 100% improvement in N-use efficiency compared with that of an intensively managed pasture based on kikuyu (*Pennisetum clandestinum* Höchst.) over-sown with annual ryegrass annually. These findings highlight the potential that the integration of complementary forages may have for improving N-use efficiency and lowering the GHG emissions per unit of milk production, although significantly more research is needed to quantify this.

The intensification of the pasture base through higher stocking rates has resulted in some producers coming close to reaching their ceiling of pasture consumption per ha and only modest increases in stocking rate are foreseen. In conjunction, some dairy regions are also forecasting significant industry growth. For example in Tasmania, the dairy industry is entering a major expansion phase with significant investment and increases in the milk processing capacity leading to a projected increase in demand for milk of up to 40% over the next 5 years (DairyTas 2012). Similarly, projected industry growth of 60–65% is anticipated in the South Island of New Zealand over the next 20 years (DairyNZ 2010). Although some industry growth can be expected through the intensification of existing dairy businesses, these potential large increases in milk demand are likely to result in non-dairy marginal areas (e.g. run-off blocks) and other farm enterprises (e.g. cropping, beef and sheep) being converted into milk-producing land. Although this potential industry growth in these regions is viewed as being extremely positive, there are several potential difficulties when moving dairying into more marginal environments. The integration of complementary forages could play a significant role in alleviating such challenges as lower soil fertility/poorer soils, reduced availability of irrigation water and a more marginal environment with respect to climatic extremes and pasture production.

Conclusion

Studies integrating complementary forages at the whole-of-farm system, particularly in the temperate environment of southern Australia and New Zealand, which are most favourable to perennial ryegrass pasture production, have found little evidence for major improvements in farm profits when moving away from this pasture based system. This is most likely due to the overarching benefits of the grazeable and perennial nature of the pasture base in comparison to the cutting and conservation required to maximise the utilisation of many annual forage crops. This highlights that for regions that are most conducive to maintaining a perennial and grazeable feedbase, opportunities exist to integrate grazeable perennial forage species to address some of the limitations of the ryegrass base. The findings of other studies reported in this paper have highlighted that complementary forages do have the capacity to alleviate some of the limitations of the pasture base and their adoption has the potential to advance the dairy industry particularly in dairy regions with constrained land and water availability. Efforts to understand their integration at the whole-of-farm system have been invaluable and further understanding is required to support their advancement, particularly if limitations to the pasture base have the potential to become more prevalent into the future due to a changing climate, increasing demands for greater environmental stewardship, dairy moving into more marginal environments and increasing competition for land and water resources. Enhancing our understanding and ability to simulate the growth and development of complementary forages and their complementarity at both a biophysical and whole-of-system level is viewed as important to further advancement of the Australian and New Zealand dairy industries.

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