THE UNIVERSITY OF SYDNEY

DAIRY RESEARCH FOUNDATION

Current topics in Dairy Production
Volume 15

2010

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Published By:
University Printing Service Sydney

TABLE OF CONTENTS


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ACKNOWLEDGEMENTS

The Dairy Research Foundation acknowledges, with gratitude, assistance provided to stage this Symposium at Camden, NSW in 2010. At the time of printing, generous support has been provided by the following sponsors:

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We would like to sincerely thank the NCFH for their participation in the 2010 Symposium. This is an extremely important issue amongst the farming community and we value their contribution at this year's event.

The staff of the **DAIRY SCIENCE GROUP** in Camden plays an integral part in the staging of the Annual Symposium. With out their dedication and assistance this event would not be possible. Thank you all!

PREFACE

Welcome to the 2010 Dairy Research Foundation (DRF) Symposium, which marks the 51st anniversary of the DRF. The DRF has proudly supported research in Dairy Science for more the half a century by integrating cutting edge research with extension activities to disseminate this information among dairy farmers nationally and internationally.

The focus the 2010 DRF Symposium is on the future and the core component of the program is farm and farmer's health. The program includes a variety of technical sessions addressing key issues such as feeding healthy forages, increasing dairy cows' reproductive fitness, managing healthy dairy farming systems and improving cow's health. In addition, this year we have organised a Farmer's Health workshop, where the DRF Symposium delegates will have the opportunity to have a free health check and an overview of farmer's health will also be presented.

During the first day Dr Charlotte Westwood (PGG Wrightson, New Zealand), Dr Neil Moss (SBScibus, Australia) and Kerry Kempton and Anthea Lisle (I&I, NSW) will present the latest findings on feeding systems for high producing dairy cows. Dr John Roche (Dairy New Zealand), Matt Izzo (University of Sydney) and Joe Chittick and sons (Dairy Farmers, NSW) are the main speakers of the "Healthy herds" session: they will provide an insight on the key drivers of reproductive efficiency in dairy cows.

As always, a great and enthusiastic group of young scientists will present their work in very brief presentations to make the industry aware of their work. This year we will have students from four Universities: University of Sydney, University of New England, Charles Sturt University and University of Queensland. The DRF Symposium is a great opportunity for young scientists to sharpen their presentation skills, to become familiar with the dairy industry but it also provides young scientists an excellent meeting ground to discuss their research projects with their peers, farmers, industry providers and researchers.

During the second day the focus will be on Healthy Farming Systems and healthy Cows. Professor Tim McAllister (Agriculture and Agri-Food Canada), Dr Ian Lean (SBScibus, Australia) and Lynne Strong (Dairy Farmer, NSW) will share their views on sustainable nutritional management of the modern dairy cow, the importance of prepartum transition diets and nutrition and feeding in practice, respectively. Professor Michael Doherty (University College Dublin, Ireland), Dr Alison Gunn (University of Sydney) and Victor Rodwell (Dairy Farmer, Western Australia) will discuss the latest development in the management of production diseases in dairy cows.

In line with the feedback that we have received after last year's Symposium there will be one 'workshop' or discussion session on each day, in which the Symposium delegates will have the opportunity to discuss key points, messages and issues in relation to what was presented during the different sessions.

The DRF Symposium will be concluded with a farm visit to Camden Park Dairy, one of the oldest working dairy farms in Australia. Camden Park is part of the historical site started by John and Elizabeth Macarthur in the 18th century.

We are grateful for the support of DairyNSW, National Foods and Bega Cheese for their support of the Young Farmer Program. This support gives young dairy farmers the opportunity to attend the Symposium.

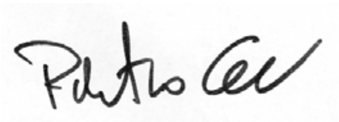
The winner of the 2010 Milk Marketing NSW Dairy Award is Dr Ian Lean, who has given a significant contribution to the Australian Dairy Industry by providing guidance and leadership as an academic, researcher and consultant, in the fields of medicine, nutrition and management of dairy cattle.

The Annual Symposium is made possible by the generous support of our corporate sponsors. Thank you all for your ongoing patronage of our event.

We would like to acknowledge the invaluable contribution of the DRF Symposium Committee and finally the Dairy Science Group (Faculty of Veterinary Science) for their help and support.

We trust that you will enjoy this year's Symposium.

Kind regards



Dr Pietro Celi Chairman of the DRF Symposium Organising Committee

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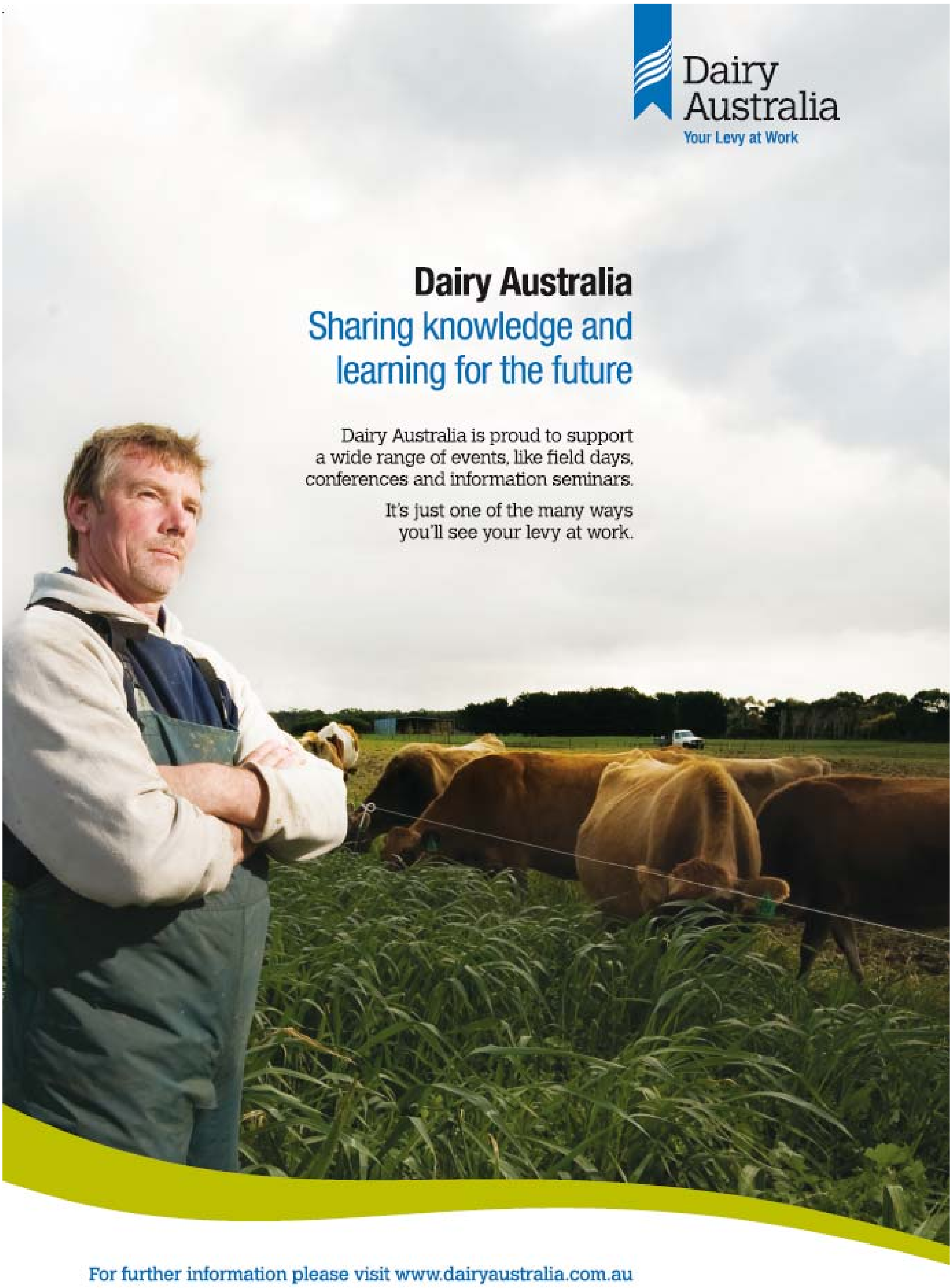
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OPTIMISING FEED INTAKE IN PASTURE BASED SYSTEMS:

HOW CAN WE GET THE MOST OUT OF PASTURE?

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Abstract

The intake of pasture dry matter (DM) by cows is a critical driver of profit for any Australian pasture-based dairy system. Pasture allowance (kgDM per cow per day) is positively associated with intake of pasture DM however excessive allowances may reduce utilisation of pasture grown. To develop an effective strategy that maximises intake of pasture by cows whilst utilising a high proportion of pasture grown requires a clear understanding of all drivers of pasture intake. Pasture DM intake (DMI) is a function of time spent grazing x bite size x bite rate. Bite size is a key driver of intake, as influenced by depth of bite into a sward and by density of pasture. Grazing time reflects management factors that influence time spent at pasture and is becoming increasingly constrained for some large dairy herds where cows spend prolonged periods of time away from pasture. Debilitating cow health conditions and / or management practices that suppress appetite will further reduce grazing time. Bite rate is a relatively fixed value for cattle and is less easily influenced by changes in management. The presentation of appropriate quantities of pasture to cows and the freedom of pastures from anti-nutritional compounds or contaminants that cause a psychogenic or behavioural aversion to the intake of pasture will improve both intake of pasture DM and utilisation of pasture. The supplementation of pasture-fed cattle with grains or forages will reduce pasture DMI through substitution, as will restriction of intake of drinking water for grazing cattle.

Developing a strategy for improved intake of pasture DM requires an understanding of the entire farm system, including cattle and the pastures that they graze, stock water access and the concurrent use of supplementary feeds.

Introduction

The use of grazing cows to harvest pasture *in situ* remains the cornerstone of the relatively simple, low-cost dairying systems of south eastern regions of Australia. The diversity of pasture type reflects multiple ecosystems characterised by wide ranging climatic, geographic and topographical parameters. Temperate southern regions favour the use of perennial ryegrass / white clover pastures, kikuyu pastures support dairying for coastal NSW whilst irrigated districts of Northern Victoria and Southern NSW combine paspalum-dominant summer pastures with an increasing trend towards the use of winter active annual and Italian ryegrasses. Irrespective of pasture plant species, the cost effective production of pasture and the efficient conversion of pasture to milk remains a common theme for almost all Australian dairy systems.

The success of a pasture-based dairy business is driven by key production indices including:

- Pasture grown (kilograms of dry matter (DM) / hectare / year) as influenced by pasture species, soil fertility, pH and drainage, topography, rainfall/irrigation and climate.

- Pasture utilised by cattle grazed *in situ* and / or taken as silage or hay (kgDM / hectare / year) expressed as a percentage of pasture grown, influenced primarily by stocking rate and by pasture management.

- Effective conversion of pasture consumed to milk yield and / or liveweight gain.

Profitable pasture-based dairying requires the balancing of effective utilisation of pasture grown with the delivery of appropriate nutrients that support the demands of an increasingly discerning high performance cow. The alteration of stocking rate (numbers of cows per hectare) between and within seasons is an important moderator of efficiency of pasture harvested. Exceptional pasture utilisation is driven by matching demand for pasture (numbers of cows) with the annual supply of available pasture grown. Conversely, attempts to fully feed high performance dairy cattle with pasture-only diets can reduce the utilisation of pasture. Inevitably a compromise is reached, with the nutritional demands of pasture-fed cows not always met in order to support optimal utilisation of pasture. Whilst stocking rate remains a key driver of dry matter intake (DMI), further moderators of pasture intake including health and well being of the cow, grazing management decisions and characteristics of the pasture species may prevent optimal harvest of pasture DM. This paper reviews concepts and ideals for pasture-fed cows with a specific focus on key drivers of DMI. Practical suggestions and ideas for improving the pasture intake of cows are discussed.

Drivers of pasture dry matter (DM) intake: The animal-pasture interface

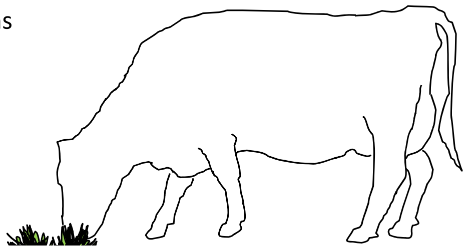
Cows that efficiently harvest and convert pasture DM to milk underpin the success of any dairy business. Successful conversion requires that managers present to cows appropriate allowances of high quality, easily harvested pasture to encourage optimal intakes by cattle whilst maximising utilisation of pasture grown. Multiple interrelating animal-centric factors interact with pasture attributes to collectively determine pasture DMI (Figure 1). No single pasture, animal or management attribute should be considered in isolation as a potential driver of DMI. Rather each component of the grazing system should be collectively considered, given the considerable interactions between each of these variables.

The Cow

- Desire to consume pasture
- Physiological state
- Freedom from disease
- Genetic merit
- Cow size
- Age
- Social interactions

Management of the pasture/cow interface

- Time for pasture allocation
- Duration of pasture access
- Pasture allocation on offer (kgDM/ha)
- Mob size and social competition



The Pasture

- Sward height and density
- Ease of prehension/harvest
- Quality: MJME, NDF, crude protein
- Dry matter percentage
- Pasture species and cultivar
- Anti-nutritional compounds
- Contaminants e.g. effluent

Concurrent/previous management practices

- Other dietry components (substitution)
- Feeding history
- Transitional management, calving
- Stock water quality and access

Figure 1. Factors that influence the consumption of pasture dry matter by cattle

The best managers of pasture-fed cattle generally have an excellent understanding of key drivers of DMI, acknowledging the interrelationships between time required by cattle to graze and the presentation of pasture that supports maximal DMI by the cow. Dry matter intake (kgDM per cow per day) is typically expressed as a function of:

Pasture Dry Matter Intake (DMI) = R x S x T

Where **R** = Bites per unit time, typically minutes; **S** = Average bite size, typically grams of DM per bite; **T** = Time available for grazing (minutes per day)

R or bites per unit time

The number of bites taken per minute is influenced by both pasture characteristics and by cow factors and tends to be a relatively fixed value on a daily basis. Bite rate per minute for pasture-fed cattle can be equal to that for total mixed ration (TMR) fed cows, provided bite size does not limit speed and ease of swallowing. Cows of high genetic merit have faster biting rates and longer grazing times compared with cows of low genetic merit (Bargo *et al*, 2003) implying potential milk yield and / or body condition benefits. Potential DMI advantages do not necessarily translate to improved body condition score if greater DMI fails to adequately compensate for the greater genetic drive to produce milk and / or pasture is not offered to cattle in an easy to harvest state.

Leafy, upright, dense, highly digestibility pasture can be quickly and effectively harvested within a fixed number of bites per day. High quality pasture is unlikely to directly restrict intake of pasture DM unless pasture allowances are inappropriately low. Conversely, as pasture grasses mature, flower and reproduce, or lose quality for other reasons including severe frosting and / or leaf loss through senescence, tensile strength and shear time increase, slowing the rate of harvest and decreasing the number of bites per unit time. Not only does nutrient composition decline in mature grass-dominant pasture but less of it may be harvested in any defined period, compromising DMI and performance. Pre-grazing topping / slashing, shortening rotation length, strategic nitrogen (N) fertiliser use or removal of poorer quality pasture as silage or hay are all advocated as ways to aid overall pasture DM intake by the herd. Topping decisions must however be taken with care because pre-grazing topping of an entire paddock of poor quality pasture in front of cattle reduces the ability of cows to selectively graze and may compromise milk yield and / or body condition. Topping / slashing behind cows is typically more appropriate while ryegrasses are heading. Similarly, care is required when shortening rotation length to encourage greater DMI because higher post-grazing residuals (typically greater than 1700 kgDM / ha) often compromise pasture quality at the next grazing. Surface moisture on external leaf surfaces can change the coefficient of friction, and hence slow bite rate via slippage of pasture between the incisors and dental pad, and from slower swallowing times. This has implications for cows grazing in wet weather, when energy requirements are likely to be increased, or following heavy dew. Similarly, where pre-grazing mowing is used to increase bite rate, total intakes can decline if grass is wet on the surface. Longer term strategies to minimize the influence of poor quality grasses on reduced bite rate (and bite size) include an increased legume component of a mixed dairy sward, as well as the selection of grasses with different heading dates, reduced aftermath heading and considering the use of high performance tetraploid ryegrasses in place of diploid cultivars where agronomic conditions support the establishment and use of newer ryegrass cultivars.

Average bite size (S)

Average bite size (0.4 to 1.1.grams of DM per bite) is considered a key driver of pasture DMI. Cow size has little effect on time available to eat or on bite rate, but can influence bite size because heavier, larger cows typically consume larger bites than smaller, lighter cows (Laborde *et al* 1998). Large cows (greater than 550 kg liveweight) fed on grazed pasture only are more likely to be underfed and fail to meet expected performance targets than smaller cows (greater than 450 kg liveweight), as they must rely on larger bite sizes to collect the feed needed to meet additional maintenance and production requirements. Pasture management and pasture quality must be optimised to profitably manage large cows on grazed pasture only. The increasing genetic merit of cows, with a predilection to yield milk at the expense of body condition, further confounds the successful management of high producing large cows on grazed pasture alone, as total DMI can be limited by the physical characteristics of the feed and the collection process. Whilst the anatomical characteristics of individual cows will to some degree influence the bite size taken, pasture-related characteristics are considered the more important modifiers of bite size. Pasture length (height) and pasture density will influence quantity of pasture DM taken per bite. For temperate pastures, pasture height is considered the major limiter of bite size, as influenced by bite depth in the sward rather than bite area (Cosgrove and Edwards 2007). Around one third of the height of pasture is removed by a grazing dairy cow, irrespective of pasture height (Bargo *et al* 2003) and reduction of pasture height is an important constraint for DMI of dairy cattle. Bite size generally increases as pasture height increases up to a maximum of 18 cm height. Long pasture does not, however, guarantee optimal bite size if the bulk density of pasture decreases and more stalky material is present within taller swards.

Further, greater quantities of DM per bite does not always imply greater DM intake because as bite mass increases, prehension biting rate can decrease (Cosgrove and Edwards 2007) due to time associated with the chewing of a greater volume of feed per bite.

Short pasture may restrict bite size, there being physically less material available to collect. Pasture plant and leaf density will influence final bite size as well as bite rate. Bulk density of pasture within the bite catchment is a more important determinant of bite size than plant erectness *per se* (Elliot and Hughes 1991). If density of pasture is low, cows will take more steps between bites and each bite collected may contain less material, limiting total DM intake. At shorter pasture heights, both grazing time and biting rate can to some degree compensate for a reduced bite mass (g of DM per bite) harvested per bite however it is generally accepted that cattle (unlike sheep), have limited scope to alter bite rate adequately to compensate for reduced bite size.

Practical tips for improved bite size:

- Review the daily per cow dry matter allowance to ensure cows are being offered pasture of adequate height and density that supports appropriate bite sizes. For ryegrass dominant swards, a pregrazing height of between 2800 and 3000 kgDM / ha and a post-grazing height of no less than 1500 kgDM / ha is generally accepted as the 'ideal' horizon within which dairy cattle will maximize bite size and DMI whilst optimizing utilisation of pasture. Cows of high genetic merit can be at risk of inappropriate loss of body condition when forced to graze to residuals of 1500 kgDM / ha during early lactation. Body condition score and / or bodyweights should be monitored through early lactation to ensure grazing practices do not impact negatively on mating outcomes or lactation persistency of seasonally calving cattle.

- Manage concurrent constraints to grazing (particularly grazing time) that may prevent a cow from compensating for reduced bite size. For larger herds, consider ways to increase grazing time to permit cows to spend more time grazing when bite sizes are limited by low pasture covers.

- Assess the 'harvestiblity' of pasture on offer in front of cows. The collection of handfuls of grass is a practical method to determine the average tensile strength and "ease" of collection by the cow. Cows that graze tougher pasture frequently need to "tug" during grazing; slowing rate of bites and the bite size collected may be less than optimum.

- Topping in front of cows. When lush quality pasture contains low DM %, topping in front of cows and allowing a light wilt pre-grazing can enhance pasture DMI by removing the need by cows to physically prehend and tear pasture, as well as allowing a faster rate of consumption of wet, low DM% pasture. Care is needed with topping decisions in late spring. Topping of flowering ryegrass material in front of cows can reduce the ability of cows to select pasture, forcing them to consume all of the flowering, poor quality material. This can reduce milk yield responses and impact on cow body condition. Topping behind cows can be more rewarding under these circumstances.

T = Time available for grazing / motivation of the cow to consume pasture

As possibly the most important moderator of pasture DMI, time spent grazing is function of:

- Time made available for a cow to graze combined with,
- The willingness of the cow to effectively utilize available time grazing.

Grazing time is generally considered as the more important modifier of the R x S x T descriptor of cattle intake particularly for larger dairy herds. With the size of the average Australian herd increasing over recent years, grazing time is becoming a more commonly encountered limiter of pasture DMI in some but not all herds. Within larger herds, the magnitude of effect of daily activities including walking and milking on time available for grazing is amplified in comparison to smaller herds. Cattle are unwilling or unable to graze for more than 10 to 12 hours per day and may have a maximum grazing duration of just over 13 hours per day (Bargo *et al*, 2003). Within a 24 hour day in addition to grazing, cows have a fixed time requirement for ruminating and sleeping. Cattle are unlikely to adequately compensate for restricted grazing time by increasing either bite rate or bite size, therefore net daily pasture DM falls. Conversely, herd management might permit ample grazing time, yet the cow fails to consume sufficient pasture due to other suppressors of appetite.

Reduced grazing time may reflect a combination of one or more of the following:

Insufficient time allocated for grazing:

Walking time: Excessive time spent walking to and from pasture will limit amount of time available for grazing. Not uncommonly walking distances to paddocks exceed one kilometre, with up to three kilometres or more seen on larger dairy units, particularly those that have expanded through acquisition of neighbouring properties. Allowances for walking speeds of between 1.5 kilometers to 4.5 km per hour (Malmo *et al* 2003) imply that herds will be on farm laneways for ½ to four hours daily. Energy expenditure associated with walking to distant paddocks, combined with energy demands of grazing will compound effects of reduced grazing time, particularly for dairy units with rolling to steep hills and where low DM% of pasture contributes to reduced harvesting efficiencies. For paddocks that are located considerable distances away from the dairy, consider cropping or harvesting pasture as hay or silage in preference to walking to reduce the potentially negative effect of both time off pasture and the energetic cost of walking. For larger dairy businesses, a once a day milked herd is a viable option for mitigating against lost grazing time for paddocks considerable distances from the dairy shed. Keeping an 'at risk' herd (younger cows, and those of lighter body condition) grazing paddocks closer to the shed is another approach to maintain higher per cow pasture DMI through longer grazing times, particularly during early lactation.

Time on concrete / laneways: Excessive time spent waiting in the dairy yard and during milking will compound the effects of short grazing times on paddocks long distances from the shed. Too frequently, cows do not have access to water during this time, further limiting a cow's desire to eat. The effects of heat stress from large closely packed mobs with lessened ability to disperse heat, either on laneways or in the dairy, will compound both energy requirements and the desire of the cow to eat. For larger herds where milking time is constrained by dairy shed capacity, consider running multiple, smaller herds to facilitate additional grazing time. If cows access a feed pad, offer access before milking such that time on concrete is not 'down time', rather provides time for rumination and processing of supplements offered on the feed pad. Practically this option may be constrained by poorer cow flow into the dairy after feed pad access.

Inclement weather: Extremes of temperature outside of the cows thermal neutral zone (5 to 20°C) will influence the DMI and metabolic activity of pasture-fed cows (NRC 2001). Shorter grazing times in response to cows seeking shelter during adverse winter weather conditions will reduce pasture DMI despite increased basal metabolic intensity and an increased drive to consume feed. Poor utilisation of pasture as a result of muddy, wet conditions will accentuate challenges of poor pasture DMI. The selection of free draining paddocks that offer shelter from the effects of wind chill, combined with offering the herd a larger than normal area of pasture are the typical approaches to managing the negative effects of very cold, wet weather on pasture DMI as well as reducing risk of pugging damage. Conversely, extreme heat and / or humidity limit grazing time as cows seek shade in preference to grazing. Pasture should be preferentially allocated at night to encourage improved pasture consumption and utilisation. Practical tips regarding the management of pasture-fed cattle through hot months of the year are well reported and summarised by www.coolcows.com.au. Importantly, not all time away from pasture is unproductive. In well-managed herds, significant numbers of cows will spend time ruminating and cud chewing whilst off pasture, important moderators of rumen well being.

Insufficient motivation by the cow to graze

Despite our best efforts to maximise time spent by cows at pasture, we cannot fully control the motivation of the cow to actively consume pasture. Her desire to graze is moderated by cow health and well being, pasture allowance, pasture quality and the freedom of pasture-associated anti-nutritional compounds that may limit the consumption of DM. Key influencers of a cow's desire to consume pasture include:

Physiological state of the cow and the desire to consume pasture: The net nutrient demand is defined by energy, protein, macro and trace mineral requirements as dictated by liveweight of the cow (and hence maintenance demands), milk yield, milk lactose %, milk fat and protein %, the requirements of pregnancy and for the dry cow, the demands of the udder pre-calving, as well as energy demands associated with walking. These demands can be calculated by feed formulation programs such as CPM Dairy or CamDairy, or energy and protein demands can be manually calculated in a factorial manner. Cows with a greater demand for energy and other nutrients will tend to have a greater 'drive' for DMI to support those needs.

Physical satiety or factors associated with the distension of the alimentary tract: For lactating dairy cows maintained on *high quality* pasture, ruminal distension is an uncommon constraint of DMI due to the relatively rapid rate of neutral detergent fibre (NDF) degradation. Conversely, for laxly grazed, *poor quality* pasture and when ryegrasses are heading in late spring, pastures characterised by a high content of slowly rumen degradable NDF may constrain intake as a result of ruminal distension. Ruminal capacity will to some extent compensate for and adapt to high NDF diets, however despite capacity adaptation, high NDF diets remain unsuitable for high performance dairy cattle. Unlike sheep, ineffective chewing of prehended pasture by grazing dairy cows results in very tightly packed ruminal contents that require extensive rumination (Waghorn and Clark 2004) to permit ruminal outflow of contents, reiterating that cows must have adequate 'spare' time within a day to ruminate and further process pasture.

Health constraints to DMI: Appetite suppression as a result of a debilitating health condition will limit a cow's ability to effectively graze, e.g. lameness, or systemic illness or disease that limits her desire to eat. Anorexia as a result of hyperthermia (high body temperature) associated with metritis or mastitis, or secondary to ruminal acidosis, ketosis or hypocalcaemia will reduce a cow's desire to graze. Perturbed ruminal function as a result of sudden dietary change as cattle transition from a pasture of poor quality to very high quality, leafy pasture may restrict DMI. Reduced appetite may reflect sub-clinical or clinical ruminal acidosis following an abrupt transition from poor to high quality pasture. Alternately high concentrations of ruminal and blood ammonia may contribute to a learned aversion by cows to high quality pasture as a result of sudden dietary change. Poor transitional management through calving will reduce appetite during early lactation. Intake of dry matter before calving is positively associated with DMI after calving, such that poor management of cows day -20 to 0 before calving will negatively impact on DMI, milk yield and reproductive performance during the subsequent lactation (Degaris *et al* 2010). Pasture-fed cattle succumb to a 'normal' loss of appetite immediately prior to calving however the extent and duration of appetite loss appears less for pasture-fed cattle than that reported for TMR-fed cattle (Roche *et al* 2003a, 2003b). Clinical and sub-clinical ruminal bloat causes ruminal distension, frothy or free gas ('feedlot') bloat will reduce DMI by pasture-fed cattle.

Temporal grazing patterns and grazing time: Diurnal variation in grazing behaviour will modify duration and pattern of grazing activity throughout a day. Under temperate climatic conditions, most grazing by ruminants occurs during daylight hours, with the greatest activity occurring during the early morning and late afternoon. Sheep have greater bite masses during late afternoon which combined with greater grazing activity lifts the rate of intake later in the day. In contrast, a greater 'drive' to eat by lactating dairy cattle motivates cows to more actively consume pasture at night in addition to during the day (Cosgrove *et al* 2006; Cosgrove and Edwards 2007). Late afternoon / pre-dusk remains for most systems the time of day when dairy cows consume the most of their daily pasture DMI, resulting from a combination of increased grazing activity and the typically higher DM % of pasture at dusk. Greater pasture DMI late in the day will also take advantage of higher concentrations of water soluble carbohydrates (WSC) and starches in grasses and legumes pre-dusk.

Proportion of time spent grazing either during day or night time hours appears to be pasture-species dependent because dairy cows grazing side by side monocultures of ryegrass and clover spent proportionately more time grazing at night than cows grazing either grass only, a grass/clover pasture mix, or grass at night and clover during the day (Cosgrove *et al* 2006). Climatic conditions will moderate grazing behaviour by cattle because hotter conditions are associated with reduced daytime grazing activity, typically compensated for by greater time grazing during the night.

Irrespective of timing of grazing, the exact control mechanisms that initiate and terminate a grazed 'meal' by a cow remain unknown and most likely reflect multiple factors including concentrations of volatile fatty acids, ammonia and ruminal pH. Taweel (2004) concluded that termination of grazing by dairy cows at dusk was triggered by factors associated with ruminal distension.

Herd size, social structure and dry matter intake: During late winter, by necessity spring calving dairy cattle are often maintained on relatively small areas of pasture (few m^2 per cow per day) to maintain average farm pasture covers during periods of slow pasture growth. Competitive, more dominant cattle frequently outcompete younger, submissive cattle for pasture because dominant cattle are typically milked first, return to new pasture breaks faster and consume most if not all pasture before younger cattle reach the paddock. Milk yield and body condition of young cattle is often compromised as a result of sub-optimal pasture DMI, further if cereal grains are fed at the dairy, this practice can increase risk of ruminal acidosis in submissive cows that compete less successfully for pasture (Shephard 2003).

The strategic use of additional temporary electric fencing to better distribute daily pasture DM allowance amongst all cows is becoming increasingly common in large New Zealand commercial dairy units. Variation in DMI between dominant and submissive last-milked cows can be controlled by:

- Holding all cows off pasture until all have been milked. This practice may be unsuitable for some properties during wet weather because of damage caused by standing cows off on laneways, and risk of mastitis from mud / faeces exposure to teats.

- Cows go back into a previous break of pasture until all cows are milked. This is useful to facilitate better post-grazing residuals because dominant cows 'tidy up' pasture residuals if pasture covers are still higher than ideal. Some managers report that dominant cattle learn to 'wait' for a new break rather than working to tidy up the existing break, as such this practice may not work under all circumstances. Risks associated with this practice include overgrazing of residuals to undesirably low levels, and pasture damage if the paddock is already heavily pugged under wet conditions.

- Use of an electric fence to offer dominant cows only a proportion of the new break of pasture (less than 25%). Dominant cows returning to the paddock can consume this area while waiting for remaining cows to be milked. When all cows are in the paddock, the electric fence is moved allowing all cows equal access. If the 25% of area is the 'front' of the paddock near the gate, this process can facilitate good utilisation of rougher quality pasture in the gateway that may otherwise be poorly utilised.

Psychogenic effects on grazing time and pasture dry matter intake: The psychogenic regulation of DM intake involves the cow's behavioural response to inhibitory or stimulatory factors in the pasture and / or the paddock environment that aren't *directly* related to the pasture's energy value or NDF / ruminal capacity effect. Palatability is the most commonly recognised pasture characteristic that impacts psychogenic change in DMI, expressed by cattle as a preference for one type of pasture and / or components of a pasture over another. Table 1 outlines examples of paddock-centric factors that may influence the intake of pasture DM.

Motivating a cow to consume more pasture, for longer, more efficiently

Setting the targets – how much will a pasture-fed cow consume? Inevitably we seek rules of thumb and measures of probable intake of pasture DM by cattle. Cows will almost always consume less pasture DM when compared with cohorts consuming a full TMR, depending on the quality and formulation of the TMR. Intake of pasture-fed animals generally increases with increasing liveweight of the cow and variation in predicted DMI can be removed by expressing pasture DMI as a ratio to cow liveweight. Cows fed unrestricted quantities of high quality pasture-only diets may consume a maximum of between 3.25 % of liveweight to 3.5% of liveweight (Bargo *et al*, 2003). In a comparison of cows fed either pasture or full

TMR, pasture-fed cows consumed only 3.39% of liveweight compared with intakes at 3.93% of bodyweight by a control group of TMR-fed cows (Kolver and Muller 1998).

Whilst accepting that pasture-fed cattle consume fewer kgDM per head than TMR-fed cattle, manipulation of pasture on offer can increase the amount of pasture consumed.

Table 1. Factors that may contribute to the psychogenic regulation of pasture dry matter intake

Pasture-centric factors that may adversely influence intake of pasture by grazing cattle
• Prostrate pasture species (e.g. grazing brome *Bromus stamineus*) compared with those with a more upright, erect growth habit (e.g. Italian ryegrass *Lolium multiflorum*)
• Diploid ryegrasses with thinner, less erect tillers consumed less vigorously compared with more upright tetraploid ryegrasses characterised by fleshier tillers and larger leaves
• Perennial ryegrass cultivars that contain the wild type endophyte, producing endophyte alkaloid compounds characterised by reduced consumption of pasture. Newer novel endophyte-ryegrass associations e.g. AR1 and AR37 are generally associated with improved pasture DMI compared with ryegrasses infected with a wild type endophyte
• High pasture contents of sulphur, potassium, and possibly nitrates
• Lower pasture contents of water soluble carbohydrates (WSC) due to recent application of nitrogen fertiliser or cultivar effects (differences in WSC concentrations have been reported between ryegrass cultivars and between tall fescue cultivars)
• Presence of leaf rust on pasture surface or fungi at the base of sward e.g. *Fusarium*
• Overzealous use of supplementary minerals, e.g. heavy application of fine lime to pasture for recently calved cows
• Recent application of effluent to pasture
• Previous grazing in recent days of pasture break with another stock class e.g. calves and associated faecal / urine staining of pasture
• No stock water access in the paddock
• Learned response by cows to daily routine of shifting cattle onto a new break of pasture, inhibiting grazing activity on existing break whilst waiting to move onto new break

Offering enough per cow daily pasture allowance while maximising utilisation of pasture grown

Dry matter intake increases in a curvilinear manner as allowance of pasture on offer increases. In a review of effects of pasture allowance on DMI of lactating cattle, Bargo *et al* (2003) concluded that pasture DMI increased 0.19 kgDM per kgDM of pasture offered over a range of pasture allowances from 20 to 70 kgDM/cow/day. A regression analysis was developed using the data from seven studies that included terms for pasture allowance and its quadratic term:

Pasture DMI = 7.70 (SE 1.49) + 0.26 (SE 0.06)PA – 0.0012 (SE 0.0007)PA^2; $\mathbf{R^2 = 0.95}$ (Bargo *et al*, 2003)

From the above equation and ignoring practical ramifications of a requirement to effectively utilise pasture grown, the 'ideal' daily pasture allowance per cow that maximise DMI was calculated to be 110 kgDM offered per cow per day. This amount could in theory support 21.9 kgDM eaten per cow per day, with 0.26 kgDM/kgDM pasture allocated increase up to 110 kgDM offered per cow per day.

The practicalities of this 'ideal' situation for maximising pasture DMI are unworkable within almost all pasture systems. By allocating these very high allocations of feed per cow per day, considerable pasture would be wasted and high pasture utilisation is a key profit driver for all pasture-based dairy businesses. Further, unacceptably poor pasture utilisation reduces pasture quality at subsequent grazings. Identifying the point at which DMI by cows is optimised whilst pasture utilisation is not compromised will vary between pasture systems. Intake of DM increased as pasture allowance increased from 20 to 54 kg DM/cow/day (Peyraud *et al* 1996), with a plateau occurring at an allowance of 33 kg DM/cow/day. In contrast Dalley *et al* (1999) reported an increased DMI as herbage allowance increased from 20 to 70 kg DM/cow/day, with a plateau occurring at an allowance of 55 kg DM/cow/day.

A practical compromise between the Bargo *et al* (2003) calculations for optimal pasture DMI intake and acceptable utilisation of pasture is challenging, however Bargo *et al* (2003) proposed a compromise of a daily pasture allowance of double that required to be consumed. For example if cows are expected to consume 18 kgDM per cow per day, allocate 36 kgDM per cow per day. Depending on stocking rate and other feeds in the diet, this approach may not always be practical and under some situations will underfeed high performance cattle.

Practical application of pasture allocation per cow per day

Practical application of these types of recommendation for pasture allocation on farm typically requires translating total kgDM of pasture on offer to available kgDM on offer. Commonly when allocating pasture to cows, we think in 'available' kgDM / hectare. Rather than thinking in total pasture allocation of e.g. 3000 kgDM / ha, we think as 'available kgDM' which is the amount that can be potentially consumed by the cow. If targeting post-grazing residuals of no lower than 1500kgDM / ha, there will be 1500 kgDM 'available' DM on offer per ha for a paddock that contains a total of 3000 kgDM / ha (Figure 2). This concept makes feed allocation potentially easier, whilst still targeting appropriate post-grazing residuals.

An example of this is the following:

A one hectare paddock at 3000 kgDM pre-grazing cover -

- 100 cows each needing 18 kgDM of pasture eaten per day
- We need cows to leave a minimum of 1500 kgDM / hectare residual behind in order to leave enough area of leaf to facilitate good pasture regrowth, yet aiming to not work cows 'too hard'
- 3000 kgDM less 1500 kgDM residual = 1500 kgDM 'available' DM / 100 cows = 15 kgDM *available* pasture per cow per day
- We have a requirement for 18 kgDM per cow per day to be harvested as pasture yet there is only 15 kgDM available if cows remain grazing within the horizon of 3000 kgDM/ha down to 1500 kgDM / ha. Either cows require another 3 kgDM of supplement per cow per day, or we allocate the herd a further 0.2 ha per day to 'top up' pasture allocation by a further 3 kgDM available DM per head per day. Allocating further area of pasture per day may decrease pasture rotation length (fewer days before cows return to the paddock) to unacceptably short periods of time, decisions must be tempered by knowledge of probable pasture growth rates over the coming days and weeks. Inexperienced pasture managers frequently increase area of pasture on offer to better feed cows, resulting in unacceptably fast grazing rotations.

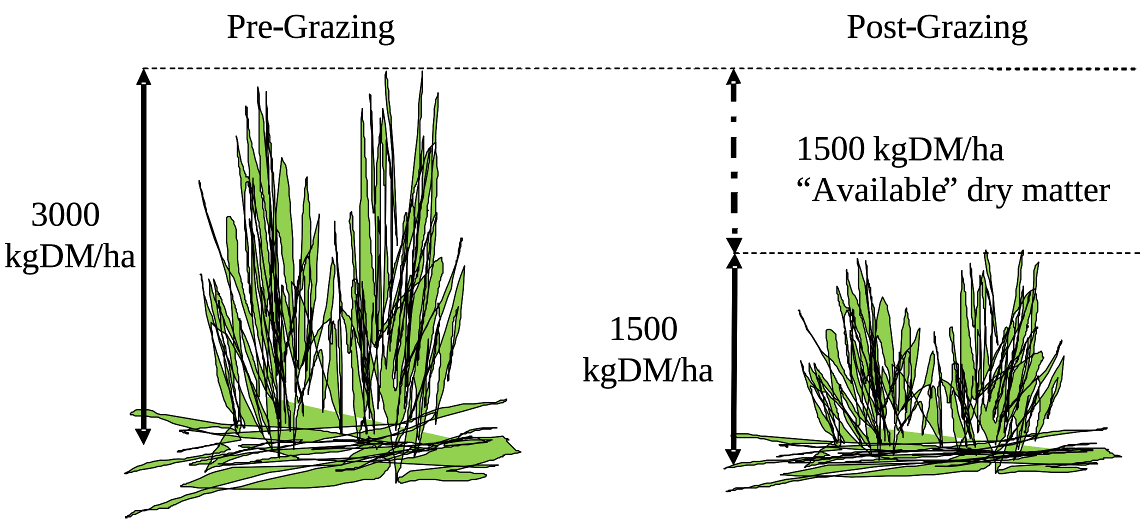


Figure 2. Pre and post grazing mass compared with 'available DM'

Frequency of moving cattle onto new pasture breaks

The greater use of subdivision of paddocks to allow frequent shifting of cows throughout the day is proposed by some farmers as a way to improve intake of pasture by cows. The theory is that cows remain more interested and driven to consume more DM when offered fresh breaks of pasture multiple times through the day, particularly when cattle are at greatest risk of poor appetite, including freshly calved colostrum cows.

Objective evidence to support this practice is lacking because Dalley *et al* (2001) reported no difference in either DMI or milk production when early lactation dairy cows were offered a break of ryegrass pasture either one or six times per day.

A compromise may be the use of '12 hour grazing' (one new break every 12 hours) rather than '24 hour grazing' (one new break every 24 hours) for cattle at greatest risk of poor appetite, specifically 'colostrum mob' cows. Twelve hour grazing, combined with a higher than typical target post-grazing residual (greater than 1700 kgDM / ha for colostrum cattle) is likely to encourage greater intake of DM by these at risk cattle. Further, more frequent shifts onto a fresh break dusted with supplemental lime and if indicated, magnesium oxide can increase the intake not only of pasture, but also of these macrominerals for colostrum cattle immediately after calving.

Note that smaller areas of allocated pasture per break during 12 hour grazing has been suspected by some herd managers to contribute to increased social pressures for submissive cows, an important issue if considerable variation in cow liveweight exists within a herd.

Pasture composition and DMI by cattle

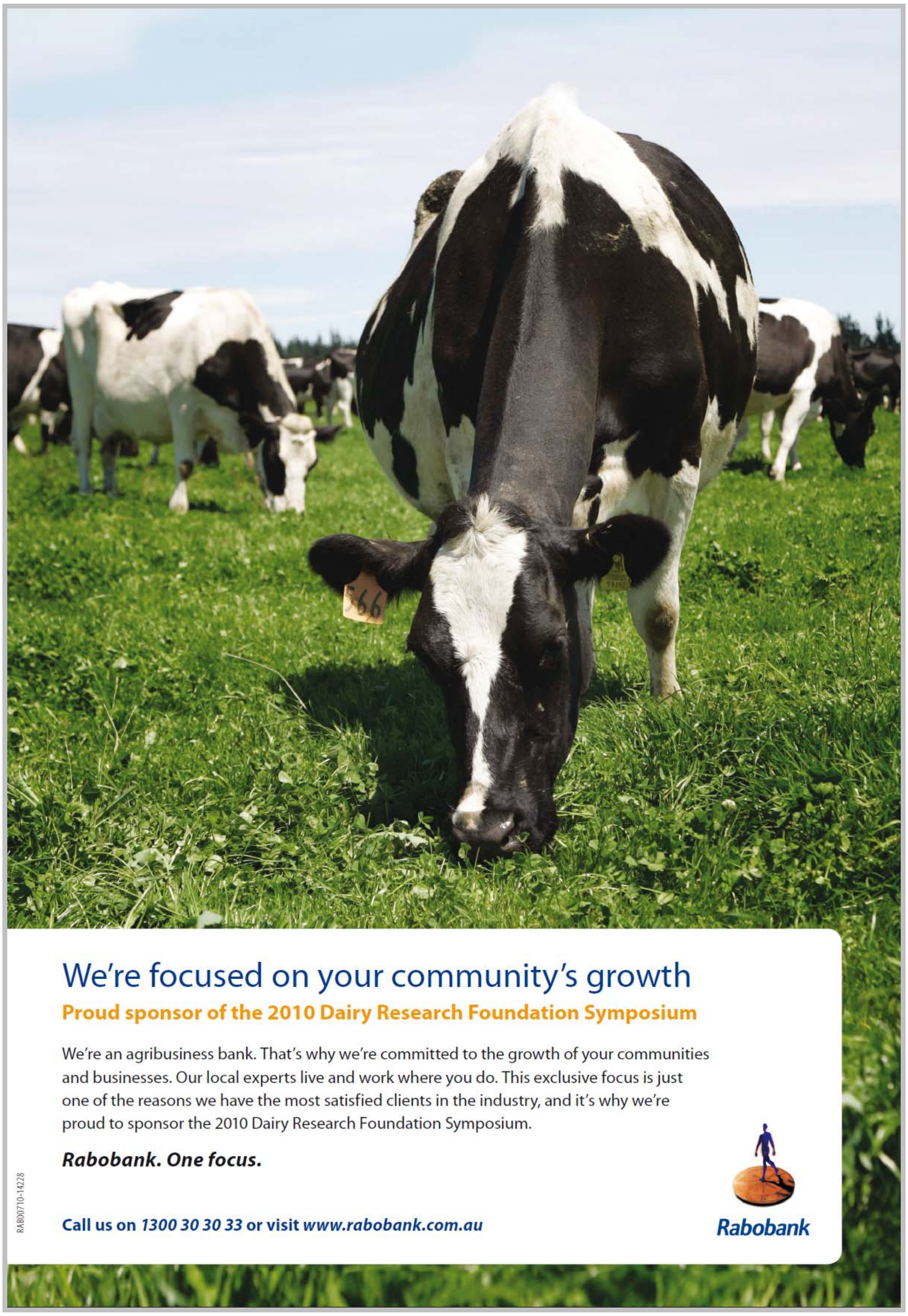
The extremely variable composition of pasture, expressed both as the proportional contribution of various pasture species and cultivars, and as the overall nutritional composition of the sward (DM%, NDF and crude protein; CP) will directly and indirectly influence DM consumed by grazing cattle.

(i) The influence of grass, legume and herb species

In sheep, a higher forage DMI is associated with forages characterised by low NDF concentrations with fewer widely spaced and fragile veins (Waghorn and Clark 2004) because less physical damage by chewing is required to reduce particle size of the forage; this relationship will likely be true for dairy cattle also. High quality legumes are desirable components of a pasture sward because legumes contain, on average, greater concentrations of desirable nutrients per kgDM and have been associated with greater DMI by cattle compared with intakes reported for grass-fed cows. The preferential grazing by cattle of pasture herbs chicory (*Cichorium intybus L*) and plantain (*Plantago lanceolata)* established as part of perennial ryegrass / white clover swards is widely reported and is likely associated with a greater total intake of pasture DM.

(ii) Digestibility and MJME content of pasture and pasture DMI

Generally DMI of pasture by ruminants is positively related to digestibility (Waghorn and Clark 2004). Conversely, as pasture DMI increases, the digestibility and megajoules of metabolisable energy (MJME) content of pasture declines, a function of more rapid rumen outflow rate and an associated reduced extent of digestion of more slowly degraded pasture DM components. Management practices that result in a more digestible pasture sward with a higher MJME content will facilitate greater intakes of pasture DM.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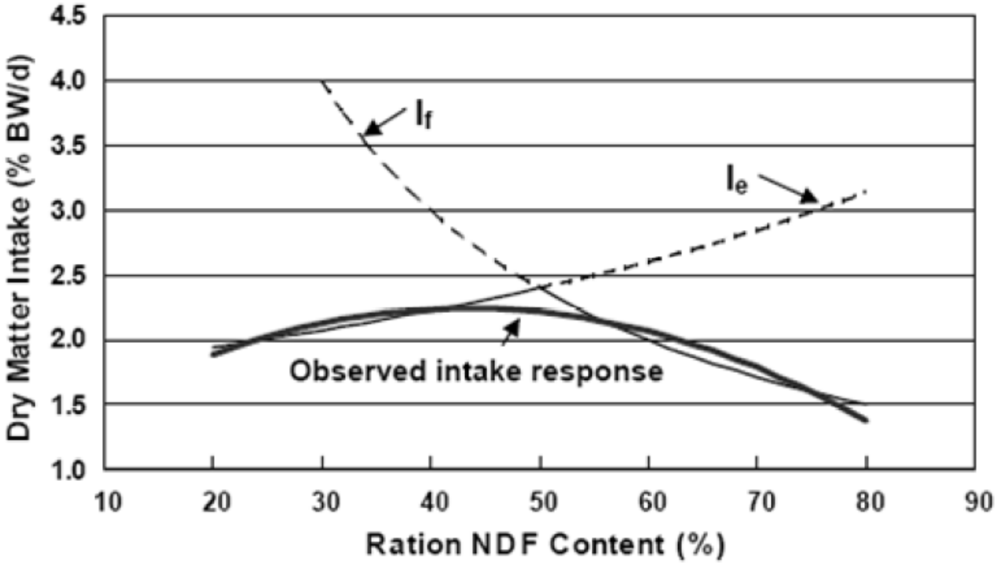

Figure 3. Illustration of intake predicted by simple concepts of energy demand (Ie) and fill limitation (If) when compared to intakes typically observed when ration NDF is varied (Mertens, 2009)

(iii) Neutral detergent fibre (NDF) content of pasture and pasture dry matter intake

For TMR-fed herds, the quadratic correlation between ration NDF content and the potential DMI of cows is well reported. At high NDF concentrations in diets, DMI may be limited by rumen fill. Conversely at low NDF concentrations, energy intake feedback inhibitors (satiety) limit DMI (Figure 3). The effects of rumen fill on grazing behaviour are unknown (Waghorn and Clark 2004), however through an increase in rumen volume, cows can adapt to the chronic ingestion of high NDF content pasture. The rumen contents of pasture-fed New Zealand cows at 70 days after calving was 22% of liveweight compared with 17% and 12% of liveweight for cows in the USA fed pasture or TMR diets, respectively (Waghorn and Clark 2004) suggesting a long term adaptation by New Zealand cattle to the ingestion of relatively high NDF pastures.

An often cited ‘rule of thumb’ of cows being unable to consume more than 1.2% of liveweight as NDF is often employed for TMR situations. Importantly, this TMR NDF rule of thumb is unlikely to directly apply to cows consuming pastures that contain temperate high quality species. Kolver (1998) described the relatively rapid ruminal rate of NDF degradation of lush, vegetative pastures compared with that of hay and silages. Total mixed ration derived NDF-based rules of thumb as influenced by rumen fill are less likely to apply to cows consuming good quality pasture. It remains likely that the practical use of NDF as a rule of thumb predictor of intake of pasture DM is either inappropriate, or requires the use of a higher multiplier value, e.g. cows consuming an upper limit of 1.5% of bodyweight as NDF based on the data of Kolver and Muller (1998).

(iv) Dry matter content of pasture

It is unlikely that low DM% pasture *per se* limits performance, but to collect 20 kg DM of wet grass may necessitate a wet volume intake of 200 kg of 10% DM pasture. For a confined cow fed a TMR formulated at 40% DM, wet intake is only 50 kg to provide 20 kg DM, requiring relatively fewer mouthfuls, with less physical exertion and less motivation required. The pasture fed cow may have insufficient grazing time each day to harvest adequate feed, or if poorly managed or of different genetic background may simply lose motivation to graze once maintenance needs have been met, if pasture collection is difficult. A DM content of between 40 and 60% DM is often applied by nutritionists as a guide to an 'ideal' TMR or partial mixed rations (PMR) diet. With DM contents as low as 11% DM (Stevenson *et al*, 2003) reported for high quality, immature leafy pastures, the intake of a high volume of water relative to DM has been proposed as a potential modifier of DMI by dairy cattle, particularly when surface water is also present as a result of rainfall, dew and irrigation. Dry matter % of pasture is typically lowest in the morning due to the presence of surface water, with DM% increasing throughout the day as surface water evaporates.

Mechanisms that limit voluntary consumption of low DM%, wet bulk pastures are unclear. A limited capacity for cows to efficiently harvest adequate quantity of fresh wet pasture is a likely moderator of DMI, particularly when grazing time is restricted by management constraints (time off pasture due to prolonged milking times, walking distances) and / or when pre-grazing pasture mass is low.

Ruminal distension as a result of the consumption of a large bulk of wet material is unlikely to contribute to reduced DMI by cattle consuming low DM% pastures. Damage to plant cells during prehension and chewing allows for virtually complete release of intracellular water and soluble nutrients, allowing the ready absorption of water. The placement of a balloon containing water in the rumen of young growing lambs limited the DMI of dried but not fresh (DM 15 to 25%) forages (John *et al* 1987).

Practical steps to remediate the effects of reduced DMI for cattle consuming low DM% pasture include;

- Reviewing concurrent constraints to grazing time. For example, if large herd size (s) implies considerable time by cattle away from pasture, explore options to reduce herd sizes by running multiple mobs of cattle and / or reducing walking distances by cattle at greater risk of sub-optimal DMI, specifically cattle in early lactation and before / during mating.

- Supplementation with high DM%, high energy feeds including cereal grains, molasses to compensate for reduced DMI by cows consuming low DM% pasture. The effects of substitution must be carefully monitored, typically through daily monitoring of post-grazing residuals and weekly update of a whole farm 'pasture wedge' and average pasture cover. Potential benefits to the cow of high energy supplements will be negated if post-grazing residuals lift above required levels, causing pasture wastage.

- Topping / slashing of immature, leafy pasture in front of cows. A light wilt of topped / slashed material to 25 to 35% DM can encourage intake with cattle often attracted to wilted material in preference to standing, low DM% immature pasture. Harvesting efficiencies are offered as a result of increased grams of DM per bite and a lesser requirement to prehend / tear pasture from the base of the plant. Benefits may be outweighed by the per hectare cost of slashing, including diesel, labour costs and tractor and mower repairs and maintenance however by including the value of improved pasture quality at the next grazing, in many cases slashing / topping can be cost effective.

(v) Fat content of pasture and pasture dry matter intake

The fat content of any diet is typically assumed to correlate negatively with DMI, through the energy content of fat contributing to increasing satiety of appetite when cows consume more energy dense diets that contain more fat. High concentrations of dietary fat may decrease ruminal fermentation and digestibility of fibre and hence decrease rate of passage of fibre through the rumen. Fat contents of high quality leafy pasture may exceed 7% of DM and are characterised by a relatively high proportion of polyunsaturated fatty acids (PUFA). Total fat intakes often exceed the recommended upper concentration of no more than 5% of dry matter and faeces from these pasture-fed cattle can sometimes appear 'greasy' or 'oily'. The relationship between potentially high PUFA intakes by pasture-fed cattle and pasture DMI requires further elucidation.

(vi) Water soluble carbohydrate content of pasture and pasture DMI

The concentration of water soluble carbohydrate (WSC) varies considerably between pasture species and potentially between cultivars of ryegrass and clover (Edwards *et al*, 2007), as well as being influenced by temperature, season and use of nitrogenous fertilisers. The positive correlation between water soluble carbohydrate (WSC) content of pasture and grazing preference is reported anecdotally in the field yet is not strongly supported by investigations of the association between DMI by cattle and concentration of WSC in pasture species under controlled experimental conditions (Taweel 2004, Edwards *et al* 2007).

(vii) Concentrations of macro minerals

Anecdotal reports suggest that under some conditions, high pasture concentrations of potassium and sulphur may negatively influence the consumption of pasture DM.

(viii) Anti-nutritional compounds

Anti-nutritional compounds associated with pasture including mycotoxins and endophyte alkaloid compounds may reduce the consumption of pasture DM by grazing cattle. Mycotoxins include those associated with fungal growth in dead litter at the base of the sward including *Fusarium* spp. The presence of crown or leaf rust (*Pucinnia coronate*) on the surface of ryegrass plants may reduce the rate and extent of consumption of pastures by grazing cattle. The production of a range of endophyte alkaloids by many 'wild type' perennial ryegrass-endophytic fungal associations are negatively associated with the acceptance of pasture by cows. Newer perennial ryegrass-novel endophytic associations produce alternate profiles of endophyte alkaloids that are less likely to negatively impact on pasture DMI of cattle. Pastures with a high content of nitrate N have been associated anecdotally with a higher incidence of pasture refusal by cattle.

Substitution and the effects of supplementary feeding on pasture DMI

Substitution is an extremely important modifier of pasture DM by cattle, defined as the decrease in kgDM of pasture eaten for every kgDM of supplement eaten. Substitution is a complex concept, because it is sometimes viewed negatively (if pasture is substituted and wasted in the paddock) but often positively – if pasture is 'spared' from being eaten such that pasture covers can be built up quickly e.g. to build pasture covers heading into the winter.

The ability of a supplement to influence the intake of pasture is ranked on a scale of 0 to 1. A supplement with a score of 0 means if a cow is offered 1.0 kgDM of a supplement, she will continue eat her full quota of pasture. A supplement with a score of 1.0 means that for every 1.0 kgDM of supplement, a cow will eat 1.0 kgDM LESS of pasture. A reduction in pasture intake caused by supplementation is often subsequent to shorter grazing times (cows sit down with their appetites satisfied, earlier). Starchy supplements (cereal grains, tapioca, hominy or other starch by-products) can cause a low rumen pH and depress numbers of fibre digesting bacteria which may slow the digestion of fibre, further reducing the intake of pasture.

The ideal outcome for supplementation is when substitution is less than 1.0 – that is, when cows consume their supplements but also continue to utilise pasture well such that total daily DM intake is increased.

Substitution is commonly (and often rightly) blamed for the apparent absence of milk yield response to a supplement. When substitution rates are high (close to 1.0), cows eat the supplement but eat proportionately less pasture = no apparent short term change in milk yield. This is a good outcome if an average farm pasture cover (kgDM/ha) is lower than ideal and we are attempting to lift covers e.g. heading into the winter. A high substitution rate can be undesirable if pasture covers are already at target levels because there is an increasing risk of pasture wastage unless the pasture surplus is controlled.

As part of a supplementation program, pastures must be monitored with a regular farm walk to watch for the effects of substitution. If covers are lifting in response to the feeding of supplements, management decisions can be made, including

- Reducing supplementation rates
- Changing types of supplement for one that is less likely to cause substitution
- Ceasing supplementation all together
- Increasing stocking rate on grazed areas by dropping areas of the milking platform out for silage, cropping or regrassing or bringing non-milking stock onto the milking platform (dry cows, calves or heifers).

Many factors influence substitution and it can be difficult to predict the extent to which cows will substitute pasture due to multiple interactions. Influential factors are summarised in Table 2.

Negative substitution rates

Occasionally, offering supplements can promote a greater than expected milk response, most often due to a synergistic benefit linked to the feeding of that type of supplement (Kellaway and Harrington, 2003). Whilst less common, examples include molasses offered to cows eating a very poor quality diet – for example, dried off summer pasture of poor quality or very high rates of poor quality silage. Offering a source of palatable physically effective neutral detergent fibre (peNDF) to cows that are sub-clinically acidotic can help stabilise rumen pH, potentially improving appetite such that the fibre source increases total appetite and DM intake.

Table 2. Feed and management factors that influence substitution rate

Factor	Low substitution rate	High substitution rate
Pasture allowance	Low pasture allowance	High pasture allowance
Grazing time	Short time on pasture (e.g. in large herds)	Plenty of grazing time
Pasture type	Poor quality pastures	High quality pastures
Type of supplement	Forage (silages) and non-starchy concentrates (e.g. PKE)	Starchy (e.g. cereal grains, tapioca)
Frequency of feeding of supplements	Many times a day	Once a day
Processing of cereal grains	Well processed – just cracked	Overprocessed, fine and dusty
Feeding rate of cereal grains or other starchy feeds	Low feeding rates (usually less than 3 to 4 kg per head per day)	Higher feeding rate (more than 3 to 4 kg per head per day of cereal grains)
Type of starchy feed	Oats, barley, maize grain	Wheat, tapioca, hominy
Level of fat in the diet	Lower fat supplements	Higher fat supplements
Stage of lactation	Late lactation	Early lactation

From Table 2, it is apparent that multiple, interrelating factors will influence substitution rate and that no single factor should be considered in isolation.

Access to stock water and effects on pasture dry matter intake

Despite pasture containing relatively more water on an 'as fed' basis than silages and hays, and cows obtaining metabolic water from the catabolism of nutrients, the restriction of access by pasture-fed cows to stock water will reduce daily pasture DMI. Cows respond to water restriction by reducing meal size, possibly as a protective homeostatic mechanism for maintaining the normal osmotic buffer function of the rumen and therefore regulating osmotic balance of body fluids (Burgos *et al* 2001). Undesirable water quality attributes including undesirable organoleptic (taste and odour) attributes, dissolved calcium, phosphorus, magnesium and sulphur can affect water intake and therefore, intake of pasture DM. Conversely, excessive intakes of salts such as NaCl can increase water intake as the cow attempts to eliminate excess sodium with little if any consequence for total daily DMI. Water for pasture-fed cattle should be of acceptable quality to encourage maximum intake of water and hence pasture DM. Appropriate location of easily accessible troughs is important to maintain pasture DMI, particularly under hot environmental conditions.

Conclusion

The successful management of the interface between pasture and the grazing cow is a critical driver of profit for pasture-based dairy businesses. Whilst achieving the target 'fine line' balance of achieving optimum pasture DMI by cattle and excellent utilisation of pasture is challenging, achieving this balance is an appropriate and attainable target for all pasture-based dairy businesses. Poor intakes of pasture DM increase reliance on purchased supplementary feeds, increasing exposure of a dairy business to the vagaries of price for purchased silage, hay, grain and protein meals. Optimising the consumption of home-grown forage, including pasture grazed *in situ* remains a key objective for most dairy businesses, provided the price of pasture grown is cost effective, as influenced by land values, fertiliser and cost of irrigation, if applicable. Pasture allowance remains possibly the most important driver of pasture DMI and is one key aspect of pasture management that can be both monitored and controlled by herd managers. Inadequate grazing time due to constraints of large herds spending excessive time off pasture may limit time available to graze and negatively impact on an expected positive association between pasture allowance and pasture DMI. Bite size as influenced by pasture allowance and bite rate contribute to net daily pasture DMI, albeit to a lesser extent than grazing time. Pasture must be presented to cows as a high quality, easy to harvest feed and remain free of associated compounds that might otherwise reduce a cow's desire to consume pasture. By allowing cattle access to adequate quantities of high quality pasture for an appropriate length of time, grazed within the horizon of between 1500 kgDM and 3000 kgDM per ha for temperate pasture species will typically allow cattle sufficient bite sizes to support optimal intake of pasture DM, whilst utilising acceptable quantities of pasture grown. Cow body condition score and / or liveweights must be monitored to ensure pasture utilisation is not being achieved at the expense of cow well being. Management of cattle for optimal appetite requires a cow that is well managed through calving, such that appetite is not suppressed by poor periparturient management. Freedom from disease conditions that impact directly and indirectly on ability to graze and desire to eat is a critical prerequisite for maximising a cow's desire to consume pasture DM. Maximising DMI by pasture-fed cattle requires an understanding of all factors that collectively influence DMI by individual cattle whilst optimising utilisation of pasture grown.

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WHERE ARE THE FEEDING SYSTEMS HEADING TO IN AUSTRALIA?

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Abstract

Australian dairy feeding systems are diverse. While still pasture based, more complex systems are evolving that better reflect local resources and capitalise on market opportunities. These allow farmers to improve feed conversion efficiency and better manage risk. Changes made in feeding systems require careful planning and there are implications for farm development and management which should be considered holistically. Requirements of modern feeding systems are discussed and examples of these in practice are presented.

Introduction

The Australian dairy industry has traditionally been perceived and portrayed as pasture based. This depiction has led to our industry being viewed both domestically and overseas in a very similar light to that of New Zealand. Hence we have evolved very similar grass based management and farming philosophies to our South Pacific counterparts. Rightly or wrongly, we still very much perceive ourselves as pasture based and much of the industry's politics, extension and advisory services are tailored towards the concept that "home-grown-feed" is the lowest-cost way to feed Australian dairy cows.

Ongoing reductions in dairy terms of trade, climate variability and market volatility continue to place pressure on dairy margins and the limits of traditional accountancy based methods of "cost control" to maintain dairy incomes are rapidly being reached. The industry has responded with increased stocking rates and farm output. However, this strategy has generally been accompanied with increased risk. Coupled with this, animal well being, water availability, climate, environmental and "right to farm" issues are increasing pressure on farms and farmers. Dairy farm management and feeding systems are being forced to evolve to meet these challenges or to exit. Farmers are responding by creating innovative feeding systems that better utilise local climatic and commodity opportunities, which can maintain or grow profits as well as help manage seasonal, market and social risks. Our feeding systems are becoming some of the most diverse in the world and generic approaches to extension and management are increasingly being found wanting.

Feeding systems

The Australian dairy industry perceives and markets itself as being pasture based. On review of recent data from Dairy Australia, it appears that this perception should be revised. As set out in Figures 1 and 2 below, 35% and 45% of herds were fully fed by supplements for an average duration of 4.8 months in 2009 and 2010 respectively. Our industry has clearly adapted to a variety of challenges including higher stocking rates, drought and wet weather and reductions in irrigation water availability with major changes in feeding systems.

Feeding "systems" can be defined as the whole farm approach and philosophy of production, procurement and delivery of feed to animals. A modern dairy feeding system should aim to:

1. Deliver balanced and safe rations
2. Efficiently grow and utilise home grown feed (when part of the system)
3. Minimise wastage
4. Optimise feed conversion efficiency
5. Efficiently manage nutrients and effluents
6. Provide optimal animal comfort and wellbeing and minimise disease incidence

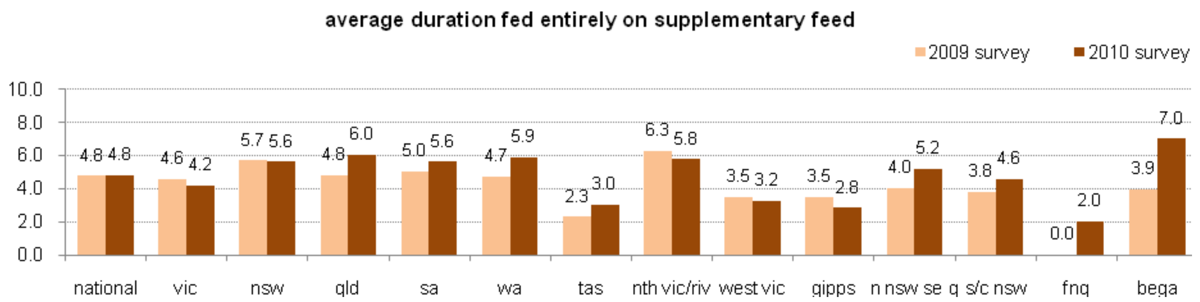

Figure 1 Average duration of herds fed entirely on supplementary feed. (*Source: Dairy Australia 2010 National Dairy Farmer Survey)*

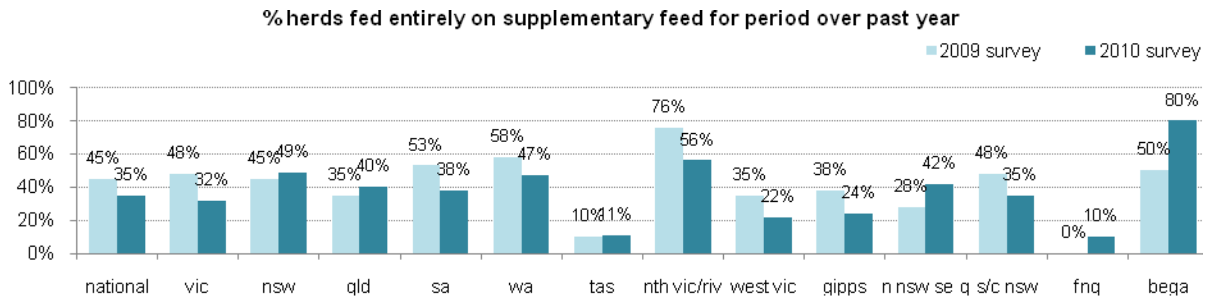

Figure 2. Percent of herds fed supplementary feed.

(*Source: Dairy Australia 2010 National Dairy Farmer Survey)*

Feeding systems in the Australian dairy industry are extremely diverse. While it could be argued that each Australian dairy has its own unique feeding system, they have been loosely classified by Dairy Australia into 5 categories:

1. **Pasture + other forages + low grain/concentrate feeding in bail** (Grazed pasture + other forages + up to 1.0 tonne of grain/concentrates fed in the bail).

2. **Pasture + other forages + moderate-high grain/concentrate feeding in bail** (Grazed pasture + other forages + more than 1.0 tonne grain/concentrates fed in the bail).

3. **Pasture + partial mixed ration (PMR) ± grain/concentrate feeding in bail** (Pasture grazed for most or all of the year + partial mixed ration on feed pad ± grain/concentrates fed in the bail).

4. **Hybrid system** (Pasture grazed for less than nine months per year + partial mixed ration on feed pad ± grain/concentrates fed in the bail).

5. **Total Mixed Ration (TMR) system** (Zero grazing. Cows housed and fed total mixed ration)

While system 1 is still the predominant feeding system in Tasmania, system 2, (i.e. moderate to high grain in the bail with some supplementary forages) is becoming the predominant system nationwide (Figure 3). In 2009/10, 93% of all herds were fed grains or concentrates. The average amount fed per cow was 1.58 tonnes per year (Figure 4), indicating that at least 25% of feed for milking cows is now brought in feed (Dairy Australia, 2010). Partial mixed rations and hybrid systems (systems 3 and 4) are becoming increasing popular, driven by previously mentioned pressures in modern farming and acknowledgment of the efficiency and flexibility of these two systems.

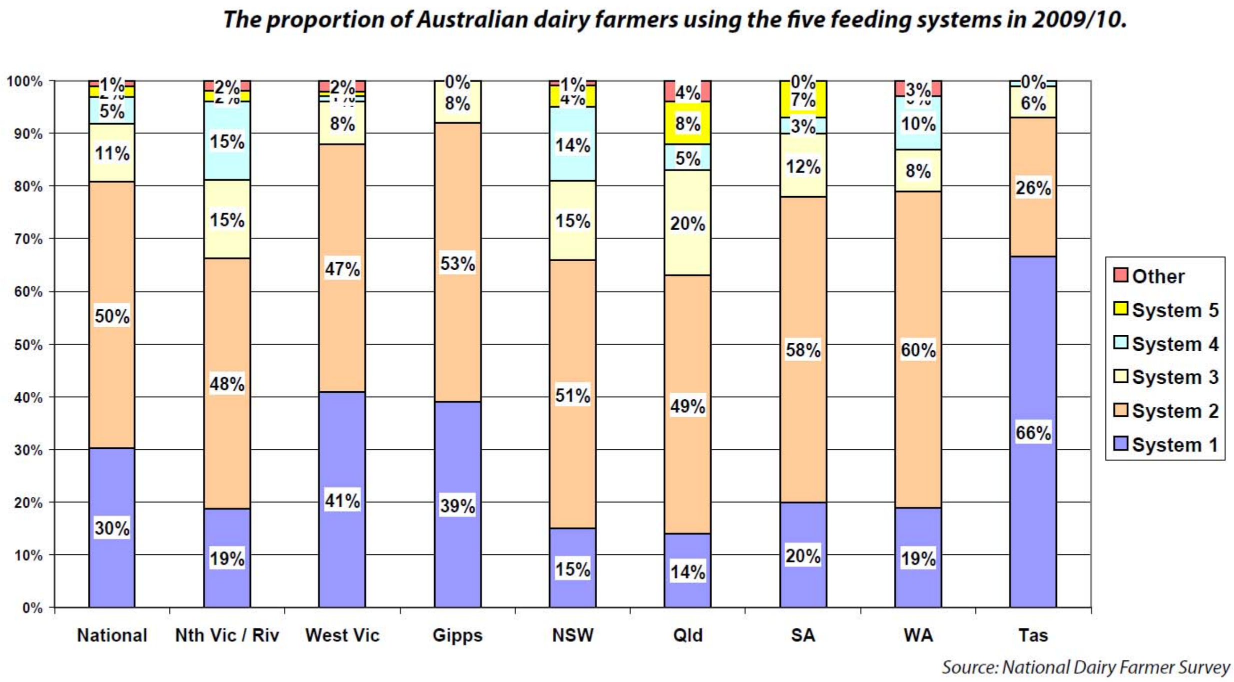

Figure 3. Concentrates fed per cow per year

(*Extract from Dairy Australia 2010 National Dairy Farmer Survey).*

When reviewing a farm feeding "system", it is important to consider the pasture/fodder production delivery strategies used on the farm as well as the facilities and infrastructure used to mix and deliver conserved or harvested feeds and concentrates. These are referred to as feed out "methods". Feed out methods have been classified by Dairy Australia, based on their relative levels of complexity and permanency (Appendix 1). Farms using feeding system 1 and 2 by definition do not have a feed pad and a mixing wagon, so hay / silage and other supplements would be fed out on bare ground or on top of pasture (Feed-out methods 1 & 2). Farms using feeding system 3 and 4 may use semi-permanent or permanent feed pads for a partial mixed ration (PMR) (Feed-out methods 3, 4 or 5). Farms using feeding system 5 would use feed-out method 5 for a total mixed ration (TMR). Most farms across the 5 feeding systems would feed at least some grain / concentrates in the dairy parlour (i.e. feed-out method 6).

Farmers have many considerations and choices when determining what feeding system best suits their needs and capacity and should consider the following when making a choice of what style or components of feeding system they are best to adopt.

1. **What are the strengths and deficiencies of their existing system and to what extent are existing resources underutilised?**

   Dairy farmers should regularly review their production and feeding system and ensure that it is appropriate for their current and future needs. Before major changes in feeding systems are made, they should ask the following questions:

   - Are current resources and opportunities being utilised appropriately?
   - Can more be extracted from the resources currently at hand through management rather than investment?
   - Can the current system be pushed harder without excessive exposure to risk?
   - Are the owners happy with the current system and do they think they will be in 5 or 10 years time? In answering this, different perceptions of owner "happiness" and motivation need to be individually considered.

   Once these questions are answered, decisions on appropriateness of current feeding systems and strategies, or the need to overhaul or change feeding systems can be made. In some cases, farmers may consider relocation as a superior investment response to continuing to farm in an unsuitable location or facility.

2. **What risks need to be managed with the feeding system and how can this be best done with available resources?**

   Feeding systems are core to a farm's risk management strategy. Risk takes many forms. As stocking rates have risen and requirements for productivity and profitability have increased, most dairy farms have increased their level of risk dramatically. Rain-fed grazing enterprises are subsequently much more vulnerable to drought and feed shortages than ever before. Irrigation farms are far more exposed to reductions in water availability due to competing demands, climate variability and political risk. The effect of local and more widespread drought has been felt by most in the industry in recent years. An even greater risk to many farms that have increased cow numbers is prolonged wet weather, but not necessarily improved infrastructure such as laneways to match. More recently, farms have been exposed to volatility in input cost risk. For example, high fertiliser inputs with nitrogen and other fertiliser costs have more than doubled in the period immediately prior to the GFC (provide name in full). This has encouraged many farmers to review their forage production choices and to look at ways to better manage nutrients associated with collectable effluents. When implementing a feeding system, milk market risk and volatility needs to be considered (see point 3).

3. Which milk market are they supplying and how does this market reward production of milk at different times of the year?

Consolidation of milk processors with loss of regional manufacturing capacity and a return to quota-style tiered milk payment systems in the north eastern states will encourage dairy farmers to review their feeding systems. Pasture systems will need to be reviewed to shift the feed curve to "the left". The ability to rapidly transition herds from summer pastures to temperate pastures early in autumn will allow farmers to lift production more rapidly from summer lows. Management strategies of kikuyu and other summer grass pastures will need to be refined to minimise trash build up and optimise quality and we are likely to see the emergence of more summer active non-grass pastures in suitable regions. This will enable farmers to capture autumn production incentives with a greater proportion of income derived from pasture (where appropriate). Similarly, continued focus on spring and summer silage quality and improved skills in sourcing forages and concentrates from off farm based on quality and value rather than price alone, will allow those feeding in PMR and TMR systems to stabilise production through the warmer months and rapidly increase production in autumn. Facility design, management strategies and ration formulation that consider heat and humidity stress will influence production through the warmer months and will have a significant carry over effect as herds enter higher pay periods.

4. What local advantages and restrictions exist with respect to:

a. Climate

i. Agronomic: Farmers need to select agronomic systems that are appropriate for their region and resources. Areas with suitable rainfall or irrigation and high summer temperatures will continue to explore zero grazing forage production systems, but need to ensure that they have the feeding systems that will allow efficient utilisation of conserved feeds. Resilient pastures that offer protection from wet weather and mud in summer, autumn and early winter will need to be retained or integrated into these more intensive systems where mud and pooled water create major issues with mastitis and lameness. Resilient grasses such as kikuyu will form an integral component to these systems in the subtropical/tropical areas of Australia, as farms in these areas develop pasture systems which take a portfolio approach to climate risk management. More temperate, Mediterranean climates will continue to suit ryegrass based milk production.

Water use efficiency will form the core of many farmers' pasture decision making process. Perennial rye pastures that require 1,000L of water to grow 1kg dry matter (DM) of pasture through summer will not be tolerated by those inside and outside the industry. Increasingly, farmers will choose to water less area more efficiently through the warmer months, and in conjunction choosing water efficient crops such as maize, millet and forage sorghums. This choice is emerging in herds from the Atherton to Tasmania and will continue to drive the industry towards a more PMR based system as we have seen emerging in areas such as Northern Victoria and Southern Queensland in recent years.

ii. **Cow comfort and management:** Facility design will continue to focus on management of heat stress and humidity. Feeding strategies that optimise feed intake in warm months will continue to evolve. These will include an increase in bringing the feed to the cows rather than the cows to the feed, pasture manipulations such as pre-mowing and design of rations to minimise fermentative heat production. Higher stocking rates accentuate the effect of wet weather on laneways and pastures. Farmers that make provisions for feeding in wet weather will be able to minimise the effects of predicted less frequent but more severe rainfall events. Milk companies will continue to demand higher milk quality and the public will continue to scrutinise dairy cow comfort and well being. Milk consumers will not accept product where these sensitive issues are not addressed.

b. Commodities

Freight costs will force farmers to make better use of locally produced commodities. This will lead to an increase in intensively managed dairy farms in the cropping zones where crops and forages are more readily locally available. In many cases, these feeds will be available at lower costs than home grown forages, opening up more areas with potential for intensive dairy systems. Similarly, population increase in urban areas and related processing of grains and legumes for human feed or biofuels will increase supply of by-product feeds. Ready availability of these commodities and relative costs compared to more distantly sourced concentrate options will encourage survival of dairies within 150km of the major urban centres. It will also encourage facility and feeding systems that will allow their safe and efficient storage and feeding.

c. Developmental/social/environment factors

Existing dairy farmers and dairy developers will need to be increasingly attentive to both local and state legislative requirements as well as the appearance and image of their operations when refining and developing their feeding systems. As “right to farm” issues increase in prominence, farmers that do not appropriately engage their local communities and legislative bodies in a proactive and receptive manner will continue to find carrying on their day to day business more challenging. Ownership of land no longer carries a right to conduct business without due consideration of those in the immediate and local vicinity and the environment. Smart feeding system development will focus on investment that delivers both to the cows and the environment.

5. What is the capacity and willingness for further investment?

The capacity and willingness of individual farm businesses to invest is highly variable. Many farm businesses are content with current levels of production and exposure to financial risk. Others may be at a stage in their farming cycle where they can not justify further investment in depreciating capital or facilities that may be only utilised for a few years while they see out farming or progress to farm succession. In these businesses, small changes can often be made to grazing and pasture strategies that require minimal investment and only change in practice or ideology. Small investments in temporary feed out facilities can greatly reduce wastage.

Other farms may be in a development phase and investments in feeding systems, including pastures and forage production systems, are well planned and funded in lines with the strategic and production objectives of the businesses involved.

6. What “down-stream” effects will occur as result of changing feeding systems?

Change in feeding systems rarely occurs in isolation and needs to be considered with respect to potential “down-stream” effects. A thorough planning process that looks at the effect of a change in feeding system on the entire farming system needs to be instigated. For example, construction of a feed pad to deliver mixed rations will have significant implications on effluent management systems, requirements for machinery, labour, storage of commodities, capacity of dairies to manage more cows or the ability to handle increased volumes of milk to name a few. A system change that results in production of 40 tonnes of dry matter per hectare, much of which will need to be conserved and fed back out to a larger and/or better fed herd, needs to consider how this feed will be harvested and stored, how it is to be fed out, what facilities and machinery are needed to do this, what additional nutritional inputs are required to optimise this feed, what are the implications on animal health of moving from an all grazing to a partial or total mixed ration system and how is the additional nutrient transferred from cropping areas back to feed-out areas to be managed. The investment, managerial and labour implications of these related systems changes need close evaluation when altering feeding systems on farms that have functioned effectively (or ineffectively) in the past.

The future feeding system, what will it look like?

Australian dairy systems have shown extraordinary resilience and adaptability over many years. Effective and sustainable dairy feeding systems will continue to evolve in response to the issues raised in this paper. Our climatic and regional diversity dictates that there will not and should not be a generic Australian feeding system (with the two clauses of having systems that allow full feeding of dairy livestock and optimise feed use efficiency). Pastures and home grown forage production will continue to be a feature of most operations and farmers now have a suite of technological and managerial strategies that will continue to increase forage yields and improve feed quality. A portfolio approach to forage production will help farmers manipulate the pasture curve to suit markets and manage risk. Pasture systems will need to be region suitable, drought tolerant, highly water efficient, harvestable and reliant on less imported nutrient, particularly nitrogen.

Farmers that grow more forage will need to develop facilities that allow for their efficient storage and feeding. There is little point in growing more feed if you are unable to utilise it! While some increases in home grown feed can displace imported forages and fully feed previously underfed cattle, the increases that are possible will allow the feeding of more cattle on smaller areas.

Use of grains and by-product feeds will continue to increase. These will be used to optimise ration function converting a greater proportion of grown nutrients into milk. They will also be used to maintain production when pasture growth does not meet demand. In many situations, they will be used as the nutrients provided can be more cost effective than home grown feed, particularly if land value is included in the costs of producing feed.

Wastage, feed use efficiency, animal well being and milk quality and nutrient management will dictate the need to invest in and construct flexible feeding systems that are visually, environmentally and animal friendly. Systems developed will need to be robust in both dry and wet weather.

"Tales of 4 feeding systems- short stories of the future Australian feeding system"

Luke and Leo Cleary – Wauchope, NSW

When we commenced work with Luke and Leo in 2002, they were operating a simple but effective pasture based dairy operation, milking around 150 cows in a year round calving system. The last 8 years has thrown considerable challenges at the business, but has also seen a major overhaul of the feeding system and productivity of the whole operation. The first challenge was to define and consolidate the pasture system. The farm had approximately 70 hectares of "bike shift" and "fixed irrigation". Like many at the time, they had been advised to remove the existing kikuyu base and shift towards a southern, perennial ryegrass based pasture system. This was successful for a couple of years, but the poor growth of ryegrass in the hot and humid summer and the resultant invasion of unpalatable summer grass weeds had not been considered by previous, but well intended advisors. Identifying the local advantages of the mid-north NSW climate, we set about a process of re-establishing a kikuyu base to much of the farm. Thrown into this, the severe droughts of 2003 forced much closer scrutiny of water use efficiency and also highlighted the areas' exposure to rare but severe droughts. Strategic use of irrigated BMR sorghums, provided a rapidly growing water efficient crop, which was also used as a regeneration tool for re-establishment of kikuyu pastures. There was also investment in a simple but effective rack feeding system for the herd, which allowed purchased hay to be fed with reduced wastage.

Surviving the droughts, Luke and Leo started to look to the future. It was clear that Luke was committed to the business; however, it was also clear that the size of the operation would not be adequate to provide for two families in the long term; as well as being able to afford to employ labour and generate some lifestyle. As luck would have it, the neighbouring property came up for sale and this was snapped up. The strategic location of this property was ideal for the dairy and it also freed up some land to allow installation of a 30 hectare pivot irrigator. This gave the operation considerable scope to integrate significant plantings of whole crop forage sorghum used in a double crop rotation with annual ryegrass and oats, delivering estimated total annual yields on this part of the farm exceeding 30 tonnes of dry matter per Ha. Subsequently, direct drilled maize has been grown in place of the forage sorghum in years when grain prices have been higher. Most recently, BMR forage sorghum was used to provide grazing fodder and silage for the milking herd based on low grain costs and a desire to reduce some of the risk associated with maize cropping on the NSW mid-north coast.

In combination with as shift from round bale to pit silages the feed out method was changed from a feed cart with feed being fed out on the ground; to a low cost temporary conveyor belt feed pad system. This has since been upgraded to portable concrete troughs on a packed gravel base. Wastage has been greatly reduced and environmental issues associated with mud and manure on feed pads have been addressed.

In 2010, a twin auger vertical mixing wagon was purchased. This type of wagon was preferred as it gave excellent handling of round bales as well as pit silage (both of which were in use) as well as hay purchased from off farm. It has allowed utilisation of well priced by-products such as wheat millrun, which play a role in displacing some of the concentrate and forage elements of the diet.

It was also important that the calving pattern was considered holistically with the feeding system and the local climate. The previous year round system was changed to a seasonal calving, starting in April with an autumn peak and finishing in mid- September. This allows the farm to be over sown in autumn when milker numbers are at their lowest; with numbers rapidly rising as pasture production starts to improve from mid-April onwards. Chemical suppression of summer pastures and removal of trash has given rapid establishment of early pastures. Integration of forage brassica (Pasja) into early autumn plantings has further shifted the pasture curve to the left, accelerating the lift in production from the difficult period in late summer and early autumn. They are also looking to trial specialty high quality herb and legume pastures this summer that will enable control of invasive summer grasses while reducing nitrogen inputs and tapping down into deeper moisture profiles.

Luke and Leo have now developed a modern feeding system that utilises the farms' ability to grow pastures for 12 months of the year, capitalising on the warmth and humidity in the summer to grow forage crops and kikuyu pasture for conservation and grazing; and the mild autumn to spring period for growing temperate pasture species. They have invested in infrastructure that allows them to cope with regional climate variability and they can program their summer cropping system based on market forage and grain conditions. Stocking rates can be lifted with less risk and they can capitalise on by-product opportunities as they arise.

Chaldari Dairies – Meningie, South Australia

Chaldari Dairies is a truly locally adapted feeding system in the sandy soils to the south east of Meningie in South Australia. The owners have developed a feeding system based on periodic grazing of extensive lucerne pastures and a very simple concrete feed pad system. The sandy soils, excellent drainage and low rainfall in the region, make this area ideal "dry-lot" country. Lucerne, once established on the farm is extremely persistent and able to respond rapidly in these soils to rain when it comes. Some opportunities are taken with rye grass and cereals in wetter winters but generally, rainfall can penetrate into the deeper soil layers in winter for use by the deep rooted lucerne in the warmer months. Not put off by conventional southern wisdom saying that farming in the south east without rye grass pasture as the main base is unviable, they developed relationships with local hay, silage and grain suppliers that consistently deliver them an overall ration cost per megajoule, that are lower than those being claimed by medium input regional grass-pasture based farmers. This is aided by their lucerne pastures, when available that are estimated to produce high quality dry matter for less than 5c/kg. At the time of writing, total ration cost was approximately 16c/kg dry matter with only 5kgs DM of grazed lucerne in the diet.

Chaldari's feeding and production system capitalises on low coast land that is suitable for dry feeding of cattle and makes the most out of local feed market opportunities. Smart management has identified the importance of relationships with local growers consistently delivering well priced ration ingredients in a simple but effective feed delivery system that minimises wastage and allows for easy collection of nutrients. Lucerne pastures are locally adapted, persistent and productive when moisture is present.

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Menzies dairy- Nowra, NSW

Seeking warmer weather and looking for opportunities to expand their business, the Menzies made the trip down the escarpment from the Southern Highlands of NSW to Nowra on the Shoalhaven river delta. The farm they purchased had plenty of land, some irrigation provided through town waste water recycling scheme, and a good rotary dairy. However, it

had significant room for increasing production compared to its previous history and there was a need to expand production to provide for two families. Initially, the Menzies spent the first year settling in getting a feel for the local climate and the risks associated with a flat farm on heavy alluvial soils. They also had to develop an appreciation for the local kikuyu based pasture system compared to their previous mostly ryegrass pasture system in the highlands. A number of key risks and opportunities were identified quickly.

- The farm and region were shown to be at high risk of both drought and prolonged periods of wet weather
- Laneways were very susceptible to damage during wet weather
- The climate suited production of maize silage and this could be grown under both irrigation and dryland conditions
- There was more recycled water available than was being used
- The existing kikuyu base was very productive but needed careful management to control it

The first priority for the business was to be able to safely feed cattle under all weather conditions. A concrete feed pad was constructed. This was placed in the major arterial laneway providing mud-free access to the rest of the laneway network. This doubling up of functionality provided access to the rest of the farm, allowing minimal-waste feeding during dry or wet times or at times when pasture growth was slowed. Home grown maize silage could be grown under high security under some of the pivot area and with moderate security in the dryland areas under reasonably reliable summer rainfall. The silage wagon was replaced with a mixing wagon allowing the maize silage to be mixed with home grown rye silage, as well as regionally sourced commodities such as dried distillers grains, wheat millrun and corn hominy, all procured within 100km of the farm. Cows could be easily fed, even during wet periods and then turned out onto nearby kikuyu paddocks while the rest of the farm transitioned from summer to winter pastures during the often wet autumn period. A second pivot was installed reducing drought risk and a program of soil testing and correcting key problems including low potassium levels, acidity and some areas of salinity with lime has lifted pasture production dramatically. Stewart has developed chemical control strategies for the kikuyu pastures that suppress it without compromising production the next year allowing early planting of rye and oats and a rapid change over from summer to winter pastures. Over time, cow numbers have been able to double and the family now manage two separate herds, one Holstein and one Jersey on the same property with double the stocking rate of the previous owners and room for further growth if desired.

Peter and Kylie Squires- Central west NSW

Peter and Kylie run a grazing based operation 30 km's to the south east of Dubbo on an irrigation property sourcing most of its water from bores with periodic water availability from the Macquarie River. They had made the journey from the mid-north NSW coast 15 years ago and had developed a pasture system based on irrigation of ryegrass and lucerne pastures. Severe droughts in the early and mid 2000's had put the operation under considerable stress at times and business needed to grow to accommodate other family members and to allow employment of sufficient staff to provide some lifestyle for the owners. On initial review, one of the key issues was irrigation choices. In attempting to keep a large area of patchy lucerne and ryegrass watered over summer, very little feed was being grown. Winter pastures were also underperforming due to suboptimal sowing rates, earth mite and weed problems and not enough nitrogen being applied. The farm was well suited to pasture and fodder production and plans were made to continue to focus on this. In the first year, winter pastures were cleaned up and nitrogen applications increased, boosting spring production and allowing full feeding of the herd and an increase in production. Winter rainfall was reasonable and growth in some of the dryland areas was good enough for making medic silage and hay. Peter already had some dryland lucerne planted under some triticale and this was able to establish. With a goal of setting the farm up with forage for next winter as well as feeding the herd through the summer, a large area of the irrigated farm was sown down to forage sorghum. However, rather than trying to keep all pivots going, one was turned off allowing better watering with the two pivot areas during the summer period. Some additional summer rain and strategic use of nitrogen allowed the Squires to fully feed the herd through the summer, as well as putting away a large volume of sorghum silage and hay for use next year. Their immediate goals had been met. Through the next few years, confidence and results in forage production on the property have greatly improved. Rotating long and short season rye based pastures with forage sorghum have reduced reliance on purchased feed and strategic use of summer fallows on the irrigation have allowed early ryegrass and oats to be sown in late February and early March giving excellent winter feed in mid-April.

Peter has also developed good links with local grain and hay producers. These have allowed him to consistently source good quality grains in close proximity to home at very favourable prices. Grain is processed on farm (approximately 2 tonne per cow per year) and fed through the dairy. With appropriate buffering, they can confidently feed up to 10 kg's/head per day if needed. The hay feeding system has been refined with the use of hay racks and more recently, mobile hay carts. This has reduced wastage but ultimately, the plan is to set up an undercover concrete feed pad for feeding in wet and dry weather. The shed for this has already been built providing some protection from the summer sun and shade sails and a sprinkler system at the dairy help keep cows cool in summer and dry matter intake levels up. Ironically, wet weather is as significant a risk to the operation as is drought and the area of irrigated kikuyu is to be increased this year to give a stable platform for loafing cows in wet autumns as well as water and nitrogen efficient pastures from November until April.

The neighbouring property has been leased and another property purchased allowing Peter and Kylie to do a fantastic job with their heifer rearing, as well as diversifying into Holstein and cross bred beef production. The herd size has grown to nearly 300 cows in milk and production is up by 50% in 3 years. The feeding system now makes the most out of its irrigation resources, takes dryland opportunities as they arise and takes local advantages with grain and hay supplies. Feeding infrastructure is evolving as funds allow providing access to grazing when required and to feed supplements efficiently minimising waste and the effects of heat stress.

Appendix 1 From *Dairy Australia Grains2Milk summary report – Feed wastage study 2009* © Copyright Dairy Australia p6

Six feed-out methods used by Australian dairy farmers

Six main feed-out methods used by Australian dairy farmers have been defined by Dairy Australia's Grains2Milk program and SBScibus for the purpose of the feed wastage study as follows:

1. Temporary, relocatable (bare area)

Definition: Forages or partially mixed rations are fed out on the *bare ground* in the paddock or under *an electric fence line, in hay rings or old tractor tyres*, using existing equipment at the site (eg. a tractor and bucket or silage cart, etc.). In this system the cows are *not grazing* the paddock where the feed is fed out and the paddock is commonly referred to as a *sacrifice paddock*. There are no prepared surfaces for the feed-out area. In this system the feed-out facility can be readily located to other sites around the farm; this may be required in special circumstances when the paddock becomes muddy following a heavy rainfall event.

2. Feed allocated on pastures in the paddock

Definition: Forages or partially mixed rations are fed out into the paddock where the cows are grazing. The feed is usually fed out either straight on top of the pasture anywhere in the paddock or under an electric fence line using equipment commonly found on most dairy farms (most likely a tractor and bucket or silage cart).

3. Semi-permanent

Definition: Forage mixes or more complex mixed rations are fed out on a semipermanent feed-out area with a compacted surface that uses low-cost troughs, such as conveyor belting, second-hand feed or water troughs or other materials. The equipment used for feed-out is usually a silage cart or mixing wagon.

4. Permanent, basic but functional

Definition: Complex mixed rations are fed out using a purpose-built feed-out facility with a compacted surface that has concrete feed troughs or a narrow cement strip under electric wires or cable to prevent cows trampling feed. A mixing wagon is usually used for mixing and feed-out.

5. Permanent, minimal waste, maximum control

Definition: Complex mixed rations prepared using a mixing wagon are fed out using a purpose-built feed-out facility, most likely with a cement surface for the cows and one or more feed alleys. This may be covered with a roof and may also incorporate a loafing area or cow stalls. Headlocks or cabling and even in some cases an electric wire are used to restraint the cows to prevent feed losses due to trampling.

6. Grain feeding in the dairy parlour

Definition: Supplementary grain or pellets are fed in the dairy during milking. This system is used in both conventional herringbone and rotary dairies. A wide variety of systems are found in dairies from some of the more advanced and costly where the feed allocation can be altered according to the manager's requirements. In some instances cows can be individually fed using one or more supplements, and the trough space is divided between cows using physical barriers, i.e. gates or a looped rail separating the cows' heads in the trough. To some more basic systems where only one supplement and/or amount can be fed to the cows and the trough area has no physical barriers separating the cows.

Acknowledgement

Thank you to the farmers who have allowed me to share part of their story.

References

Dairy Australia Grains2Milk summary report – Feed wastage study 2009 © Copyright Dairy Australia 2009

Dairy feeding 2010- updates and insights © Copyright Dairy Australia 2010

FUTURE DAIRY 2'S HUNTER VALLEY FARM COLLABORATION PROJECT

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Abstract

The Hunter Valley Farm project is a collaborative effort between FutureDairy, the Industry and Investment NSW dairy extension team and 6 commercial farmers in the Hunter region. The project was initiated in July 2009 with the goal of applying the principles of Complementary Forage Rotations (CFR) and Systems (CFS) developed by FutureDairy at Camden on contrasting farm systems. The methodology included an initial full farm analysis; a planning exercise with the farmers; setting goals and a fortnightly monitoring process that included forage yield and quality. Feeding decisions and the financial implications of these have been tracked monthly and analysed using the Mini Milk biz decision support tool. After the first 12 months all farms have increased on farm feed production (tDM/ha), particularly on the part of the farm dedicated to the CFR. Farmers have all highlighted their increased confidence around feed budgeting and achieving higher home grown forage production as key outcomes of the project.

Introduction

Since the start of the Future Dairy project, the research team has successfully implemented the Complementary Forage Rotation (CFR) on the dairy at EMAI, consistently achieving over 40 TDM/ha. They then moved focus to a whole farm approach and developed the Complementary Forage Systems (CFS) trial at Corstorphine dairy farm, to integrate the forage rotation principles with pasture production.

The next stage in making the learnings from these approaches more accessible and relevant to farmers was to apply the CFS principles on commercial dairy farms. After consultation and collaboration with Industry & Investment NSW dairy extension team, the Hunter Farm Project was launched in July 2009. Six farmers were enlisted to work together with the research and extension teams to ground truth the research.

Methodology

Selecting the farms

The criteria used to choose the farmers to participate were

- that they were keen to increase the amount of home grown feed produced on farm and reduce their reliance on purchased feed where possible
- that they had the resources and desire to try something different in forage production

- that they were prepared to provide farm data and to regularly monitored

About the farms

The six farmers selected were: Ross McDarmont and farm manager Tim Freeman, Ian Simpson and David Butler, all from Denman (Upper Hunter cluster); George Allen from Singleton, Rodney Richardson from Gresford and David Williams from Vacy (Lower Hunter cluster).

According to the Dairy Australia definition of Feeding Systems, two of the farms could be described as System 2 (Pasture plus other forages with moderate to high concentrate feeding in bail), and four farms could be described as System 3 (Partial mixed ration with or without concentrate feeding in bail). These two feeding systems are by far the most common within the Hunter Valley dairy industry. Only two of the farms had grown maize for silage in the past, and the other four had no experience with bulk crop silage.

The process during year 1

- MilkBiz full farm business analysis has been conducted for the 08/09 and 09/10 financial years.
- Goal setting exercise – a summary of the farm's position as at July 09, feed budget and actions plan developed
- Tracking of cash costs and feeding data using Mini MilkBiz (an Industry and Investment NSW decision support tool) on a monthly basis for each farm with the purpose of monitoring movement in the farm's feeding strategy and outcomes across the year.
- Nutrient analysis of all feeds on farm on a fortnightly basis, with results presented to farmers each month in a format which can be easily interrogated
- Photographic diary of pastures and crops on farm across the 12 months
- Farm walks and group discussion of current position and short- to medium- term challenges
- Group discussion of on farm management of different species and whole farm interactions
- Cost, yield and quality analysis of CFS area production
- Anecdotal learning – feed management and planning processes

Outcomes (after 1 year)

Key farm production outcomes

- All farms have progressed positively towards the goals established at the start of the project
- All farms have increased on farm feed production (tDM/ha), particularly on the part of the farm dedicated to the CFS

- Introduction of brassica crops into the farm system for the first time (3 farms)
- Introduction of whole crop silage into the farm system for the first time (2 farms)
- Firmer planning and increased confidence around feed budgeting across the year

Increased capacity of farmers and project team

A significant outcome of the on farm collaboration has been the increased confidence and capacity of the collaborating farmers, as well as the advisors and research team. These changes have come about through:

- a formalised planning process to set goals and assess the potential impacts of CFS implementation;
- monthly collection and analysis of data through Mini Milk Biz, giving farmers regular feedback of the physical and financial impacts of their feeding decisions;
- regular and independent collection and testing of feedstuffs for nutrient analysis, allowing for use in ration formulation and forward feed budgeting;
- regular and in-depth farmer group meetings with the Future Dairy and I&I NSW staff present to provide guidance and technical expertise;
- the openness of data sharing and pooling of ideas and experiences between collaborating farmers.

Table 1: Summary of impact of CFS application across the six Hunter Valley monitor farms

<table>
<tr><th></th><th colspan="2">Farm A</th><th colspan="2">Farm B</th><th colspan="2">Farm C</th><th colspan="2">Farm D</th><th colspan="2">Farm E</th><th colspan="2">Farm F</th></tr>
<tr><td>CFR Rotation used from October 2009 and forage yields achieved*</td><td colspan="2">Maize
21 tDM/ha
Brassica & annual ryegrass 9.8tDM/ha</td><td colspan="2">Maize
15 tDM/ha
Annual ryegrass 6.97tDM/ha</td><td colspan="2">Forage sorghum silage
12.8 tDM/ha
Ryegrass/ lucerne/ chicory/oats mix 8tDM/ha</td><td colspan="2">Maize
19.5tDM/ha
Brassica, annual ryegrass & oats 13 tDM/ha</td><td colspan="2">Maize 1
15.9 tDM/ha
Maize 2
9.5 tDM/ha
Triticale with maple peas 8DM/ha</td><td colspan="2">Forage sorghum silage
10tDM/ha
Perennial ryegrass & clover
8tDM/ha</td></tr>
<tr><td>CFR area: ha
:% of milking area</td><td colspan="2">17 ha
15%</td><td colspan="2">10 ha
15%</td><td colspan="2">9 ha
15%</td><td colspan="2">8 ha
15%</td><td colspan="2">20 ha
14%</td><td colspan="2">8 ha
6%</td></tr>
<tr><td>Total projected yield on CFR area</td><td colspan="2">31 tDM/ha</td><td colspan="2">22 tDM/ha</td><td colspan="2">21 tDM/ha</td><td colspan="2">33 tDM/ha</td><td colspan="2">34 tDM/ha</td><td colspan="2">18 tDM/ha</td></tr>
<tr><td rowspan="2">Forage utilisation over whole farm CFS
(tDM/ha)</td><td>08/09</td><td>09/10</td><td>08/09</td><td>09/10</td><td>08/09</td><td>09/10</td><td>08/09</td><td>09/10</td><td>08/09</td><td>09/10</td><td>08/09</td><td>09/10</td></tr>
<tr><td>10.8</td><td>12.4</td><td>13.2</td><td>13.6</td><td>12.2</td><td>13.4</td><td>11.5</td><td>14</td><td>11.0</td><td>12.2</td><td>11.0</td><td>11.5</td></tr>
</table>

Difference in forage utilisation	15%		3%		10%		26%		10%		5%	
Cost of home grown feed $/tDM**	281	260	165	126	121	91	160	169	112	145	104	108
Difference in cost of home grown feed	-7.6%		-23%		-25%		6%		29%		4%	
CFR targets for 2010 / 2011	20 ha Total **36tDM/ha** Maize *25tDM/ha* Brassica (leafy turnip) and ryegrass (short season annual) *11tDM/ha*		10 ha Total **36tDM/ha** Maize *25tDM/ha* Brassica (leafy turnip) and ryegrass (short term annual) *11tDM/ha*		9 ha Total **26tDM/ha** Forage sorghum silage *13tDM/ha* Pasture *13tDM/ha*		8 ha Total **38tDM/ha** Maize *25tDM/ha* Brassica (leafy turnip) and ryegrass (long term/biennial) *13tDM/ha*		20 ha Total **40 tDM/ha** Maize crop 1: 20tDM/ha Maize crop 2: 12tDM/ha Triticale and legume: *8tDM/ha*		12 ha Total **25tDM/ha** BMR *12tDM/ha* Brassica (leafy turnip) and ryegrass (long term/biennial) *13tDM/ha*	

*Forage yields for the autumn-winter crops include and estimate yield for the period July to late September (to complete 12 month cycle)

** Over the whole farm (i.e. not just the cost of forage produced in the CFR area)

Conclusions

The first 12 months of the collaborative process for Future Dairy Stage 2 has been successful in farms moving towards their individual goals. All of the six farms increased forage production significantly on the part of the farm targeted for applying the CFR-CFS principles. For most this translated into extra home grown forage over the whole milking area, and decreased their costs of home grown feed as well. However, two of the farms did not make significant increases, mainly due to other factors outside of the scope of the project.

The project team and all of the six collaborating farmers have committed to a further twelve months of participation in the project. During this time, different species across each farm will be evaluated for their contribution to the dry matter production across the farm. Farmers feel that they now have more confidence to strive for higher production off the allocated CFS area, as well as concentrating on controlling their purchased feeds.

Acknowledgement of the project team

The collaborative process has functioned with the following support:

Future Dairy Research Team:	Assoc Prof Yani Garcia (Project Leader)
	Ajantha Horadagoda (Lab manager)
Industry and Investment NSW:	Anthea Lisle (Livestock Officer – Dairy)
	Kerry Kempton (Technical Specialist – Dairy)
	Neil Griffiths (District Agronomist)
	David Deane (Technical Officer)
	Michael Ison (Livestock Officer – Dairy)
	Greg Mills (Industry Development Officer
Private industry:	Andrew Farr (technical support)
	Dr Neil Moss (consultant to 3 of 6 farms)

NUTRITION X REPRODUCTION INTERACTION IN PASTURE-BASED SYSTEMS: IS NUTRITION A FACTOR IN REPRODUCTIVE FAILURE?

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Abstract

Dairy cow fertility has declined in recent decades, coincidental with large increases in milk production. Cows take longer to return to oestrus, display poorer signs of oestrus, may have poorer conception rates and have greater early embryo loss. The problem is often considered to be nutritional, at least in part, and, therefore, can be corrected through dietary adjustment. Although acknowledged as highly digestible, high quality pastured forages tend to be low in non-structural carbohydrates (NSC), high in rumen degradable protein and the temporal supply may not be adequate for cow demand at key times; diet adjustment is often recommended to overcome these limitations. However, the interaction between nutrition and reproduction is poorly defined and study results are often contradictory. Increasing energy balance postpartum has been associated with early return to oestrus and increased pregnancy rates and, therefore, anything presumed to improve energy balance is recommended. However, the effect of energy balance is not consistent and is probably confounded with feed ingredients; furthermore, there is compelling evidence that energy balance cannot be greatly altered in the first four to five weeks after calving. Supplementation with NSC in lieu of structural carbohydrates reduced the postpartum anoestrus period in some studies, but the effect is inconsistent. In addition, dietary NSC content and improved energy balance have been implicated in poorer quality oocytes and embryos, and may contribute to higher rates of early embryo loss. High levels of degradable protein result in increases in blood ammonia and urea nitrogen, factors implicated in lower embryo survival in cows fed a total mixed ration. In comparison, pasture-based cows have blood urea nitrogen concentrations two- to three-fold greater than those reported as compromising fertility, but pregnancy rates do not appear to be affected. The reason for this inconsistency is unclear, but may reflect differences in adaptation time to the high protein diet or an indirect selection for cows that tolerate greater concentrations of blood urea nitrogen and ammonia. Dietary fat content and fatty acid composition have been intensely researched for their role in reproduction. Increasing dietary fat content from a low base (20 g/kg DM) has reduced duration of postpartum anoestrus. However, the effects of dietary fat on embryo quality and luteal regression vary and are difficult to interpret. It does not appear that reproduction will benefit from addition of fats to fresh forage diets. In summary, care should be taken in interpreting associative analyses and results from different farming systems. Calving condition score is negatively associated with time to first oestrus, a factor negatively associated with conception rate; therefore, nutrition and lactation length in the season prior to the breeding period are important. Early lactation nutrition does not influence energy balance during the first four to five weeks postpartum and dietary NSC content has inconsistent effects on the time taken to return oestrus. Dietary protein does not affect pregnancy rate in grazing dairy cows and the effect of dietary fat composition is not clear. Although nutrition is an important component of a successful reproduction, dietary adjustment to improve pregnancy rates is unlikely to result in large effects.

Introduction

Dairy cow fertility has declined in recent decades, coincidental with large increases in milk production (Berry *et al*. 2008; Friggens *et al*. 2010; Lucy 2001; Royal *et al*. 2000). Cows take longer to return to oestrus (Lucy 2001), display poorer signs of oestrus, may have poorer conception rates and have greater early embryo loss (Table 1: Lucy, 2001; Diskin, 2008b; Friggens *et al*. 2010). For example, milk production in the United States increased by 20% in the 1990s while inter-calving interval increased 7.5% (1.0 months) and cows required 33% more services/conception (0.75 services: Lucy 2001). Similarly in New Zealand, production of milk fat and protein increased 12% during the last decade, inter-calving interval lengthened from 368 d to 370 d and inseminations/cow increased by 5% (0.07 inseminations/cow) (Burke *et al.* 2008; LIC 2009). Although, multifactorial reasons underlie the recent decline in fertility, the associated increase in milk production has been a consistent feature. Consistent with this premise, nulliparous heifers have superior (10-20% greater) pregnancy rates compared with primiparous and multiparous cows (Macmillan *et al*. 1996; Sartori *et al*. 2002).

Table 1. Reproduction outcomes in low to moderate and high producing dairy cows (adapted from Diskin *et al*. 2006).

Day of reproduction cycle	**0**	**7-21**	**22-90**
Low to moderate milk yield	Fertilisation rate	Pregnancy rate	Pregnancy rate
	90%	60-65%	50-55%
High milk yield	Fertilisation rate	Pregnancy rate	Pregnancy rate
	90%	45-50%	40-45%
Reason for pregnancy failure	Failure in embryonic development	Failure of the embryo to prevent luteolysis	Late embryonic losses

Friggens *et al*. (2010) explained this conflict between production and reproduction in evolutionary terms; the cow must prioritise maternal investment between the current calf and the future calf. A large investment in milk production (i.e. for the current calf) results in less nutrient availability for investment in future offspring (reproduction). From an evolutionary standpoint, it is in the cow's best interest to ensure sufficient nutrients for the current calf, as she has already invested considerable resources in getting it to this point; she, therefore, will prioritise milk production over reproduction until the calf has attained an adequate level of viability. This is best demonstrated in beef breeds, with the suckling effect extending time to first ovulation (Stagg *et al*. 1998). As the current calf becomes less dependent on milk for nutrient supply, the cow's priorities change to investment in the future calf, with a resumption of ovulation, oestrus, and breeding. Although dairy cows are not subject to the suckling effect, they are subject to intense selection for milk production and lactation lengths far greater than those required to sustain a calf. The same evolutionary mechanisms are likely, therefore, to remain in play, resulting in declining fertility with increasing milk production.

The decline in fertility is a problem of increasing importance on dairy farms because of the associated considerable financial loss. This effect is arguably most evident in seasonal pasture-based dairy systems, where maximising the proportion of the diet as grazed grass, an important factor in minimising production costs, requires an inter-calving interval of 365 days. Evans *et al*. (2006) modelled the influence of calving spread and replacement rate changes between 1990 and 2003 in a seasonal-calving pasture-based system and reported a decline in real profit of €150/ha (AU$216/ha) associated with the decline in fertility, or €4.62/cow.year (AU$6.68), assuming a stocking rate of 2.5 cows/ha. Similarly, Burke *et al*. (2008) reported a net benefit of NZ$4.00 (AU$3.22) per 1% improvement in the 6-week in-calf rate within New Zealand. The magnitude of this economic benefit was equivalent to that previously estimated for Australian herds (J. Morton, pers comm.).

The decline in reproductive performance is primarily manifested as a lower pregnancy rate and more days from calving to conception (days open; Diskin 2008a), although negative effects on duration of postpartum anoestrum have also been reported (Lucy, 2001; Friggens *et al* 2010). The problem is often considered to be a result of the greater negative energy balance (EBAL) associated with cows intensively selected for milk production (Roche *et al*. 2006). This hypothesis has merit, with association analyses implying relationships between measures of EBAL in early lactation and reproduction outcomes (Beam and Butler 1999; Roche *et al*. 2007b; Roche *et al*. 2009a). However, care must be taken not to confuse inductive reasoning from observations (hypothesis generation) with experimental evidence of cause and effect; because something is associated with a particular reproductive outcome does not necessarily mean the outcome will be different if steps are taken to alter the associated factor. Despite this, there is a growing belief among farmers and industry professionals that manipulating nutrition (e.g. increased dry matter intake [DMI], altered structural [SC] to non-structural carbohydrate [NSC] content, altered protein composition, dietary fat content and fatty acid composition, etc.) will be the panacea to reproductive woes.

In this review, the perceived nutritional problems associated with grazed forages will be outlined, the underlying physiology associated with reproductive failure and factors associated with this physiology will be discussed, and nutritional treatments to alter those associated factors and improve reproduction examined, with particular reference to systems where grazed forages form the basis of the nutritional regime.

Nutrient supply in systems – perceived problems

Although it is acknowledged that intensively grazed forages can be of high quality (i.e. high metabolisable energy with reasonable protein content), concerns are often expressed around adequacy of feed supply at different times of the year, cow potential DMI relative to actual, a greater negative EBAL in unsupplemented grazing cows relative to supplemented grazing cows or those fed TMR, and the composition and nutrient balance of the most commonly grazed forages (Mulligan *et al*. 2007).

Temporal patterns of supply

Although herbage growth patterns and rates will vary with climate conditions, the basic principles of a pasture-based system are consistent – utilise herbage grown as the primary feed, conserve herbage grown surplus to cow requirements, and introduce either home-produced or purchased supplements when herbage growth is not sufficient for cow nutrient requirements. A stylised representation of the dairy cow requirement/herbage production interaction is presented in Figure 1.

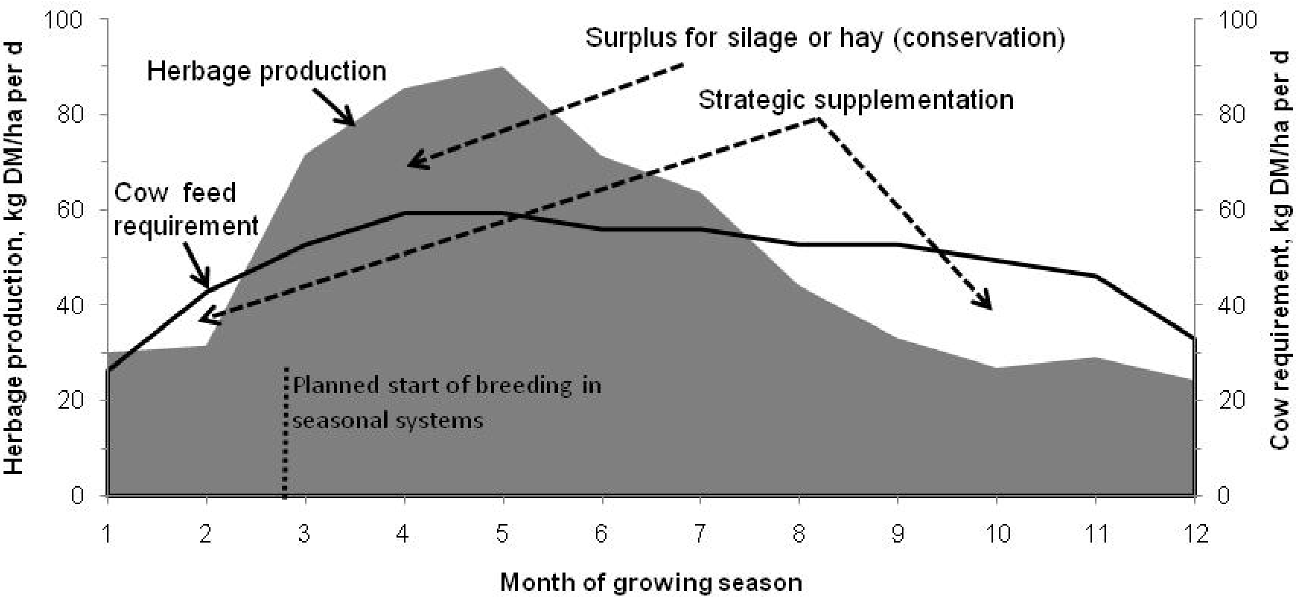

Figure 1. A stylised relationship between dairy cow feed requirement (per ha) and pasture production (per ha). (shaded area = pasture supply, solid line = cow demand assuming a stocking rate of 3.3 cows/ha).

In temperate and Mediterranean-type climates, with or without irrigation, herbage production is characterised by a spring peak that typically exceeds DMI requirements of the herd, depending on climate, stocking rate, nitrogen fertiliser, and herbage-production potential of the soil class. Generally, cool temperatures result in less than required herbage growth in winter/early spring, and insufficient moisture and excessive temperatures result in reduced summer herbage growth and less than desired herbage quality. These climatic factors and their association with the seasonality of herbage growth and quality were presented in detail by Roche *et al*. (2009c).

Start of breeding to maintain a 365-day inter calving period coincides with the spring flush in herbage growth and adequate herbage provision in moderately stocked dairy pasture-based farms. However, climatic conditions are variable, even in what would be regarded as relatively stable climatic zones (e.g. New Zealand); Roche *et al*. (2009b) reported that although soil temperatures at ≥10cm depth are greater than 80% repeatable over a 14 day period within and across years, minimum herbage temperature, a likely better predictor of herbage growth than soil temperatures because of proximity to the plant growing point, was only 36 to 44% repeatable. In addition, rainfall, and, therefore, moisture availability in non-irrigated farming systems, was 3% repeatable within fortnight-across years and solar radiation was 57% repeatable within fortnight, across years. These three factors (temperature at the plant's growing point, soil moisture availability and solar radiation) are the dominant forces in determining forage growth rate (Holmes 1989). Their lack of repeatability within fortnight across years suggests that, although average herbage supply should equal dairy cow feed demand before the onset of breeding, this may not always be the case and that, although feed supply may equal or exceed demands prior to the onset of breeding, there is no guarantee that this adequacy of provisions will remain for the duration of breeding. The impact of periods of underfeeding and, therefore, provision of supplements, and the timing of these nutritional events on reproduction outcomes will be discussed further.

Dry matter intake

One of the greatest limitations of dairy systems based on grazed forages is the relatively low DMI of cows relative to their potential intake. Kolver and Muller (1998) reported that greater than 60% of the milk production difference between grazing cows and those fed a total mixed ration (TMR) was DMI. Similarly, Kolver *et al*. (2002) reported that grazing cows consumed 12 to 28% less than cows of similar genetic merit for milk production offered a TMR in confinement. It is not possible to determine with certainty the reason for the difference in DMI between grazing cows and TMR-fed cows. However, plausible explanations can be inferred from what is known about cow behaviour and intake regulation. Regulation of DMI is a complex process and was comprehensively reviewed for domesticated ruminant animals by Roche *et al*. (2008). Although dietary physical factors play a role, there are compelling data that indicate they are not primary drivers. For example, Vazquez and Smith (2000) reported that although forage NDF content was negatively associated with forage DMI (-0.11 to -0.13 kg forage DMI/percentage unit increase in forage NDF), forage NDF content explained less than 6% of variation in DMI. Consistent with this, in situations where access to the pasture is time-limited, cows have longer grazing bouts and greater DMI/grazing bout (Gregorini *et al*. 2009), suggesting that physical factors are not wholly responsible for cessation of grazing. Further support that feed physical characteristics are not primary DMI-regulating factors comes from experiments where cows were fed with low fibre supplements. When grazing cows are supplemented with a low fibre cereal grain, time spent grazing (Bargo *et al*. 2003) and forage intake (Stockdale 2000) decline by at least as much as would occur if a high fibre concentrate were offered (Bargo *et al*. 2003; Penno 2002). Roche *et al*. (2006) reported that supplementing grazing cows with cereal-based concentrates resulted in changes to the intake-regulating neuroendocrine axis, reducing the concentrations of circulating 'hunger'-representing hormones, and speculated that it was this that led to the earlier cessation of grazing in supplemented cows.

Rather than being a result of nutritional differences between grazed forages and TMR, the difference in DMI is more likely reflective of evolutionary constraints and energy accounting by cows. Cows are naturally diurnal (Hafez and Schein 1962; Roche *et al*. 2008), exhibiting normal grazing behaviour between dawn and dusk and resting and ruminating primarily during darkness. This diurnal pattern probably reflects an innate evolutionary programming to time feeding so as to limit the possibility of predation (Roche *et al.* 2008). In addition to the predation factor, the 'drive' to eat is regulated by a complex neuro-endocrine accounting system that estimates the costs and benefits associated with acquiring more feed. Grazing is expensive from an energy perspective (Brosh *et al.* 2006); there comes a point, therefore, when the acquisition of additional feed would not provide sufficient benefit to justify the energy expense. The curvilinear association between herbage DMI and herbage allowance

(Dalley *et al*. 1999) is consistent with this premise; as cows are offered greater amounts of herbage, DMI increases but by less than the additional amount offered. As a result, residual DM yields also increase. Although cows can remove more herbage, as verified by the lower residual DM yields at lower herbage allowances, they 'choose' not to. Similarly, if supplementary feeds are offered, the energy accounting system recognises a less expensive way of acquiring energy, the supplementary feed is consumed (provided it is palatable), increasing the revenue side of the 'energy ledger' and, consequently, reducing the time the cow would otherwise have expended in grazing. This, and the fact that there is likely an evolutionary-limited grazing duration, means that grazing cows, even when supplemented, will not achieve their genetic potential DMI. In comparison, cows in confinement expend less energy in acquiring feed (Brosh *et al.* 2006) and are able to achieve greater intakes in a shorter timeframe than cows grazing fresh forage (Thorne *et al*. 2003).

In summary, grazing systems are characterised by cows that are unable to achieve their genetic potential for DMI (when compared with cows offered unrestricted access to a TMR). However, the difference is not a reflection of diet composition (i.e. nutrition), *per se*, and is more a consideration of time available for grazing during daylight and complex nutrient accounting systems; as a result, the difference in DMI between TMR-fed cows and grazing cows can be only partially corrected through supplementation.

Energy balance

Although all mammals have evolved to utilise stored reserves postpartum (Roche *et al*. 2009a), it is the timing of the loss relative to re-breeding and the degree and duration of the BCS loss that is of particular interest from a reproduction perspective. A gestation length of 282 days means that the required timing of re-establishing pregnancy coincides with BCS mobilisation.

Increased selection for milk production is associated with a greater loss of body reserves (Pryce *et al*. 2002; Berry *et al*. 2003) and there is concern that grazing dairy cows experience an even greater negative EBAL than TMR-fed cows because of their lower DMI (Mulligan *et al*. 2007). It could, therefore, be hypothesised that grazing dairy cows would benefit, from a reproduction perspective, from provision of high quality supplements. This hypothesis is predicated on the belief that provision of such feeds will reduce the negative EBAL that grazing cows experience as a consequence of lower energy intakes relative to cows fed TMR and/or insufficient NSC to elicit a change in BCS loss. Published data does not, however, support this effect of nutrition in early lactation on EBAL. Figure 2 and 3 represent full lactation BCS profiles of grazing cows compared with TMR-fed cows and cows managed at low to very high stocking rates in a farming system, respectively. Although the data highlight significant effects of nutritional regime on the BCS profile, early lactation changes in BCS are similar in the respective comparisons, irrespective of nutritional regimen. The rate of BCS loss until 30 to 40 days in milk (DIM) is similar in cows grazing perennial-ryegrass dominant pastures and those offered a TMR formulated to maximise milk production (Figure 2; Kolver *et al.* 2002; Roche *et al.* 2007a). Similarly, cows managed under different stocking rates and, therefore, different forage allowances (Macdonald *et al*. 2008) through early lactation (Figure 3) lost BCS at a similar rate for the first 30 to 40 DIM. At 30 to 40 DIM, provision of additional feed (low stocking rate and TMR treatments) or a greater amount of NSC (TMR treatment) resulted in an earlier nadir and a greater rate of BCS gain. These effects of nutrition are consistent with other studies. Roche *et al*. (2006) published BCS profiles from different genetic strains grazing perennial-ryegrass dominant pastures and reported no effect of nutrition on the rate of BCS loss in early lactation. However, supplementation with starch-based concentrates resulted in an earlier nadir BCS (3 days earlier nadir/kg DM concentrate supplement consumed/d) and a greater rate of BCS gain post-nadir. Similarly, Roche (2007) reported no difference in either live-weight or BCS change for the first 5 weeks of lactation in cows offered either 17 or 35 kg DM herbage/d (measured to ground level) and consuming 8.6 or 13.5 kg DM/d, respectively, consistent with the effect of stocking rate/herbage allowance on BCS loss. Roche *et al*. (2010) feeding isoenergetic diets differing in the proportion of SC to NSC also reported no effect of nutritional treatment on either BCS or live-weight change. Delaby *et al*. (2009) fed cows either 16.3 or 20.4 kg DM of one of two TMR diets differing in the SC to NSC content but not energy density (i.e. MJ/kg DM). Consistent with the previous presented effects of DMI and dietary SC to NSC content, they reported no effect of diet on BCS loss during the first month of lactation, after which the cows on the higher DMI-higher NSC treatment reached nadir BCS earlier and gained BCS more quickly. Pedernera *et al*. (2008) also reported that BCS and live-weight decreased to a similar extent whether cows were fed to achieve either 6,000 or 9,000 L of milk.

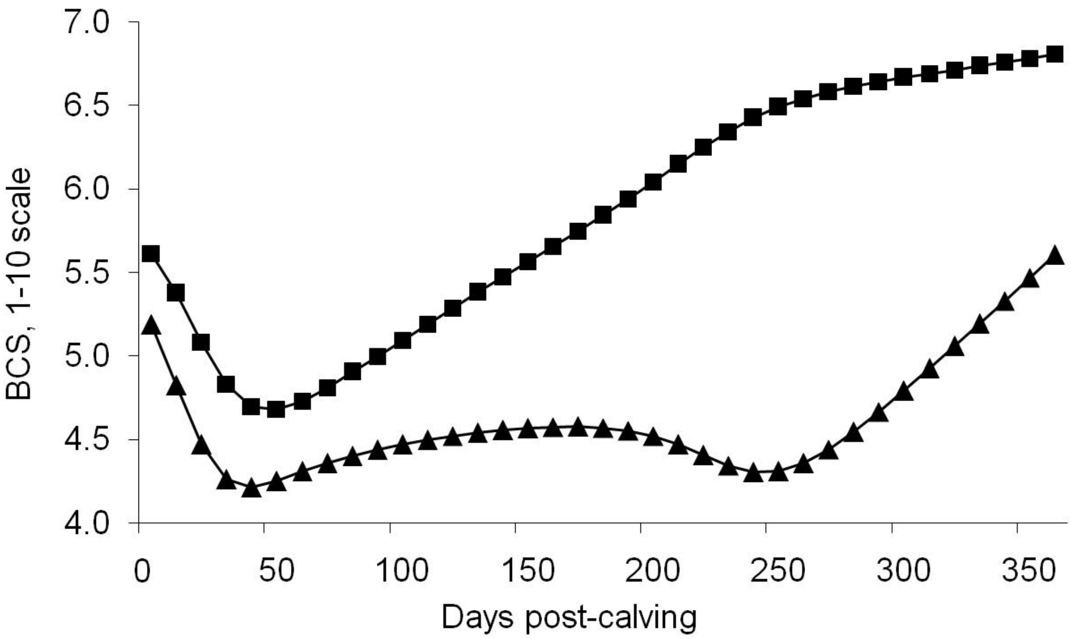

Figure 2. Body condition score profiles of cows of similar genetic merit for milk production either grazing a perennial ryegrass-dominant pasture (▲) or offered a total mixed ration (■) in confinement. Profiles were produced from equations published by Roche *et al*. (2007a).

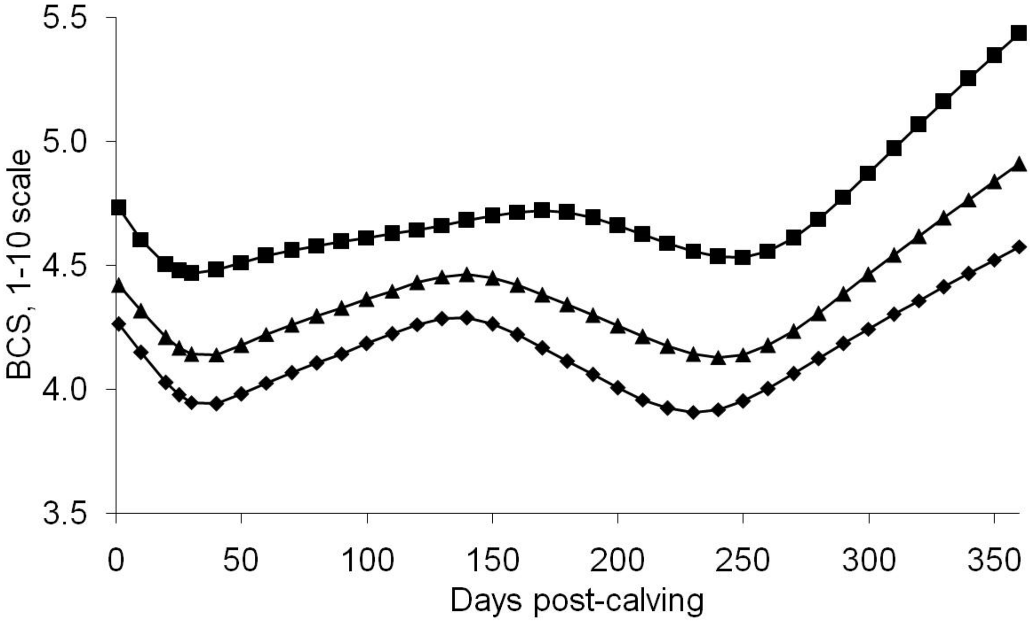

Figure 3. Body condition score profiles of cows stocked at 2.2 (■), 2.7 (▲) or 3.7 (◆) cows/ha and grazing a perennial ryegrass-dominant pasture. Profiles were produced from equations published by Roche *et al*. (2007a).

These results are largely in agreement with what is known about the effect of parturition and nutrition on the homeostatic and homoeorhetic regulators of lipolysis and lipogenesis. For a recent review of these processes, the reader is referred to Roche *et al*. (2009a). Briefly, physiological changes at parturition uncouple the somatotropic axis, facilitating increased growth hormone secretion and lipolysis, limit insulin production, and, therefore, its suppression of lipolysis, and reduce peripheral sensitivity to insulin. These are all homoeorhetic adaptations that facilitate nutrient direction to milk production. The somatotropic axis becomes 're-coupled' between 30 and 60 DIM and, although there are very little data in grazing cows, it appears that feed allowance or dietary SC to NSC interact with DIM and genetic merit for milk production in the timing of this re-coupling (Lucy *et al*. 2009; Grala *et al*. 2010). Cows offered a greater feed allowance (Lucy *et al*. 2009) or fed 3 to 6 kg DM/d of concentrates (Grala *et al*. 2010) have increased concentrations of insulin and IGF-1 and reduced growth hormone concentrations by 30 to 60 DIM (Lucy *et al*. 2009), reflecting an earlier re-coupling of the somatotropic axis and facilitating an earlier return to positive EBAL.

Although supplementation in early lactation does not greatly affect EBAL, feeding level and feed constituents do alter circulating hormone and metabolite concentrations (Grala *et al*. 2010; Lucy *et al*. 2009; Roche 2007; Roche *et al*. 2010; Meier *et al.* 2010) and these factors may influence reproductive physiology.

Feed quality

There are a number of primary ruminant nutritional-requirement systems (ARC 1980; NRC 2001; SCA 2007). Although requirements are complex and dependent on multiple interacting factors, they have been distilled down into simple nutritional recommendations for extension to farmers and rural professionals. These recommendations are presented in Table 2, along with mean quality parameters for temperate and tropical grazed forages.

Table 2. Simple[1] nutritional recommendations (g/kg DM unless otherwise stated) for high production dairy cows and the corresponding nutritional evaluation of temperate[2] and tropical[3] pastures under optimal management.

		Recommended	Temperate pasture	Tropical pasture
CP		180, 160, 140, 120[7]	223	204
NDF		Minimum 280-320	425	616
ADF		Minimum 200[5]	228	239
NSC		Maximum 380	113	53
Starch		Maximum 300	-	-
Fat	Unprotected	Maximum 30	42	20
	Rumen protected	Maximum 30	-	-
	ω6[6]	261	92	
	ω3[6]	112	573	

[1]Distilled from international nutrient requirement recommendations (ARC 1980; NRC 2001; SCA 2007) into simple extension messages.
[2]Primary source: Roche et al. (2009c)
[3]Primary source: Reeves et al. (1996).
[4]CP=crude protein (nitrogen x 6.25); NDF = neutral detergent fibre; ADF = acid detergent fibre; NSC = non-structural carbohydrate; ω6 = omega-6 fatty acids; ω3 = omega – 3 fatty acids.
[5]Using ADF as a proxy for effective NDF
[6]Actual fatty acid content of total mixed ration formulated to maximise milk production. Primary source: Kay et al. (2005)
[7]Four values reflect recommendations in early, mid, and late lactation and during the non-lactating period for mature cows.

The quality of grazed forages is highly variable, with estimated repeatabilities within fortnight across years ranging from 22% to 54% for temperate forages (Roche *et al*. 2009c), depending on the quality parameter of interest. Nonetheless, general comments about grazed grasses can be inferred from published descriptions. Compared with diets formulated to maximise milk production, optimally managed grass pastures have excess rumen degradable protein, insufficient NSC and surplus fibre. In addition, the effectiveness of the fibre component has been suggested to be insufficiently 'effective' to stimulate rumination.

These perceived deficiencies in grazed forages are often highlighted by nutritionists as a reason for replacing a portion of the cow's diet with an alternative feed(s).

Detailed experiments have failed to support a substitution of alternative feeds for grazed forages, at least from a milk production perspective. Although offering cows an easily consumed digestible supplement increases DMI, it rarely increases DMI commensurate with the amount of supplement offered (i.e. the cow substitutes some of the offered supplement for the available forage, thereby reducing forage intake; Stockdale 2000), and supplementing grazed grasses with NSC-based concentrates has been reported to reduce the digestibility of the grasses offered (Bargo *et al*. 2003; Doyle *et al.* 2005). Additionally, in experiments where energy intake has been held constant, there has been no increase in milk production when grazed forages have been replaced with NSC-based concentrates (Carruthers *et al*. 1997; Roche *et al*. 2010), although milk composition can be altered depending on the makeup of the supplement. Modelling the difference between cows fed a TMR in confinement or those grazing a cocksfoot (*Dactylus glomerata*)-dominant pasture, Kolver and Muller (1998) concluded that less than 12% (1.8 kg milk) of the difference in milk production (15.4 kg milk/d) could be attributed to a more balanced diet, and that the estimated nutritional difference was associated with the excretion of excess nitrogen and not a deficiency in dietary NSC.

Conclusion

Although domesticated forages used for intensive pasture-based dairy production are very digestible and supplementation does not greatly influence the degree of negative EBAL in the 4 to 6 weeks following calving, availability of supply is not certain and periods of restriction may occur if supplements are not provided. Provision of additional NSC after 30 DIM reduces the period of BCS loss and increases BCS gain, reflecting a more positive EBAL than if the cow were not supplemented. In addition, different dietary ingredients result in different rumen fermentation patterns and differences in post-ruminal products of digestion. On entering the blood, these products can have marked effects on blood ammonia, urea, and glucose concentrations, which, in turn, can affect hormone concentrations and the balance of hormone axes and, possibly, follicular and uterine fluid composition. The effects of EBAL and differences in these nutrition-derived physiological subtleties and their effect on reproduction will be discussed further.

Physiological processes underpinning fertility and sub-fertility

The chain of reproduction events between when a cow calves and re-calves is long and complex, but can, for all intents and purposes, be split in two when considering the interaction with nutrition: (i) pre-ovulatory reproductive failure, with nutrition possibly influencing the timing of return to oestrus and, therefore, submission rate, and (ii) post-ovulatory reproductive failure, when nutrition might influence fertilisation and/or embryo survival and, therefore, conception rate. The effects and appropriate timing of a nutritional intervention that affects fertility will be different for both components.

Pre-ovulatory reproductive failure is primarily a function of timing of return to oestrus postpartum. An early resumption of oestrous cycles following calving is important, as delays result in reduced conception rates and pregnancy rates. Thatcher and Wilcox (1973) reported a quadratic decline in services/conception with increasing numbers of recorded oestrous cycles before 60 DIM (Figure 4). The physiological processes underpinning the postpartum return to oestrus and the effect of nutrition on these processes must, therefore, be understood.

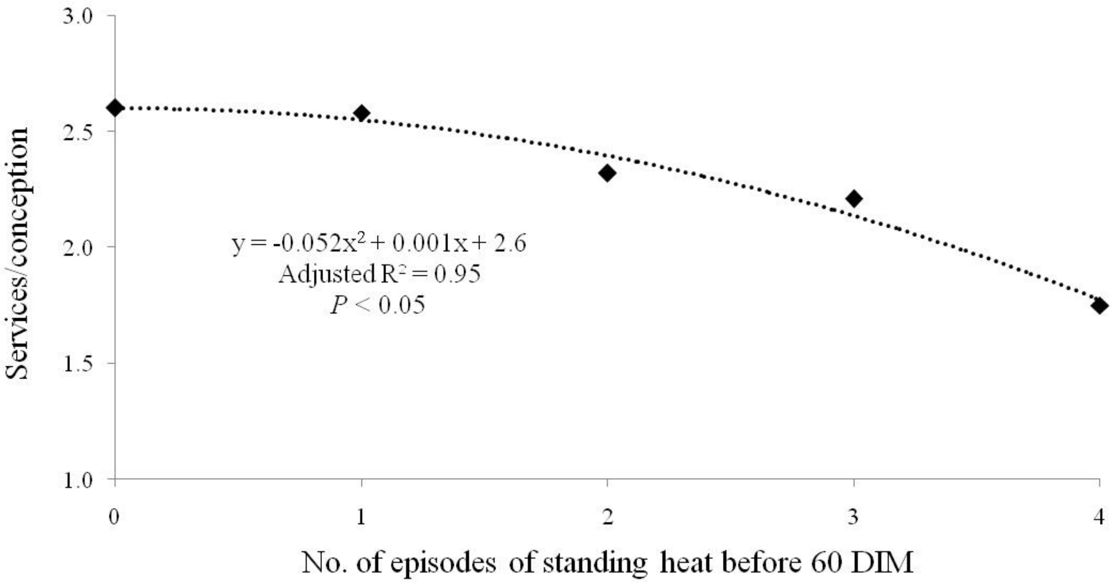

Figure 4. Services/conception for cows exhibiting 0, 1, 2, 3 or 4 heats in the first 60 days postpartum (Thatcher and Wilcox, 1973).

Post-ovulatory reproductive failure is a major component of poor reproductive performance. When high fertility bulls are used and cows are correctly inseminated, fertilisation rates of 90% and over should be expected, irrespective of cow milk yield (Diskin 2008b). Based on an average calving rate of 55%, Sreenan and Diskin (1986) calculated an embryonic and foetal mortality rate (excluding fertilisation failure) of about 40% for moderate-producing cows and they estimated that 70-80% of the loss occurred between day eight and 16 after insemination (early embryo mortality). Some of this loss might be alleviated by a nutritional intervention. The comparative figure for embryonic and foetal loss in high producing cows (i.e. those undergoing greater negative EBAL and/or those with a higher metabolic rate) is 55%, based on a fertilisation rate of 90% and a calving rate of 40% (Table 1).

Reproduction by numbers

Successful reproduction at the herd level can be described mathematically, making it easier to determine whether problems resulting in a poor reproduction outcome are pre- or post-ovulatory in origin. Submission rate (the proportion of eligible cows submitted for breeding) and conception rate (the proportion of inseminations that result in a positive pregnancy test) are interacting components of pregnancy rate (whether a cow is pregnant at a defined time within the breeding period): pregnancy rate = submission rate x conception rate (Table 3). For example, a herd that averages 90% submission rate and 60% conception rate will have 96% of cows pregnant in 12 weeks (4% empty). In comparison, if a herd averages only 70% submission rate, empty rate would be 11% in very fertile cows (conception rate of 60%), but could be as high as 27% in cows with post-ovulatory sub-fertile characteristics. The "human factor" is very important in this equation; insufficient training to recognise cows in heat or insufficient diligence in undertaking observation will result in lower submission rates. In addition, failure to properly recognise cows in heat or an overly enthusiastic submitter (person identifying cows in heat) will result in pregnant cows being re-inseminated, a known risk factor for pregnancy termination (i.e. reduce pregnancy rate) (Moore *et al*. 2005). This review will not discuss the association between management and reproductive failure, but acknowledges the importance of staff training and encouragement in achieving the desired result. The physiological factors regulating pre- and post-ovulatory sub-fertility and potential interactions with nutrition will be discussed further.

Table 3. Total cows pregnant at any time is a function of submission rate (the proportion of eligible cows submitted for breeding) and conception rate (the proportion of cows pregnant to an insemination).

Submission rate	**0.95**				**0.9**				**0.8**				**0.7**			
Conception rate	0.4	0.5	0.6	0.75	0.4	0.5	0.6	0.75	0.4	0.5	0.6	0.75	0.4	0.5	0.6	0.75
Cows pregnant, % of herd																
Week 3	38	48	57	71	36	45	54	68	32	40	48	60	28	35	42	53
Week 6	62	72	82	92	59	70	79	89	54	64	73	84	48	58	66	77
Week 9	76	86	92	98	74	83	90	97	69	78	86	94	63	73	80	89
Week 12	85	92	97	99	83	91	96	99	79	87	93	97	73	82	89	95
Empty rate[1], % of herd	15	8	3	1	17	9	4	1	21	13	7	3	27	18	11	5

[1]*Empty rate refers to the per cent of the herd not pregnant at 12 weeks of breeding*

Ovulation and postpartum anoestrus

Cows that calve late within the seasonal calving period (> 6 weeks after planned start of calving) and those slow to recover physiologically post-calving are less likely to have achieved their greatest potential for re-establishing pregnancy because they may not have cycled or may have only cycled once or twice before planned start of mating (Thatcher and Wilcox, 1973). Extended anovulatory-anoestrus remains a major cause of 'sub-fertility' in pasture-based dairy herds (Rhodes *et al*. 2003) and has been recognised as an important contributory component of 'sub-fertility' associated with increased milk production (Lucy 2001; Friggens *et al*. 2010).

Technically, postpartum anoestrus refers to the period between calving and first detected oestrus. With 'detected oestrus' as the endpoint, this interval varies depending on cow behaviour and the accuracy of oestrous detection. Prior to first detected oestrus, it is requisite that the animal begins ovulating. The period between calving and first ovulation is defined as the postpartum anovulatory interval (PPAI); commonly assessed by use of ovarian ultrasonography (McDougall *et al*. 1995a; Burke *et al*. 1995) or measurement of progesterone concentrations (Burke *et al*. 2007). A field study involving multiple herds reported that 24% of cows that had calved within 4 weeks of the planned start of mating (PSM) date had not been detected in oestrus, but that 35% of these cows were having ovulatory cycles as evident by detection of a corpus luteum (CL) on the ovaries (McDougall and Rhodes 1999). In primiparous dairy cattle, the first ovulation postpartum was seldom accompanied with a detected oestrus (13%) compared with the second (87%) or third (100%) postpartum ovulations (Burke *et al*. 1995). Consequently, the interval from calving to first detected oestrus is typically 10 to 14 days longer that the interval to first ovulation. A similar pattern of 'reproductive recovery' is evident in mature cows, although mature cows are more likely than heifers to have a detected oestrus at first ovulation (5 to 53% depending on breed and calving BCS; McDougall 1992).

Physiological processes involved in pre-ovulatory reproductive failure and possible interactions with nutrition.

A myriad of physiological and neuroendocrine events are required for a cow to resume normal oestrous activity postpartum. The timing of these events relative to each other is presented in Figure 5. The major points of control are the (i) gonadotropin releasing hormone (GnRH) pulse generator, located in the hypothalamus, which regulates the pulsatile pattern of GnRH release, (ii) gonadotropin (follicle stimulating hormone: FSH; luteinising hormone: LH) synthesis and secretion, which respond to GnRH pulses, and (iii) responsiveness of ovarian antral follicles to the gonadotropins. A feedback loop is involved whereby ovarian follicle secretions (i.e. steroids and inhibins) regulate secretion of FSH and LH.

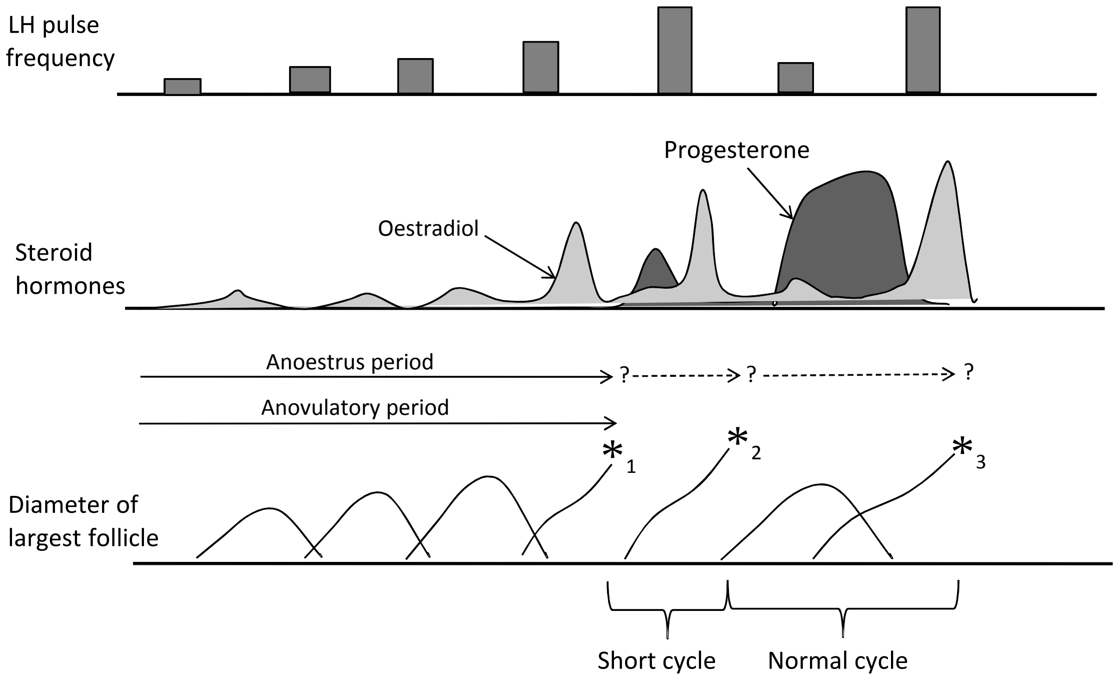

Figure 5. Schematic representation of key physiological events and endocrine patterns between calving and the end on the first normal cycle in cattle (adapted from Rhodes *et al*. 2003). Asterisks denote the first (*1), second (*2) and third (*3) ovulation after calving. The anovulatory period ends with first ovulation, whereas the anoestrous period ends when ovulation is accompanied with a detected oestrus.

Oestrous cycles are interrupted by pregnancy, and maximal placental-produced concentrations of oestradiol at the end of pregnancy provide an effective clamp on the release of gonadotrophins from the pituitary (Diskin 2008a). Without gonadotropic stimulation, there is an absence of ovarian follicles > 5 mm during the last trimester of pregnancy (Ginther *et al*. 1996). The decline in blood concentrations of progesterone and oestrogen post-calving removes the negative feedback of these hormones on gonadotropin synthesis and secretion (Diskin *et al*. 2003). As a result, FSH secretion begins shortly after calving and ovarian follicular activity resumes very quickly thereafter. In pasture-grazed cows, a wave of antral follicular development with one follicle exceeding 9 mm in diameter (the 'dominant follicle') has been recorded between 6 and 17 days postpartum, and in most cases by day 10 (McDougall *et al*. 1995a; Burke *et al*. 1995). Pulsatile episodes of LH release are detected between 10 and 20 days postpartum and circulating concentrations increase.

The first dominant follicle may ovulate, or become atretic and be replaced by one or more subsequent dominant follicles, or may continue growth and become cystic (Rhodes *et al*. 2003). A wavelike pattern of follicular development continues through early lactation (Figure 5) and there is a tendency for the dominant follicle to get progressively larger with each successive wave (McDougall *et al*. 1995a). There are typically 4 to 5 waves before ovulation in pasture-based systems; however, this number is highly variable (from 1 to more than 10) (Burke *et al*. 1995). Ovulation of a dominant follicle is dependent on oestradiol production by the follicle, as ovulation only occurs when circulating oestradiol concentrations are sufficient to stimulate the pre-ovulatory LH surge (McDougall and Macmillan 1993; Rhodes *et al*. 2003). Therefore, any factor that affects oestradiol production will affect PPAI. Oestradiol production is, in turn, dependent on sufficient LH pulse frequency and increased plasma concentrations of oestradiol are associated with elevated concentrations of insulin-like growth factor-1 (IGF-1) and insulin (Beam and Butler 1999). The number of follicular waves to first ovulation and the PPAI are highly correlated (R^2 = 0.93; Burke *et al*. 1995), because the intervals between successive waves of follicular development are consistently around 10 days (McDougall *et al*. 1995a; Burke *et al*. 1995).

Physiological processes involved in post-ovulatory reproductive failure

A schematic diagram of the endocrine patterns and physiological processes during oestrus and early pregnancy is presented in Figure 6A. The corresponding processes in a cycling but sub-fertile cow are presented in Figure 6B. The 'normal' oestrous cycle of a cow is 18 to 24 days long and can be classified into four different phases: oestrus and ovulation (Day 0), post-ovulatory or metoestrus (Days 1 to 4), luteal or dioestrus (Days 5 to 17), and proestrus (Days 18 to 20).

Neuroendocrine networks in the hypothalamus invoke oestrus and the pre-ovulatory surge in luteinising hormone (LH), stimulating ovulation (approximately 32 hours after the onset of oestrus and 20-30 hours after the pre-ovulatory LH surge). The corpus luteum is formed from the remnants of the ovulated follicle and, through a process of luteinisation, the cells switch from oestradiol to progesterone synthesis. Plasma progesterone concentration peaks about day 10. If the cow is not bred, luteal regression, the result of prostaglandin $F_{2\alpha}$ ($PGF_{2\alpha}$) and oxytocin release, stops progesterone synthesis. This removes a negative feedback on LH and allows the frequency of LH pulses to increase. As a result, rapid follicular growth and maturation are re-initiated, oestradiol production increases and oestrus begins again.

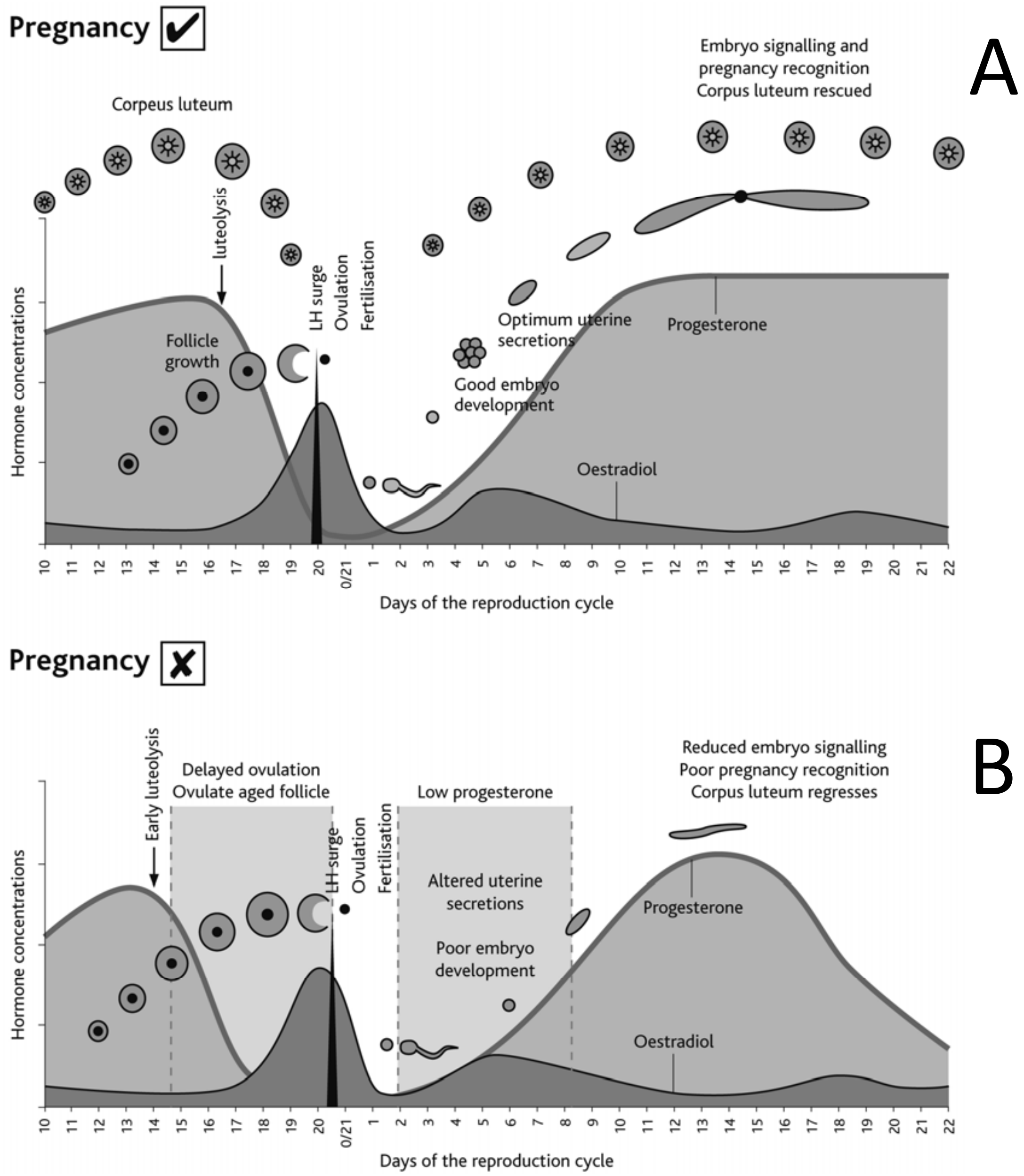

Figure 6. Schematic representation of endocrine changes and pre-ovulatory events during the oestrous cycles and early pregnancy in fertile (A) and sub-fertile (B) cows *(Source: Meier and Burke 2010).*

During early pregnancy, the fertilised oocyte undergoes the initial stages of development in the oviduct, migrating into the uterus four days after fertilisation. Once in the uterus, the pre-implantation embryo undergoes a period of exponential growth (the conceptus: trophoblast and embryo). From day 12 post-fertilisation, the conceptus synthesises and secretes trophoblast proteins that inhibit the luteolytic mechanism, enabling CL maintenance and ensuring continued progesterone synthesis. This critical step is pregnancy recognition. The pre-implantation conceptus continues to develop and undergoes a process of implantation, beginning 28 days after fertilisation.

Reproductive physiology in the cycling, but sub-fertile, cow differs from the 'normal' patterns described. The greatest cause of sub-fertility in cycling cows is a greater incidence of early embryonic death occurring between fertilisation and implantation (i.e. day 1 to 28 of pregnancy). Perturbations to the endocrine environment and the timing of endocrine events are a common feature in sub-fertility, resulting in delays in ovulation, poor oocyte (and embryo) quality and development, an altered uterine environment, and reduced trophoblast signalling and/or maternal recognition of that signal. The potential effects of nutrition on these variables will be discussed further.

Nutrition and sub-fertility

Calving body condition score: Calving BCS and, therefore, nutrition/EBAL during the previous lactation and non-lactating periods, affects the development and maturation of ovarian follicles through an effect on gonadotropin (FSH, LH) secretion and follicular responsive to gonadotropins. Chagas *et al*. (2007a) reported that the negative association between calving BCS and days to first oestrus was associated with delayed ovarian activity, infrequent luteinising hormone pulses, poor follicular responses to gonadotropins, and reduced functional competence of the follicle. A delayed onset of ovarian follicular waves was reported for Holstein-Friesian primiparous cattle that calved in low BCS and were fed generously postpartum, compared with the same breed calving in high BCS and similarly fed (Burke *et al*. 1995). Although not measured, the most likely reason for the 6-day difference in onset of follicular wave activity is a delayed postpartum rise in FSH in low BCS heifers. A similar interpretation could be made regarding the effect of calving BCS on LH secretion patterns. Holstein-Friesian heifers that calved in low BCS had an average of 8.3 follicular waves before first ovulation (day 77 postpartum) compared with 5.4 follicular waves in Holstein-Friesian heifers that calved fatter (first ovulation at day 51 postpartum). Consistent with these findings, Roche *et al*. (2007b; 2009a) reported negative associations among pre-calving and calving BCS and days to first detected oestrus, with likelihood of having a detected pre-mating heat increasing 7-8% with each additional unit of BCS at calving (10-point scale).

The effect of BCS on PPAI is influenced by cow genetics. Follicular patterns, number of follicular waves (4.7) and time to first ovulation (day 45 postpartum) in primiparous Jersey cows were not affected by extremes in calving BCS (Burke *et al*. 1995). This effect of breed was also highlighted by McDougall *et al*. (1995b) in multiparous cows, who reported a smaller effect of calving BCS on time to ovulation and oestrus expression in Jersey cows than Holstein-Friesian comparisons. The contrasting difference in breed susceptibility to a nutrition-related delay in ovarian follicular development during early lactation has not been further elucidated. However, it may point to effects of genetic selection on the duration of PPAI and not energy balance *per se*, although the two can be coincidental. deVries and Veerkamp (2000) reported that only 3 to 4% of the variation in interval to first ovulation could be explained by total energy deficit or energy balance in early lactation.

Although the physiology underpinning the effect of BCS state on PPAI is not completely understood, there is general agreement that BCS at calving is negatively associated with length of the PPAI (Chagas *et al.* 2007a; Roche *et al*. 2009a), with better conditioned cows at calving cycling earlier. In addition, calving BCS may be important in conception rate. Roche *et al*. (2007b) reported that nadir BCS was positively associated with pregnancy rate at 42 and 84 days after planned start of mating. Although, calving BCS was not associated with pregnancy rate *per se*, BCS and live weight at calving were positively correlated with nadir BCS and live weight (r^2 = 0.26 and 0.81, respectively), with lower BCS cows at calving also being a low BCS at nadir. Calving BCS may, therefore, influence pregnancy rate indirectly.

It is unlikely that the effect of BCS at nadir on pregnancy rate is a result of reduced gonadotropin production or follicle sensitivity to gonadotropin. Furthermore, it may not necessarily be associated with a greater negative EBAL, because low BCS cows at nadir can originate from low BCS cows at calving and these tend to have a less severe negative EBAL (Garnsworthy *et al*. 2008; Roche *et al*. 2009a); other factors associated with energy stores must be affecting the ovary, uterus or pregnancy directly, possibly a consequence of reduced functional competence in follicles (Beam 1995), lower trophobast growth rates because of a sub-optimal uterine environment (Gustaffson and Larson 1985; Mapletoft *et al*. 1996), or possibly reduced uterine receptivity. Further research is required to understand the effect of energy status (i.e. BCS at a point in time) on conception rate.

In conclusion, late lactation and dry period nutrition as well as length of lactation should be manipulated to achieve the desired BCS at calving. Such a BCS will minimise the duration of postpartum anoestrus, thereby improving the likelihood of a successful pregnancy (Thatcher and Wilcox, 1973). Recent reviews (Garnsworthy *et al*. 2008; Roche *et al*. 2009a) indicate that the optimum calving BCS is probably around 5, although heifers and second calvers will benefit from being in better body condition at calving; a greater calving BCS will result in excessive BCS loss in early lactation and thinner than this will extend the PPAI.

<u>Early lactation negative energy balance</u>: Early lactation EBAL is negatively associated with PPAI, with shorter durations to first ovulation associated with a more positive EBAL (Patton *et al*. 2007; Garnsworthy *et al*. 2008; Roche *et al*. 2007b; 2009a). In addition to PPAI, postpartum EBAL is positively associated with pregnancy rate to first and subsequent inseminations (Roche *et al*. 2009a). Roche *et al.* (2007b) reported that 6- and 12-week pregnancy rates declined 3 to 4% for each additional BCS unit lost postpartum (10-point scale). However, it is not clear what proportion of this effect is a result of reduced conception rates and how much is attributable to reduced submission rates. Poor nutritional state has been reported to extend the interval between first ovulation and first detected oestrus (McDougall 1992; Burke *et al*. 1995; 1996), indicating poorer expression of oestrus in cycling cows. These data are consistent with recent results from Burke *et al*. (2010b) in mature cows. They subjected cows to a severe feed restriction (~45% feed restriction) for the first two weeks of mating and reported that the 6-week pregnancy rate was 8% lower in restricted cows. However, this followed an equivalent reduction in the 3-week submission rate, suggesting that restricted cows did not have a lower conception rate, but instead had a weaker display of oestrus and were not always accurately submitted for insemination.

Physiologically, negative EBAL manifests itself in delayed ovarian activity by impinging on the pulsatile secretion of LH, reducing follicular responsiveness to LH and FSH, and ultimately through suppressing follicular oestradiol production (Diskin *et al*. 2003). Beam and Butler (1997) reported that follicles emerging after the negative EBAL nadir, rather than before, exhibited greater growth and diameter, enhanced oestradiol production, and were more likely to ovulate. Beam (1995) reported that the dominant follicle in cows in negative EBAL required more time and had to be larger to establish blood oestradiol concentrations capable of triggering ovulation; which was then delayed. In addition, oocytes from large, aged follicles are less fertile and, therefore, negative EBAL may reduce subsequent conception rate of the ovulated oocyte. Consistent with the effect of negative EBAL on follicle development and oocyte quality, embryo competency is compromised shortly after fertilisation in cows in negative EBAL (Leroy *et al*. 2005; Santos *et al*. 2004; Sartori *et al*. 2002). For example, Leroy *et al*. (2005) reported a 40 to 50% reduction in the number of Grade-1 embryos recovered from lactating dairy cows compared with beef cows and non-lactating heifers, likely reflecting the greater negative EBAL of the lactating dairy cow on embryo quality.

In addition to the effect of EBAL on time to first ovulation and oocyte/embryo quality, a negative EBAL in early lactation can delay the elimination of bacteria from the uterus (Lewis 1997), reduce innate immune response (van Knegsel *et al*. 2007) and alter the necessary postpartum uterine inflammatory response, thereby, delaying uterine repair (Wathes *et al*. 2009). As a result, the uterine environment will take longer to be in a receptive state, a key component in ensuring the successful establishment of pregnancy (Hansen 1995; Walker *et al*. 2009; 2010).

Physiological mechanisms by which a negative EBAL might affect PPAI or conception rate are postulated to involve IGF-1. Patton *et al*. (2007) reported a shorter duration of PPAI and a greater probability of conception rate to first service with greater circulating IGF-1 concentration in early lactation. Unpublished data from our laboratory agrees with the associations between plasma IGF-1 and PPAI reported by Patton *et al*. (2007); duration of PPAI decreased with increasing IGF-1 concentration in early lactation. However, blood IGF-1 concentration only explained 3 to 4% of the variation in duration of PPAI, consistent with results presented by deVries and Veerkamp (2000), and there was no association between plasma IGF-1 concentration in early lactation and pregnancy rate.

Insulin-like growth factor-1 is produced primarily in the liver under the action of growth hormone (the somatotropic axis: Lucy 2008). This axis is significantly influenced by EBAL, with a negative EBAL causing the axis to become ‘uncoupled’ (a physiological state in which elevated growth hormone concentrations do not result in commensurate increases in IGF-1 production because of a down-regulation of hepatic growth hormone receptors: Breier *et al*. 1988; McGuire *et al*. 1995; Lucy 2008) and a positive EBAL resulting in an insulin-mediated ‘recoupling’ (Butler *et al*. 2004). Lucy *et al.* (2009) reported a greater degree of somatotropic axis ‘uncoupling’ and associated lower concentrations of IGF-1 in cows under greater negative EBAL in early lactation. Insulin-like growth factor-1 has been reported to alter follicle sensitivity to gonadotropins (Garnsworthy *et al*. 2008), oocyte quality (Lucy 2001) and has been implicated in uterine receptivity and embryo implantation (Robinson *et al*. 2000). A negative EBAL in early lactation is also reported to alter the IGF system in the oviduct and endometrium (Fenwick *et al*. 2008; Wathes *et al*. 2009), potentially affecting uterine receptivity and embryo implantation. Robinson *et al* (2000) reported that components of the IGF system were differentially expressed in the uterus, and that factors that influence the expression of this system may alter uterine function through modulation of uterine glandular activity and development of uterine caruncles. In support of this hypothesis, the pre-implantation embryo expresses IGF receptors and uterine fluid contains IGF-1 and -2 (Sinclair, *et al.* 2003; Wang, *et al.* 2009; Watson, *et al.* 1999). However, the reported effects of IGF-1 and -2 on *in vitro* embryo development and IFNτ production are inconsistent (Block *et al*. 2007; Matsui *et al*. 1997; Palma *et al*. 1997; Velazquez *et al*. 2009; Wang *et al*. 2009) and a direct effect of either IGF-1 or -2 on embryo development *in vivo* has not been studied.

From the collated data, it is reasonable to conclude that factors that result in disturbances within the IGF systems are detrimental to follicle and embryo development and, perhaps, provide a mechanism for reduced fertility in these animals. Further research is necessary to determine if nutritional intervention to alter IGF-1 production or stability will improve reproduction.

Although the severity and duration of negative EBAL is a contributing factor to reduced submission rates and pregnancy rates (Roche *et al.* 2009a), how greatly early lactation negative EBAL can be influenced by nutrition must be considered. Postpartum loss of stored reserves is a mammalian adaptation for nurturing the neonate and is facilitated by peripartum homoeorhetic adaptations (Roche *et al*. 2009a). Several recent experiments have explored the effect of nutrition on the inter-lactation profile of BCS change and, in particular the rate of BCS loss in early lactation. Roche *et al*. (2006) reported that concentrate feeding in early lactation did not affect the rate of BCS loss in early lactation, but reduced the duration of BCS loss (i.e., fewer days in milk to nadir BCS), thereby slightly increasing nadir BCS. Similar conclusions were reported from an independent study in Ireland (McCarthy *et al*. 2007). This lack of effect of nutrition on rate of BCS loss in early lactation is consistent with the subsequent findings of others (Friggens *et al*. 2007; Roche 2007; Pedernera *et al*. 2008; Delaby *et al*. 2009; Roche *et al*. 2010) and are in agreement with the general conclusion of Smith and McNamara (1990), that lipolysis is primarily regulated genetically while lipogenesis is environmentally controlled. The greater post-nadir BCS gain with increasing concentrate supplementation (Roche *et al*. 2006; McCarthy *et al*. 2007) concurs with this hypothesis. There is limited evidence that manipulating dietary rumen degradable protein content influences BCS loss (Westwood *et al.* 2000), but the aforementioned studies do not support this hypothesis.

Consistent with the failure of nutritional strategies to influence early lactation EBAL, experimental treatments in which grazing cows have either been restricted (Burke and Roche 2007; Burke *et al.* 2010b) or provided with additional supplementary feeds (Fulkerson *et al.* 2001; Kennedy *et al.* 2003; Horan *et al.* 2004; Kolver *et al.* 2005; Pedernera *et al.* 2008) have failed to positively affect pregnancy rates, although in some instances submission rates have been improved (Fulkerson *et al.* 2001).

<u>Non-structural carbohydrate supplementation</u>: As already established, the frequency of LH pulses in postpartum cows is greater when animals are fully fed before calving and/or calving BCS is optimal (Chagas *et al*. 2007; 2007b; Roche *et al*. 2009a). However, it has also been demonstrated experimentally that the low BCS-induced LH pulse suppression can be restored with oral administration of a glucogenic/insulinogenic precursor, such as monopropylene glycol (Chagas *et al*. 2007b). In comparison, a generous herbage allowance after calving had no such effect in either primiparous (Burke *et al*. 1995) or multiparous dairy cows (Burke and Roche 2007). Burke *et al*. (2010a) reported a reduction in PPAI in multiparous cows from increasing the NSC to SC ratio in an otherwise isoenergetic diet postpartum and Fulkerson *et al*. (2001) reported an earlier resumption of ovulation and earlier oestrous detection with increasing level of concentrate (NSC) supplementation. These results are consistent with a physiological effect of NSC on ovulation.

The physiological mechanisms for the reported effects of feeding high-energy supplements to increase LH secretion and advance the timing of first ovulation likely involves the induction of insulin spikes (Miyoshi *et al*. 2001; Gong *et al*. 2002). Gong *et al*. (2002) and Garnsworthy *et al.* (2008) offered isoenergetic/isonitrogenous diets that varied in starch content to induce differences in circulating insulin. Insulin concentrations and the insulin to glucagon ratio increased. Diet did not affect the onset of FSH production, the timing of recruitment of the first dominant follicle, the pattern of subsequent follicle development, and there were inconsistent effects of diet on the number of small and medium sized follicles detected during each follicular wave. The data possibly indicate a greater degree of dominance by the dominant follicle, although such a hypothesis was not supported by measured oestradiol concentrations. However, the high starch diet reduced the interval from calving to first ovulation and increased the proportion of cows ovulating within 50 days of calving (Gong *et al.* 2002). Unpublished data from our laboratory also indicate a reduction in PPAI length with increasing plasma insulin; but, the proportion of variation in PPAI explained is <3%. Circulating IGF-1 concentrations were not affected by diet in the study reported by Garnsworthy *et al.* (2008); however, increasing NSC in isoenergetic diets is

expected to increase circulating IGF-1 concentrations (Kolver *et al.* 2006; Roche *et al.* 2010) and this may also be implicated in the reduced PPAI for reasons previously discussed.

There are plausible physiological mechanisms for a positive effect of NSC-enhanced plasma insulin on PPAI. Increased insulin enhances the responsiveness of ovarian follicles to gonadotrophic stimulation as well as supporting general hepatic production of IGF-I (Roberts *et al*. 1997; Butler *et al*. 2004). Insulin and IGF-I upregulate the expression of gonadotrophin receptors in follicles (Diskin, 2008a), thereby enhancing oestradiol production from granulosa cells (Gong *et al*. 2002; Spicer *et al*. 1993). While the central actions of insulin and IGF-1 are required for hypothalamic and pituitary function, there is less certainty whether these hormones have a direct action on stimulating gonadotrophin secretion during the observed responses to elevated insulin in the 'modern' postpartum dairy cow (Butler *et al*. 2004).

The effect of glucogenic/insulinogenic precursors on PPAI is not consistent, however. Kolver *et al*. (2005; 2006) reported increased insulin and IGF-1 concentrations in cows consuming either 3 or 6 kg DM of a high starch concentrate but no effect of concentrate feeding on PPAI or pregnancy rates. Horan *et al*. (2004) and Kennedy *et al*. (2003) investigated responses to supplements in cows differing in their genetic merit for milk production and survival traits and reported no effect of diet on PPAI or pregnancy rates. Similarly, Pedernera *et al*. (2008) offered diets designed to achieve 6,000 or 9,000 L milk/lactation and detected no difference in reproduction outcomes. On-farm studies investigating the use of a glucogenic supplement in early lactation to advance the timing of first postpartum ovulation have also been disappointing. Chagas *et al*. (2010) tested the effect of drenching monopropylene glycol in four herds generally characterised as having low cow body condition. Milk protein percentage was significantly increased, confirming the insulinogenic effect of diet (Rius *et al*. 2010); however, there was no reproductive benefit. Further research is required to understand the reasons for the inconsistent effect of glucogenic/insulinogenic diets on postpartum return to oestrus.

Interestingly, the effect of EBAL and dietary NSC content on post-ovulation fertility appears to be negative (O'Callaghan and Boland, 1999), with reduced pregnancy rates in cows in greater EBAL or those receiving NSC supplements compared with fermentable fibre supplements. In a series of experiments reported, oocyte and embryo quality declined with increasing concentrate supplementation. In addition, the effect was particularly apparent when the concentrate was starch-based compared with fermentable fibre-based. The physiological mechanisms involved remain poorly understood but appear to be under the influence of glucose or glucose-derived metabolites or hormones (e.g. insulin or IGF-1). Glucose infusions prior to superovulation in ewes have resulted in reduced quality embryos (Yaakub *et al.* 1997) and glucose infusion is also reported to reduce pregnancy rate (Rubio *et al.* 1997). Glucose metabolism imposes oxidative stress by elevating levels of reactive oxygen species, especially peroxide anions (O^{2-}) and peroxide (H_2O_2) (Larson *et al.* 2001; Kimura *et al.* 2005). Glucose concentrations in the reproductive tract are reportedly greater than circulating in blood (Hugentobler *et al*. 2010), potentially exacerbating the problem associated with glucogenic diets on embryo survival. Consistent with these infusion studies, glucogenic diets have been reported to reduce blastocyst rate in heifers and cows (Adamiak *et al.* 2005; 2006; Fouladi-Nashta *et al.* 2005). In comparison, feed restrictions or fermentable fibre supplements have been reported to benefit embryo development (O'Callaghan and Boland, 1999).

These data indicate that the nutrient requirements for early resumption of ovarian cycles, follicle development and embryo development may be quite different, reflecting a potential advantage to altering dietary ingredients through early lactation to ensure early resumption of oestrus and excellent quality embryos. Such a diet would require a high NSC diet until oestrus is achieved followed by a diet that did not promote insulin secretion until the end of the breeding season (Garnsworthy *et al.* 2009). These authors presented results of such a two-phase diet, wherein they compared an insulinogenic diet through to 120 DIM, a non-insulinogenic diet through to 120 DIM, an insulinogenic diet until the cows' first rise in milk progesterone followed by the non-insulinogenic diet until 120 DIM, and a non-insulinogenic diet until the cows' first milk progesterone rise, followed by an insulinogenic diet until 120 DIM. Results were not entirely convincing. The insulinogenic diet in early lactation did not result in an earlier resumption of ovarian activity or an earlier detection of oestrus; however, cows offered the insulin-inducing diet until oestrus followed by the non-insulinogenic diet had greater pregnancy rates at 120 DIM. These results suggest that further research is required to better understand the interaction between insulinogenic and non-insulinogenic diets and their effect on pre-ovulatory and post-ovulatory reproductive outcomes.

<u>Dietary protein</u>: The effect of protein nutrition on reproductive physiology in dairy cattle has been controversial for more than 20 years, with a general acceptance that dietary crude protein and, in particular, rumen degradable protein negatively affects pregnancy rate (Butler, 1998). Because cows grazing fresh forage frequently ingest rumen degradable protein surplus to microbial growth requirements; particularly during the breeding season (Roche *et al.* 2009c), this is an important nutritional area for consideration.

The physiological mechanisms whereby excess protein can affect reproductive function are hypothesised to be through elevated plasma urea and ammonia and the consequential exposure of the ovulating oocyte, embryo and uterine environment to their toxic effects (Butler 1998; Leroy *et al.* 2008; Westwood *et al.* 1998). *In vitro* embryo development is affected by elevated urea or ammonia when added to the culture medium. De Wit *et al.* (2001) noted a reduced fertilisation rate but not oocyte cleavage rate when urea was added to culture medium, suggesting that the primary effect of urea, *in vitro* at least, is associated with a lower fertilisation rate. *In vitro* studies also confirmed a detrimental effect of ammonia on pregnancy rate, with both oocyte quality and blastocyst development compromised in a high ammonia environment; the detrimental effect of ammonia on embryo development, however, appears to be dependent on the stage at which the embryo is exposed to the elevated ammonia (Hammon *et al*. 2000). The negative effect of elevated plasma ammonia on oocyte quality is exaggerated in ooctyes collected from medium sized follicles (Sinclair *et al.* 2000).

The deleterious effect of urea and ammonia on embryo quality *in vitro* and the importance of timing of exposure of the embryo to ammonia are consistent with effects reported *in vivo*; when high protein diets consisting of high levels of quickly degradable nitrogen were introduced at the time of fertilisation, embryo development was compromised (Dawuda *et al.* 2002). However, no such effect was evident when the diet was initiated mid-cycle, prior to ovulation and insemination. When cows were fed isonitrogenous diets (160 g/kg DM crude protein) differing in degradable protein content (73% and 64% of crude protein), fewer fertilised ova were recovered from cows on diets with greater degradable protein content and more cows in this group failed to produce transferable ova (Blanchard *et al.* 1990). The impact of urea nitrogen on oocyte quality was also confirmed in a study reporting a reduction in the ability of oocytes from heifers with increased levels of blood urea nitrogen (UN) to develop to the blastocyst stage (Santos *et al.* 2009). In addition to the toxic effects of urea and ammonia, excess crude protein alters uterine mineral concentration (Jordan *et al.* 1983) and reduces uterine pH (Elrod and Butler 1993; Elrod *et al.* 1993; Rhoads *et al.* 2006), and this may further compromise embryo development. For example, acidification of culture medium, by adding a weak non-metabolisable acid, had a more profound effect on embryo survival and development than increased urea concentrations (Ocon and Hansen 2003), suggesting that the negative effect of high uterine UN concentration may be two-fold, reducing both fertilisation rate and embryo survival.

Pre-ovulatory effects of dietary crude protein are inconsistent. Jordan and Swanson (1979) reported fewer days to first observed oestrus (14 days postpartum) in cows receiving a high crude protein (193 g/kg DM) ration. Ordonez *et al.* (2007) recently reported a shorter PPAI (6 days) in cows grazing nitrogen fertilised pastures and containing 254 g/kg DM crude protein compared with cows grazing 216 g/kg DM crude protein pastures. Blood UN concentrations were greater in cows grazing high N pastures (55 vs 36 mg/dL). Garcia-Bojalil *et al.* (1994) also offered diets differing greatly in their crude protein (123 and 274 g/kg DM) and resulting blood UN (9.8 and 21.3 mg/dL, respectively). They reported no differences in the number or percentages of pre-ovulatory, anovulatory, and ovulatory follicles induced during superovulation. In comparison, Barton *et al.* (1996) reported a delay of 4 days in the time to first oestrus in cows receiving a diet containing 200 g/kg DM crude protein compared with one containing 130 g/kg DM (21 vs 8.6 mg UN/dL blood, respectively). Westwood *et al.* (2000) also noted an earlier resumption of oestrous activity in cows offered an isonitrogenous diet with less rumen degradable protein. Blood UN was not affected by protein degradability (54.0 and 51.2 mg/dL for the high and low degradability diets, respectively), suggesting that the effect was not blood UN related. The reason for the inconsistency in the effect of dietary crude protein on ovulatory function is not known. However, the collated data indicate that dietary crude protein content in early lactation has little effect on follicle development and timing to first postpartum oestrus and that nutritional strategies to reduce blood UN are unlikely to result in a greater submission rate.

At first glance, the effect of dietary crude protein on pregnancy rate is much more consistent, with the majority of studies, suggesting a negative effect of excess rumen degradable protein on the probability of conception (Ferguson and Chalupa, 1989; Ferguson *et al.* 1988; 1993; Westwood *et al.* 1998; 2000; Rajala-Schultz *et al.* 2001; Arunvipas *et al.* 2003). Physiologically, high blood UN and associated elevated concentrations of blood ammonia have been implicated in embryo degeneration and alterations to the uterine environment (Butler, 1998). Using blood UN concentration as an indicator of surplus rumen degradable protein, Ferguson *et al.* (1988; 1993) reported reduced likelihood of a successful pregnancy at blood UN concentrations >20 mg/dL (3.3 mmol/L). Consistent with this, Rajala-Schultz *et al.* (2001) reported that cows with milk UN levels below 10.0 and between 10.0 and 12.7 mg/dL were 2.4 and 1.4 times more likely to be confirmed pregnant than cows with milk UN values above 15.4 mg/dL, respectively. Similarly, milk UN concentrations >15.5 mg/dL were associated with a 37% reduction in the odds of conception in Canadian dairy cattle (Arunvipas *et al.* 2003) and dietary crude protein tended to be negatively associated with likelihood of a cow to conceive. In comparison, however, Westwood *et al.* (2000) reported a lower conception rate to first service (45% vs 72%) in cows receiving a diet high in rumen degradable protein, although blood UN was not affected by treatment; they speculated that the effect was a result of the greater negative EBAL in cows receiving more rumen degradable protein, although they did not rule out an effect of by-products of protein metabolism.

The majority of studies have been undertaken in cows being fed a TMR containing low to moderate dietary crude protein concentrations relative to the crude protein content of temperate pastures. Cows grazing temperate pastures often have blood and milk UN well in excess of the 'ideal' concentrations reported previously. For example, Roche *et al.* (2005) reported blood UN concentrations of 42.0 mg/dL and milk UN concentrations of 40.5 mg/dL in dairy cows grazing high crude protein pastures (286 g/kg DM) in early lactation. Similarly, Kolver and Macmillan (1994) reported blood UN concentrations rising from 28.5mg/dL at calving to 42.0 mg/dL eight weeks in milk and Ordonez *et al.* (2007) noted blood UN of more than 60 mg/dL in early lactation cows grazing nitrogen-fertilised pastures. If dietary crude protein or rumen degradable protein, or blood UN were negatively associated with reproductive outcomes, these data suggest that the problem should be greatest in grazing cows. On the contrary, however, pregnancy rates tend to be high in such systems (Burke *et al.* 2008; Horan *et al.* 2004) and do not appear to be influenced by dietary crude protein content or blood UN concentration. Kenny *et al.* (2001; 2002) investigated the effect of dietary crude protein and fermentable energy supplementation on pregnancy outcomes in beef heifers. They concluded that although blood urea concentrations were 77% greater in their high crude protein treatments (29.9 vs 16.9 mg/dL), embryo survival was not affected and, in fact, embryo weight was greater in heifers receiving the high crude protein diet (Kenny *et al.* 2001). Ordonez *et al.* (2007) also reported no difference in embryo survival in dairy cows grazing 254 or 216 g/kg DM crude protein pastures, despite the very large differences in blood UN (55 vs 36 mg/dL). Consistent with these data from grazing systems, Garcia-Bojalil *et al.* (1994) reported no difference in numbers or percentages of normal embryos, abnormal or retarded embryos, and unfertilized ova in non-lactating cows offered either 123 and 274 g/kg DM crude protein diets (blood UN = 9.8 and 21.3 mg/dL, respectively).

In conclusion, although there are sound physiological reasons for a negative effect of metabolites originating from surplus rumen degradable protein on embryo survival, and there is consistent evidence for a negative association between blood UN and the probability of conception *in vitro* and in TMR-fed cows, data from grazing systems indicate a lack of effect of either dietary crude protein or blood UN on fertility outcomes. The reason for this inconsistency is not known but current data do not indicate a reproduction benefit to reducing dietary protein in pasture-based systems. A greater understanding of the physiological mechanisms that protect the grazing dairy cow from excess rumen degradable protein is required to improve our understanding of reproductive failure.

<u>Dietary fat</u>: The influence of dietary fat on reproductive performance is poorly understood because much of the published data come from studies having nutritional rather than reproductive objectives (Staples *et al*. 1998). The rationale behind altering dietary fat to improve reproduction outcomes is two-fold:

1. use of dietary fat supplements in early lactation to increase energy intake, reduce negative EBAL and thereby assist the physiological processes that are primarily responsible for ensuring a resumption of ovulatory cycles after calving (Lucy *et al*. 1992), and
2. Physiological effects of fatty acids (FA) in reproductive tissues (Mattos *et al.* 2000; Wathes *et al*. 2007).

The potential benefit of fat supplementation on ovarian function was validated in early postpartum cows by Lucy *et al*. (1991), who reported enhanced growth and function of the dominant ovarian follicle in cows supplemented with 22 g/kg DM of calcium salts of long-chain unsaturated fatty acids (UFA: Megalac; Church and Dwight Co., Inc., Princeton, New Jersey, USA). These results were consistent with the effects of an improved EBAL on ovarian function. A further study, however, indicated that the positive effect of fat supplements in early lactation was not due to improved EBAL *per se*, but rather through a more direct effect of fat on follicular function (Lucy *et al*. 1993). A likely explanation for this mechanistic action of fat involves the ovarian requirement for cholesterol to synthesise steroids (Gwynne and

Strauss 1982; Staples *et al*. 1998); dietary fat consistently increases plasma cholesterol concentration in cows (Grummer and Carroll 1991). The effect of fat on steroid production, however, appears limited to long chain UFA. Zachut *et al*. (2008) reported increased follicular androstenedione and oestradiol concentrations, and a greater expression of P450 aromatase mRNA in granulosa cells in cows supplemented with long chain UFA but not those supplemented with saturated FA (SFA: C16:0 and C18:0).

In agreement with the hypothesis that UFA directly affect ovarian function, total number of follicles, the size of the pre-ovulatory follicle and NEFA and insulin contents in follicular fluid have all been increased in cows supplemented with long chain UFA (Lucy *et al*. 2003; Mattos *et al*. 2000; Zachut *et al.* 2008). In addition, Fouladi-Nashta *et al.* (2007) reported improved blastocyst production from mature and cleaved oocytes in cows supplemented with long chain UFA, even though there was no evident effect on oocyte quality; the fat also buffered oocytes against the negative effects that high milk yields have on oocyte development potential. In addition to the positive effect of UFA on follicular competency and oocyte quality, Scott *et al*. (1995) reported that a greater proportion of cows fed long chain UFA displayed stronger signs of oestrus. These data reflect a positive effect of dietary UFA on pre-ovulatory and peri-oestrous physiology and create an expectation for an improved submission rate with UFA supplementation. However, the research originates in relatively low fat diets and there are few data available on likely implications for cows grazing fresh forages already high in polyunsaturated fatty acids (PUFA) (Kay *et al.* 2005; Wales *et al.* 2009). Kay *et al.* (2006) supplemented cows grazing perennial ryegrass-dominant pastures with one of two sources of rumen protected fatty acids; the sources were isolipid (~50 kg/kg DM added lipid) but differed in their SFA to UFA ratio (0.62:0.38 and 0.29:0.71 SFA to UFA, respectively). Unpublished data from that experiment indicate no effect of supplementary FA or the composition of the fatty acid supplement on the duration of the PPAI, although negative EBAL was less in supplemented cows. Although inconsistent with the majority of studies undertaken with TMR-fed cows, these results may reflect the already high PUFA content of a fresh forage diet (Kay *et al.* 2005; Wales *et al.* 2009), with additional UFA failing to add benefit, or it may reflect the lower milk production of grazing cows and the associated lower metabolic challenge.

In addition to the pre-ovulatory effects of UFA, there is evidence that dietary long chain PUFA act as specific regulators of post-ovulatory reproductive processes also. However, the effects of dietary fat content and FA composition are inconsistent *in vitro* and *in vivo*. Dietary FA can affect post-ovulatory reproductive function in two ways:

1. through affecting oocyte and embryo quality, and

2. through altering the maternal physiological processes involved in luteal regression, preventing the prostaglandin-induced termination of progesterone synthesis

Endometrial FA reflect dietary FA (Bilby *et al.* 2006b; Childs *et al.* 2008b; Meier *et al.* 2009). For example, endometrial ω-3 PUFA concentrations were more than two-fold higher and eicosapentaenoic acid (ω-3 C20:5) concentrations alone more than seven-fold higher in the endometrium of cows fed isolipid diets high in ω-3 PUFA (500g/kg fatty acid) compared with cows fed diets low in ω-3 PUFA (2 g/kg fatty acid) (Coyne *et al.* 2008). Fresh forages contain a greater proportion of ω-3 PUFA (linolenic acid: C18:3; Table 2) than TMR and this difference should be reflected in endometrial UFA concentration and in the ratio of ω-3 to ω-6 UFA. Consistent with this, Meier *et al*. (2009) reported a 50% greater ω-3 to ω-6 ratio in the endometrium of grazing cows than traditionally reported for cows fed TMR (from 10 to >15.5) (Bilby *et al*. 2006b; Childs *et al*. 2008b), consistent with the expected differences in dietary PUFA composition (see Kay *et al*. 2005). These data reflect a better FA composition in the diet of grazing dairy cows from a reproduction standpoint that cows fed an unameliorated TMR.

However, the effect of dietary FA composition has been variable, with some reports of enhanced effects to changes in FA content and ratios on early embryo development and other reports concluding no effect and even negative effects. For example, Leroy *et al*. (2010) reported reduced developmental potential and greater mRNA expression for genes related to apoptosis and metabolism in embryos cultured in palm oil-derived hyperlipidaemic serum. This may have related to the source of FA used, as embryonic development was also reduced in Holstein-Friesian cows fed SFA compared with those fed PUFA (Thangavelu, *et al*. 2007), suggesting that FA composition is important. However, Marei *et al*. (2010) reported reduced oocyte development following addition of linolenic acid (an ω-3 PUFA) during *in vitro* maturation, consistent with the negative effect of the hyperlipidaemic diet presented by Leroy *et al.* (2010). In comparison, Cerri *et al.* (2009) reported that cows fed a diet rich in linoleic acid and other UFA had a greater proportion of excellent, good, and fair quality embryos than embryos from cows fed palm oil (primarily C16:0), and embryos from cows fed PUFA had a greater number of blastomeres. In other studies, however, supplementary PUFA failed to alter oocyte quality or subsequent embryo development (Bilby *et al*. 2006a; Fouladi-Nashta *et al*. 2007; Childs *et al*. 2008a), although the high fat diet improved blastocyst production from mature and cleaved oocytes (Fouladi-Nashta *et al*. 2007). In comparison, Petit *et al.* (2008) reported that supplementation with ω-3 UFA (flaxseed oil: linolenic acid: C18:3) decreased embryo quality compared with feeding calcium salts of palm oil (SFA: C16:0). Despite this, they noted that treatment had no effect on the subsequent pregnancy rate of heifers receiving frozen grade-1 embryos. The reasons for the inconsistent effects of dietary fat content and FA composition on oocyte and embryo quality are not known and make recommendations to improve fertility impossible.

The other post-ovulatory mechanism in which FA may have a role is in oxytocin-induced prostaglandin synthesis. Twenty-carbon PUFA are the precursors for physiological compounds called eicosanoids, of which prostaglandins are a key family. As prostaglandins play important roles in luteal regression and pregnancy maintenance, targeting a reduction in prostaglandin synthesis through modifying dietary PUFA content has been an area of increasing research interest as a potential means to improve fertility (see reviews by Mattos *et al.* 2000; Wathes *et al*. 2007; Weems *et al*. 2006).

Polyunsaturated FA reduce prostaglandin (PGF2α) synthesis in both endometrial explants (Cheng *et al.* 2001) and cells (Mattos *et al.* 2003) *in vitro.* However, results from *in vivo* studies do not necessarily agree. For example, Cheng *et al.* (2005) reported that ω-6 PUFA had a greater reducing effect on PGF2α synthesis than ω-3 PUFA, while Petit *et al.* (2004) reported an increase in PGF2α secretion when cows were supplemented with ω-6 PUFA. Studies examining the effect of dietary ω-3 PUFA supplementation on PGF2α secretion have also produced inconsistent results *in vivo*. Supplementation with fish oil reduced the oxytocin-induced secretion of PGF2α in some studies (Thatcher *et al*. 1997; Mattos *et al.* 2004), had no effect elsewhere (Moussavi *et al*. 2007; Childs *et al.* 2008a), and led to an increase in PGF2α and the expression of mRNA for prostaglandin E synthase in the endometrial tissues of cows in other experiments (Childs *et al.* 2008a; Coyne *et al.* 2008).

The inconsistent effects of dietary and tissue FA content on reproduction variables are difficult to interpret and few studies have reported the effect of fat supplements on either conception rate or early embryo mortality. Staples *et al.* (1998) examined 100 research papers where the effect of fat on reproduction was reported. Of those reporting conception rates, 11 studies observed positive effects or a tendency for a positive effect, whereas three studies reported strong negative effects. Since that review, one of the few studies reporting pregnancy losses, Ambrose *et al.* (2006) reported that a flaxseed (primarily ω-3 PUFA: C18:3) supplement reduced pregnancy losses and increased conception rate to timed AI when compared with a sunflower seed (primarily ω-6 PUFA: C18:2) supplement. A similar tendency for embryo mortality was observed by Petit and Twagiramungu (2006) when flaxseed was compared with other fat sources. These data indicate benefits of ω-3 PUFA on pregnancy rate. More recently, however, Juchem *et al.* (2010) reported that a calcium salt rich in linoleic and other trans-octadecenoic acids resulted in greater pregnancy rates at 27 and 41 days after insemination compared with cows fed palm oil, suggesting a benefit of ω-6 PUFA over SFA. The reasons for the inconsistency in research results are unclear and require further investigation. However, cows grazing fresh forages tend to have high concentrations of dietary fat (>40 g/kg DM), of which more than 50% are ω-3 PUFA and more than 25% are ω-6 PUFA. From what is known, the amount of fat and the balance of ω-3 PUFA to ω-6 PUFA would appear sufficient for optimal ovarian function and to ensure maximum pregnancy rates. Supplementing grazing cows with fatty acids is, therefore, unlikely to be beneficial.

Conclusion

Pregnancy rates have declined with increasing milk yield and an associated greater negative EBAL. Grazed temperate forages are a highly digestible feed, but are low in NSC and high in degradable protein relative to a TMR formulated for maximum milk production. Positive effects of NSC on ovarian function and negative effects of rumen degradable protein and associated blood and uterine fluid ammonia and UN concentrations have led some to recommend supplementary feeding practices pre-breeding and during the breeding season to overcome these deficiencies and to improve pregnancy rates. Although seasonal shortages of forage can be alleviated by supplementation, improving EBAL and BCS and, thereby, improving ovarian function, supplementation of grazing dairy cows to alter nutrient composition does not appear beneficial in improving pregnancy rates. The primary focus of the nutritionist aiming to improve reproduction should be to ensure late lactation nutrition and lactation length are managed to achieve optimal calving condition.

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REPRODUCTION IN HIGH PRODUCING DAIRY HERDS IN NSW:

WHERE ARE WE AND WHAT ARE WE DOING?

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Abstract

Milk production has increased significantly over the last few decades in the NSW dairy industry with a concurrent decline in reproductive performance. Several factors have played a part in this correlation including increasing herd size, increased metabolic clearance of reproductive hormones, increased risk of negative energy balance and genetic correlations between milk production and fertility. There are many strategies that have been implemented in NSW dairy herds in order to counteract this negative trend including increased utilising of reproductive hormones and manipulation of the ovarian cycle; increased use of heat detection aids; genetic selection for better fertility; batch calving and nutritional supplementation.

Introduction

Milk production has increased dramatically over the last few decades in the NSW dairy industry due to major improvements in nutrition, management and genetic gains through the use of superior AI progeny test bulls. According to industry statistics, the average NSW dairy operation in 1989/90 consisted of approx 86 cows producing approx 2,900L per cow per year while in 2008/2009 the herds consisted of 215 cows producing approx 5,750L per cow per year. (www.dairyaustralia.com.au) Coinciding with the increased productivity has been a decrease in reproductive performance of not only Australian herds but worldwide, particularly for the dominant Holstein Friesian breed. (Van Arendonk *et al*., 1989; Buckley *et al*., 2000; Sorenson *et al*., 2007) The following article examines the links between milk production and reproductive performance and explores some of the strategies used to overcome these challenges.

Reproduction, milk production and genetics

Annual calving rates in Holsteins are below 40% in most cases with some reporting rates as low as 25%.(Royal *et al*., 2000; Sorenson *et al*., 2007) The decline in calving rates in US Holsteins has been decreasing at a rate of 0.5-1.0% per year.(Bousquet *et al*., 2004; Lucy, 2005) There is a proven link between milk yield and fertility with correlations found in the range of 0.2-0.4 indicating that selection for milk yield alone could lead to poorer fertility.(Roxstrom *et al*., 2001b; a) In reaction to this negative correlation and declining fertility, there has been a move from the emphasis of production to non-production traits in international selection indices, although the variation in the relative weight in these indices is quite diverse.(Miglior *et al*., 2005) The relative emphasis of health and reproduction in the Australian Profit Ranking in 2003 focused on fertility traits was approx 17%,(Miglior *et al*., 2005) recently in April 2010, an updated APR was developed placing even more emphasis on daughter fertility, survival and mastitis resistance with a continued move away from production traits. However, the use of breeding selection to improve fertility is a slow process and other measures need to be taken to maximise reproductive performance. The decline in reproductive performance of milking cows has not been reflected in heifers indicating that there a factors other than simple genetics that are at play.(Kuhn and Hutchison, 2005)

Metabolic impact of high milk production

Most dairy cattle suffer a negative energy balance (NEB) during the first few weeks of lactation when energy output in milk exceeds energy intake. Selection for increased milk production decreases the amount of energy that is used for maintenance as energy is diverted into milk production leading to NEB and decreased body condition, both of which are linked to poorer fertility. NEB is increased in higher producing cattle predisposing them to poor ovarian function. One of the reasons for poorer fertility is that NEB causes an increase in the amount of circulating non esterified fatty acids (NEFA) which accumulate in follicular fluid, disturbing follicular development. Follicles take approximately 6 weeks to mature to the point of ovulation, thus any nutritional stress placed on the cow during this recruitment phase may lead to poorer fertility. Higher milk production also increases feed intake(Veerkamp *et al*., 2003) but it does not improve feed efficiency as maintenance requirements are increased due to increased liveweight and metabolic activity. For instance, US Holstein maintenance requirements have increased by greater than 25% over the last 30 years.(Agnew *et al*., 2003) Increased metabolic activity also has a negative impact on reproduction as it leads to increased catabolism and clearance of steroidal hormones such as oestradiol and progesterone.(Roche, 2006) Lower concentrations of oestradiol on the day of oestrus are highly correlated with the occurrence of sub-oestrus, thereby making the detection of oestrus in high-yielding cows even more difficult.(Rodrigue-Martinez *et al*., 2008) Decreased blood progesterone concentrations during early embryo development is also associated with decreased conception rates.(Stronge *et al*., 2005) There is tremendous variation in the magnitude of negative energy balance amongst cows of the same breed with similar milk yield indicating that there is opportunity to select for improved coping mechanisms. The majority of NSW dairy herds are still significantly reliant on grazing, this leads to a fundamental problem in that large framed Holsteins are unable to consume enough dry matter in order to maintain body condition, optimise milk production and achieve good fertility. This problem with feed intake has been partially rectified through the use of supplementation with either grain, partial mixed rations or confinement with total mixed rations.

Conception rates

Conceptions rates (CR) have declined considerably as milk production has increased. A recent study on the CR of Holsteins in the southeastern US showed that from 1985 to 2000, the CR in primiparous lactating cows had decreased from approximately 52% to 45%.(Huang *et al*., 2009) Several other US studies have shown a similar decline in CR. (Washburn *et al*., 2002; Rajala-Schultz and Frazer, 2003)The CR data for year round herds in Australia is not as well documented. The InCalf project examined the conception rates of year round herds in the late 90's, CR of greater than 53% are recommended as a target in the InCalf fertility focus report which were based on the findings of this study. Using herd data from 2008-2010 collected by the Livestock Veterinary and Teaching Unit, analysis of CR show that all of the herds rarely achieve above 40% CR on a regular basis in lactating cows.

Traditional fertilisation rates have been quoted as greater than 90% but more recently studies have shown fertilisation rates as low as 75%.(Sartori *et al*., 2002) A number of factors may be associated with this decline including accumulation of NEFA in follicular fluid during NEB jeopardizing oocyte development;(Leroy *et al*., 2005; Vanholder *et al*., 2005) or delayed ovulation due to suboptimal levels of progesterone leading to aged oocytes.(Bage *et al*., 2002)

Coinciding with the increased failure of fertilisation has been an increase in early embryonic mortality (EEM) due to non infectious causes. Some of the factors involved with EEM include poor oocyte quality, lowered circulating progesterone concentrations and sub-optimal uterine environment due to reduced progesterone and insulin like growth factor.(Leroy *et al*., 2008) Excess rumen degradable protein (RDP) also has been associated with the development of poor uterine environment through elevations in uterine pH.(Butler, 1998) Previous published reports have found relatively high CR in Australia and New Zealand despite high amounts of RDP.(Williamson *et al*., 1992) Westwood *et al* 2002, hypothesised that Australasian dairy cows may tolerate higher levels of rumen degradable proteins than North American cattle because negative effects of feeding higher RDP are not exacerbated by excess body condition loss.(Westwood *et al*., 2002) With increased intensification and total mixed ration operations this may become a problem in the future. These articles reflect the experience in our herds. In contrast, the majority of herds that we work with tend to have the highest conception rates during the high risk periods in spring/early summer when the ryegrass or kikuyu pastures contain crude protein levels up to 24% of which a significant proportion is degradable. In recent times, one of the herd test centres in NSW attempted to relate herd test milk urea nitrogen values with reproductive performance but were unable to show any significant correlation.(Stevenson, 2009)

One of the changes that have occurred in year round operations in NSW over the past few decades has been the shift away from using specialised AI technicians such as veterinarians to on farm personnel. Several authors have identified wider ranges and lower conception rates in DIY operators.(Brightling, 1985; Morton, 2000) The training and retraining of these personnel can often be minimal, they have less practice, they are often unsupervised and unfortunately due to poor record analysis on a significant number of operations, poor performance is often not detected for prolonged periods. The InCalf program has attempted to rectify this problem by informing the commercial operators about the importance of regular retraining of all AI technicians on farm. On the farms, that we work with we can see wide variations in the success of individual technicians and attempt to identify the ones that are below average and suggest that they either be retrained or be allocated different responsibilities. Unfortunately in order to realistically determine the competency of an AI technician a minimum of 250 breedings is recommended, which can be extremely difficult in smaller herds.

The AI industry has attempted to balance the needs of farmers to get cows pregnant and also to obtain as many inseminations as possible per ejaculate.(Buckley *et al*., 2003) Multiple studies have shown differences in conception rates between AI sires.(Jansen and Lagerweij, 1987; Buckley *et al*., 2003) Many of the problems associated with semen are not under the direct control of the farm manager. On farm control measures are aimed at monitoring semen nitrogen levels, use of narrow mouth tanks and ensure storage conditions are in place to prevent damage to tanks.(Lean, 2000)

Anecdotally, we have found that CR achieved by natural matings is higher than that achieved by AI. This leads one to consider that the problem in conception is not simply a cow problem but may be related to semen factors, AI technique or optimal AI timing. In the literature, there are a few studies which support our observations,(Macmillan *et al*., 1977; Langley, 1978) while others have shown that no differences exists(Shannon and Vishwanath, 1995;

Buckley *et al*., 2003) while others have shown higher calving rates to AI than natural matings.(O'Farrell and Crilly, 1999) It is interesting to note that most of the studies that showed poorer CR to AI were from the 1970’s 1980’s, the advances in cryopreservation and semen preparation have been significant which may negate the value of these studies today.

Heat detection

Failure to detect oestrus accurately is the greatest limiting factor to achieving optimal reproductive performance in herds utilising AI worldwide.(Nebel and Jobst, 1998) For instance, it is estimated that the dairy industry loses 300 million dollars annually due to poor oestrus detection due to decreases in milk production, delays in days to first service, prolonged days open and extended calving intervals.(At-Taras and Spahr, 1998) Worldwide estimates of heat detection rates (HDR) include 50% in the USA, 37% in South America and 70% in Ireland.(Barr, 1975; Cavestany and Galina, 2001; McCoy *et al*., 2002) Several studies have also noted that a significant number (up to 60%) of cows are not in or near oestrus when they are inseminated.(Reimers *et al*., 1985; Saumande, 2002) Heat detection rates below 50% are common in many herds in NSW with herds that achieving 60% HDR on a consistent basis considered good if not excellent.

The duration of oestrus has become much shorter over time in direct relation to increasing milk yield.(Lopez *et al*., 2004) Today’s cows have shorter oestrus cycles, display fewer standing oestrus and show oestrus for a shorter duration. Consequently, there has been a continual decline in heat detection rates over the years. For instance, one study that looked at HDR from 1985 to 1999 showed a decline from 51 to 42% across 10 dairies in Ohio.(Washburn *et al*., 2002) Cows that have less reliance on mobilised body tissue, lower milk production and lower genetic merit are more likely to display oestrus.(Lean, 2000) The amount of time dedicated to observation of oestrus activity is often minimal due to the number of other jobs that are required on farm. A recent survey in the US of large dairy herds found that cows were checked approximately 2-3 times daily for a total period of approximately 30 minutes.(Caraviello *et al*., 2006) Given that the average cow is mated 9 times for a total of 27secs in an overage 8hr oestrus period, it is not difficult to see why simple observation without the use of heat detection aids is prone to failure.

The push towards larger herds and increased intensification/automation has led to decreased observation of individual animals and increased use of short term labour that are often inexperienced and have a poor understanding of cow behaviour. Labour units are much more difficult to motivate and often less likely to do as good a job as family members who have a vested interest in the success of the reproductive program.

Strategies utilised to optimise reproductive performance

Genetic Selection for improved reproduction

Selection for cows with improved reproductive efficiency is a long term solution for reproductive decline in the dairy industry. As mentioned previously, although the heritability for reproductive traits is low, there is a significant coefficient of variation amongst reproductive traits which suggests that selection for improved daughter fertility is possible. As one would reasonable predict, the potential drawback for this selection process is that there are negative genetic correlations between daughter fertility and milk yield.

Manipulation of the oestrus cycle and control ovulation

The use of reproductive hormones to manipulate the oestrus cycle through the control of the development of follicular growth, the promotion of ovulation in anovulatory cows, the regression of the corpus luteum in cyclic cows and the synchronisation of oestrus and ovulation prior to observed or timed breeding is the most common strategy employed on commercial dairies. The choice of program depends markedly on the individual herds. For instance, for very large herds, the employment of a fixed time breeding protocol such as OVSYNCH rather than a protocol which involves mating to observed heats may be more effective and cost-efficient. The majority of herds we work with utilise prostaglandin and mate on observed heat. This is by far the most simple of the hormonal strategies but on most properties it is the most effective.

The efficacy of hormonal synchronisation strategies depends largely on the people who are involved in the implementation of the programs. It is vital that injections are given to all cows at the appropriate times and the cows are then bred at the appropriate time. The efficacy of hormonal programs such as OVSYNCH can vary widely between operations. Typically we have seen that in higher producing herds (>30L per cow per day) CR following OVSYNCH have been higher than CR to natural or prostaglandin induced breedings. OVSYNCH has not been as successful on lower producing herds, and is attributed to an increase in 3 wave cycling patterns in lower producing cows compared to the 2 wave patterns that occur in high producing cows.(Townson *et al*., 2002)

As the majority of cows are not pregnant following first service, there is also the opportunity to increase the days to conception by re-enrolling cows into a fixed time OVSYNCH protocol prior to pregnancy diagnosis. This program involves the administration of GNRH 7days prior to pregnancy diagnosis and then if found to be empty at pregnancy diagnosis they will receive the prostaglandin injection. At present, this practice has not been adopted by any herds that we work with but it is has been done with success in many herds in the US.

Prolonged Interval to First Service

One of the methods to improve conception rates in high producing herds is to prolong the days to first service. A recent study by Stevenson and Phatak, 2005 noted that delaying first service improved conception rates. This can be achieved using a double PG program (Presynch), Presynch + OVSYNCH, or double OVSYNCH program.(Pursley *et al*., 1995; Navanukraw *et al*., 2004) The improved conception rates need to result in an improved pregnancy rate, i.e. more animals pregnant by the same days in milk.

Heat Detection Aids

Many different approaches to improve oestrus detection have been investigated including tail paint, tail chalk, heatmount detectors (KAMAR/scratchies), automated activity monitors (pedometers), automated mounting detectors and in line progesterone meters. The ideal system for detecting oestrus should include: continuous surveillance, accurate identification, minimal labour requirements, cost effective and high accuracy and efficiency (>95).(Senger, 1994) Unfortunately, at this point in time there is no system that ticks all of these boxes. Tail paint has been shown to be an effective aid to heat detection in pasture based operations.(Macmillan and Curnow, 1977; Cavalieri *et al*., 2003) Combined with early morning and late evening observations, checks for paint loss at milking times should result in a heat detection of close to 90%. Efficiencies of heat detection using tail paint have ranged from 44 to 96%.(Macmillan and Curnow, 1977; Pennington *et al*., 1986; Sawyer *et al*., 1986;

Diskin and Sreenan, 2000) The sole use of tail paint in NSW is not as widespread as in Victoria and South Australia; many operators choose to combine tail paint with heat mount detectors. Some of the reasons behind lower usage rates include difficulties in interpretation with untrained staff and the need to constantly apply the paint to animals all year round. The use of heatmount detectors was shown to be slightly less effective (approximately 5%) at detecting oestrus when compared to tail paint.(Cavalieri *et al*., 2003) Reported efficiencies of heatmount detectors range from 56 to 94% while the accuracy of heat detection ranged from 36 to 80%.(Diskin and Sreenan, 2000) Despite this, many herds utilise them with great success. Each of the different aids has their deficiencies which make their use challenging at different times. For instance, scratchies become very difficult to interpret during the hotter months due to the presence of flies and tail swishing and the propensity for cattle to congregate under tress.

Automatic measurement of a cow's activity has been recognised as effective and potentially reliable method to detect the onset of the oestrus period in dairy cows for decades.(Kiddy, 1977; Moore and Spahr, 1991)Cows that are in oestrus do 2-4 times more walking than a non-oestrus cow.(Diskin and Sreenan, 2000) Initial attempts at establishing a credible system were hampered by failure of units to continue operating for long periods, lack of user control and ability to adjust settings, lack of automated reading data and failure of units due to caking of manure.(Moore and Spahr, 1991) Recent papers have examined pedometers and found sensitivities ranging from 75 – 95% with error rates of between 12-50%.(Firk *et al*., 2003) Automated activity meters utilise an algorithm to predict when the cow is on heat based on increased activity. The sensitivity and specificity of this monitoring system can be changed by altering the software. Improved efficiencies have been achieved by previous oestrus case points with activity using the computer algorithms,(Firk *et al*., 2003) in other words previous oestrus information improves the accuracy of heat detection. Pedometers have been found to be particularly useful in confined housing systems. One of the problems with using them for pasture based systems is that interpretation of activity spikes is difficult when cows are constantly moved to different paddocks. Like most systems, despite being automated there is still a human component that is essential. It is not uncommon for herd that utilise pedometers to have greater than 10% of cows with either faulty pedometers or no pedometer at all. When this is used as a sole heat detection aid, this can be a significant cause of poor heat detection efficiency.

Rump mounted, radiotelemetric, pressure sensing systems are commercially available overseas and have been the subject of a few peer reviewed trials.(Cavalieri *et al*., 2003) The pressure sensors record any mount greater than 1 second and send a signal back to a computer which stores the information. Cows are considered in oestrus when greater than 3 mounts occur in a 4hr period. Studies that have been performed using these systems have shown contradictory results with some showing improved oestrus detection(Walker *et al*., 1996; Stevenson *et al*., 1998; Xu *et al*., 1998) when compared to visual observation while others have shown that they have been inferior.(Saumande, 2002) As yet, we are unaware of any herds that utilise this technology.

Several trials have compared different heat detection aids in both Australian herds and overseas herds. In the Australian study, by using any of the four methods of heat detection (tail paint, heat mount detectors, pedometers and radiotelemetric meters) greater than 80% of heats were detected.(Cavalieri *et al*., 2003) The study found very small differences between the sensitivity and positive predictive value of the four heat detection methods. One of the problems with using the results of this study is that the herds used were seasonal operations, so the oestrus activity of the animals would be greater due to a large number of cows being on heat.

Inline milk progesterone assay has long been used as the gold standard for detection of oestrus in cattle. Daily milk progesterone would enable the owner to not only identify oestrus but also to potentially identify potentially pregnant animals. The presence of low progesterone alone is not necessary an indicator of oestrus, however high milk progesterone is considered a confirmation that a cow is definitely not in oestrus. At present, cost is a major limiting factor in using this in the dairy industry but with improved technology, it is not difficult to predict that in the next few years this will be a part of the milking plant. Milk progesterone will also be important to get a greater understanding and prevalence of the so called "phantom cow" which fail to return to oestrus following insemination despite not being pregnant.

Batch Calving

Some herds in NSW particularly those on the North Coast of NSW have changed from year round calving to batch calving. Batch calving is employed in some operations to avoid mating cows during the hottest periods of the year where CR are often well below other times of the year.

Batch calving has one main advantage from a reproductive standpoint in that there is a shorter period of mating which allows for increased effort in heat detection. The use of synchronisation programs in this system also means that there are a greater number of cows on heat at the same time which should lead to increased HDR. The downsides with the system is that if a cow fails to become pregnant during the predetermined joining period then she will not be joined until the next mating period. There is also much greater risk in that if something catastrophic occurs during the mating period, e.g. semen tank fails, bulls break down, a disease epidemic occurs then there will be a considerable drop in the percentage of the lactating herd pregnant ultimately resulting prolonged calving intervals and increased days in milk.

Nutritional management

Nutritional strategies are essential to optimise reproductive performance through minimising NEB, optimising the rumen environment, encouraging dry matter intake and optimising protein to energy ratios where possible. Nutritional strategies will not be discussed in detail in this paper and the reader is directed to alternate sources.(Roche, 2006)Supplementation with certain fats such as linoleic acid increase progesterone concentration in blood plasma, attenuates the production of prostaglandin, and can lead to an increased CR.(Rodrigue-Martinez *et al*., 2008) A few herds are currently trialling the use of exogenous conjugated linoleic acids (CLAs) in pre-calving diets, initial anecdotal results have shown promise but more time and greater number of herds will be required in order to get a more objective measurement. Use of CLA has also improved reproductive performance when used in lactating cow diets but the inhibition of milk fat has diminished its potential usefulness.(Lean, 2010)

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ADDRESSING THE REPRO PROBLEM: WHAT ARE THE KEY FACTORS

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Where are we?

Located in the Southern Illawarra region of NSW, the farm covers a total area of 176ha and fronts the Princess Highway at Rose Valley. The property consists of alluvial creek flats which run into heavy well drained swampy soil and then rises to steeper Clay /basalt based hills.

Our family will have been on the original portion of the farm for 100 years in October 2012.

We have no irrigation on the farm but 2 bores supply our drinking water and some water to the dairy. We also rely on town water to use in the dairy and an average rainfall of 1250mm to 1500mm per year.

The family are all involved in running the farm and we also have 4 full time employees, including casuals, working for us.

All feed and fodder is grown within our own business at Gerringong or on a dry land cropping farm located in the Central West where our heifers are also run. We don't rely on contractors for any part of our operation.

Milking Herd:	*325 year round calving*
Milking Area:	*100 ha*
Total Farm Area:	*176 ha*
Dry land cropping Area:	*1210ha*

Our herd is 100% registered Holsteins. We have no crossbreed cows left within the herd and we are now using 100% artificial insemination.

Production: - 7600 l/cow.

- 2.5 million/litres annually.

- 25,000 l/ha

Pastures: Summer: - Kikuyu/clover

- Perennial ryegrass /chicory/clover

Winter: - Annual Ryegrass/clover

- Oats, Leafy Turnips

The milking areas on the farm are sown annually or re-sown with perennials or oats to lead into summer silage.

Addressing Reproductive Issues on Farm

We started to change the herd over from Illawarra's to Holsteins in the early 90's with the purchase of some registered cows and all matings over Illawarra cows to Holstein bulls. By the mid 90's, we had entered a herd health program with a local veterinarian practice. These were started as monthly visits but as we progressed the visits became weekly with herd health held every Tuesday. This is when herd health, particularly fertility, became a specific focus. Noticeable improvements were made with the introduction of heat detection aids, hormone treatments and CIDR's.

Information was collected and entered into computer software programmes but we had problems getting information on what improvements and advancement we were making within the herd. We tried the InCalf program but found the results were varied as the programme seemed to be more applicable to seasonal calving herds.

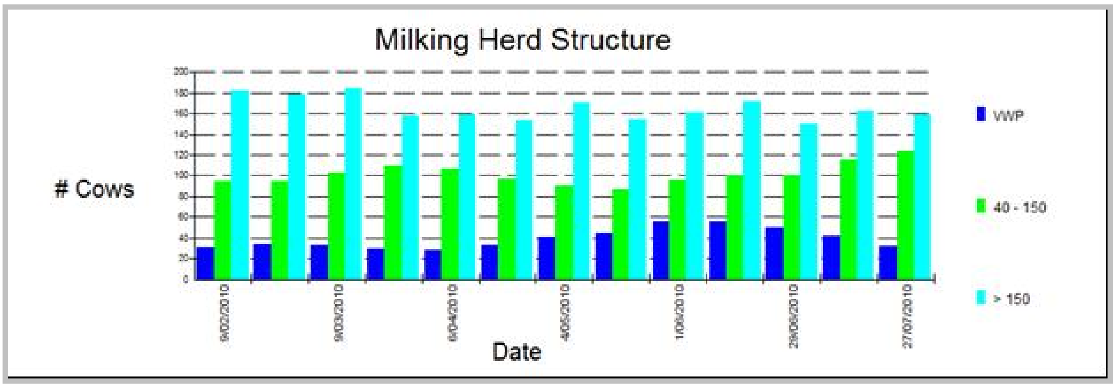

Figure 1. Milking Herd Structure

As the herd health program developed, we were able to reduce the number of days to pregnancy testing from 56 to 42 post insemination, and we now have it at 35 days, enabling us to determine the non pregnant cows much earlier. All pregnancy testing is done by ultrasound. This enables us to pick up pregnancies, non-viable pregnancies, twins, irregular heart beats in the foetus and can make visible a host of other issues not able to be diagnosed manually.

We started using the Livestock Veterinary Teaching and Research Unit, Faculty of Veterinary Science, The University of Sydney in early 2008 and were able to link the information we had on the **Easy Dairy** cow program, to the program they had developed for collating herd information. Following the first visit we were given a number of information which gave us an idea of the direction of the herd over the previous 9 months. The insight we have gained from the information has shown us that in Nov 2007 Days to First Breeding was 85 and in July 2010 it is down to 67 days. Our aim is to be close to 65 days.

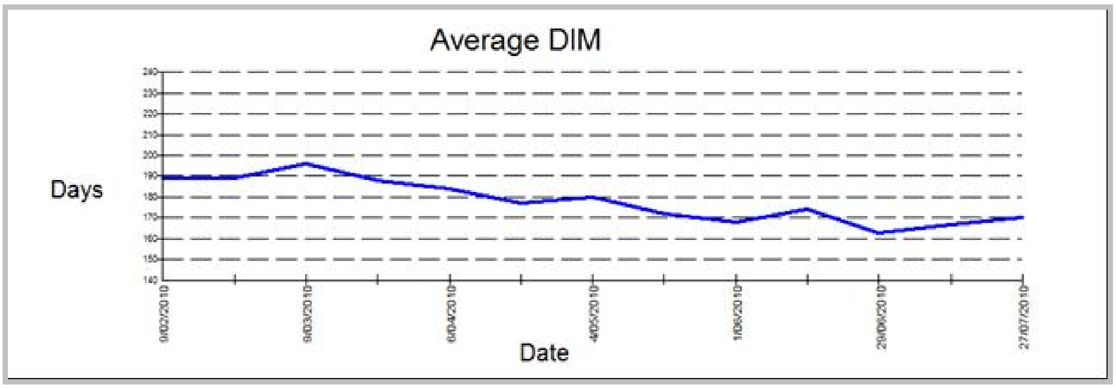

Figure 2. Average days in milk

Average days to conception of the overall herd have also declined from 140 days in Nov 2007 to 100 days in July 2010. This has been reflected in our average days in milk being reduced from 205 days in Nov 2007 to 170 days in July 2010. The drop in days in milk means that we are consistently miking a fresher herd which utilises feed more efficiently.

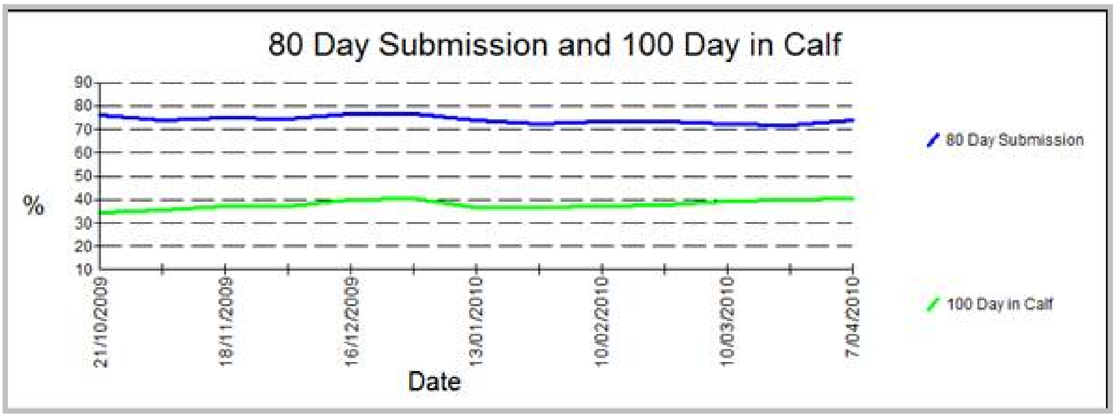

Figure 3. 80 Day Submission rate and 100 Day in Calf rate

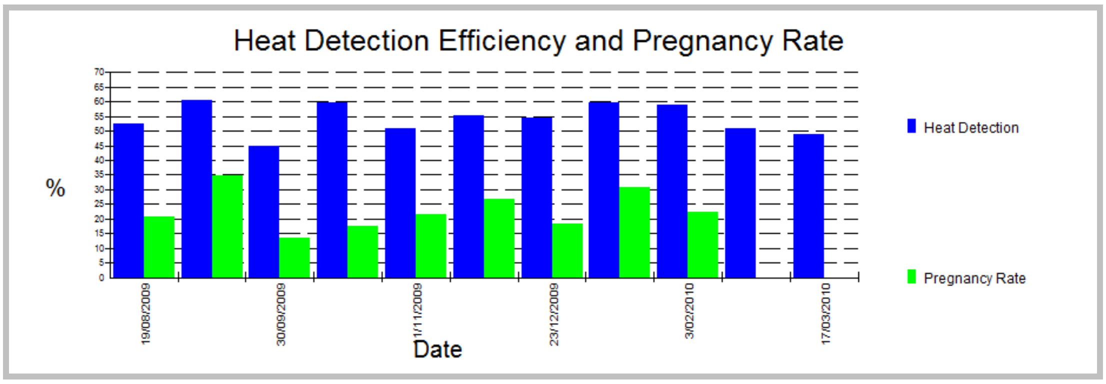

Figure 4. Heat detection efficiency and pregnancy rate

Other important drivers of reproductive performance are Heat Detection Efficiency and Pregnancy Rate. Heat Detection Efficiency is the number of cows detected on heat out of the number of cows eligible to be bred. Pregnancy rate is the number of cows confirmed pregnant out of the number of cows eligible to be bred. Our aim is to have greater than >50% Heat Detection and >20% pregnancy rate every 3 weeks.

The first report that came out in March 2008 included the following information: lactating and Dry Cow Numbers, Milking Herd Structure, Average Days in Milk, Average days to First Breeding and Conception and % Lactating Herd Pregnant. In the July 2010 the following information was presented as a graph and Table.

This information included: adult cow numbers, lactating and dry cow numbers, Milking Herd Structure (Figure 1), Average Days in Milk (Figure 2), 80 Day Submission and 100 Day in Calf (Figure 3), Average Days to First Breeding and Conception, % lactating Herd Pregnant, % Cows >150 DIM that are Not Pregnant or DNB, Heat Detection Efficiency and Pregnancy Rate (Figure 4), Conception rates by Technician, Conception Rate x Times Bred, Conception rate by Days in Milk, Conception rate By Sire (Table 1), PGF Breeding Outcomes

Current Mating Program

- Calving to 45 days, making sure cow is clean, prostaglandin and Metricure is given if needed.
- From Day 45, fortnightly prostaglandin injections are given until insemination takes place.
- If no heat is detected by 80 days in milk, the cow is presented to our veterinarian for and ultrasound evaluation.
- Cows are given 3 matings to proven bulls and then Progeny Test semen is used
- Cows are usually culled after 5 matings as a general rule but are also treated on an individual basis with the cow's history and days in milk influencing what action might be taken.

Inactive or anoestrous cows are enrolled in an OVSYNCH program which consists of the following:

OVSYNCH Protocol

- Day 0 (Tuesday AM Vet visit) – Give 1ml of GnRH (FERTAGYL, GONABREED) into muscle
- Place KAMAR
- Day 7 (Following Tuesday AM) – Give 2ml of prostaglandin into muscle
- Day 9 (Following Thursday AM) – Give 1ml of GNnRH into muscle
- Day 9 (Thursday PM) – Inseminate all cows that have not had a heat.

Herd Fertility has been an evolving process for a long time for us, but in the last few years we feel we have taken big steps with the introduction of such concise reports. We have the ability to quickly recognize where there is a problem or a deficiency starting to occur in our system and we can work on it sooner rather than later.

INVESTIGATION INTO THE EFFECT OF VARIABLE MILKING INTERVALS ON TOTAL YIELD OF DAIRY COWS IN AN AUTOMATIC MILKING SYSTEM, UNDER TYPICAL AUSTRALIAN PASTURE-BASED CONDITIONS

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Abstract

The increasing adoption of automatic milking systems (AMS) in pasture-based farming systems, drives continued research in this area. As a "new way of farming", AMS poses some vastly different challenges to those seen on conventional milking farms. One of the issues not yet understood is the impact of variability of milking intervals and milking frequencies within and between cows throughout the lactation. Within an AMS cows can have similar milking frequencies with dramatically different milking intervals comprising that milking frequency. Minimising the variation in milking frequency has the potential to impact positively on the cow (milk production and health) as well as on the system itself (machine utilisation and queuing). The relationship has been described, showing trends by which a higher variability in milking interval in a cow is usually related with a lower yield per lactation. With this in mind some simple but effective ways of addressing this issue have been outlined and may form the framework for future research areas.

Introduction

The initial adoption of automatic milking systems (AMS) as a new solution to address labour issues was enhanced by the possibility it offered of managing higher milking frequencies and much better data related to production and health of individual cows, changing the whole dairy management into a new farming concept. The first farms were established in Europe in the early 1990's in closed intensive barn systems, and arrived for the first time in a pasture-based system in early 2000's with the establishment of the Greenfield Project in New Zealand (Jago *et al*., 2002) and were followed later on by the FutureDairy Project in Australia (Garcia *et al*., 2007). FutureDairy has demonstrated that good pasture utilisation levels, key to pasture-based farming profitability, could be achieved with AMS. An increasing number of commercial farms have adopted this new way of farming.

The AMS system is based on voluntary and distributed cow traffic. Key performance indicators of these systems are usually based on number of milkings or litres harvested per day per milking unit, which is in turn related to the number of cows, the amount of milk produced per cow and the number of milkings per cow, as a result of the distributed and voluntary movement of these animals around the farm.

Under pasture-based conditions, both frequency of milking and total daily milk yield / cow, are usually lower than in indoor loose housing systems. Previous studies under pasture-based conditions have addressed the effect of supplementary feeding (Jago *et al*., 2007), water (Jago *et al*., 2003), minimum milking interval (Jago *et al*., 2004), stage of lactation (Jago *et al.*, 2006), and premilking teat preparation (Davis *et al.*, 2008) on the general performance and throughput of AMS.

However, no research has been published from pasture-based systems regarding the impact of variability of milking intervals within and between cows on lactational milk production. Limited research on milking intervals has been done in closed barns (Bach and Busto, 2005) and several studies have covered the impact of increased number of milkings on milk production, yet results cannot be directly extrapolated to pasture-based AMS.

In this study, historical data from the FutureDairy AMS farm was analysed to investigate the relationships between number of milkings, milking interval distribution and the variability of milking interval, on milk production by individual dairy cows. It was hypothesised that increased variability in milking interval had an adverse effect on milk yield.

Materials and methods

Data from the FutureDairy AMS research herd (Elizabeth Macarthur Agricultural Institute, Camden, Australia) were retrieved using DeLaval VMS Client software program.

The aim was to obtain whole lactation data of cows that were milked at some stage during 2008, i.e. had calved in year 2007 and were dried off in year 2008; calved and dried off in 2008; or calved in 2008, but were dried off in 2009. The other premise was that cows should have at least 305 days in milk (DIM), in order to make cross references comparable with the international literature. This left 97 cows to analyse whole lactations.

Simple regression analyses were used to investigate associations between frequency of milking, production level, number of lactation, milking interval and yield throughout the lactation.

Results and discussion

Being a voluntary milking system, the amount of milkings per cow across the lactation varied, with a wide range of distribution (Figure 1). A summary of the data is presented in Table 1.

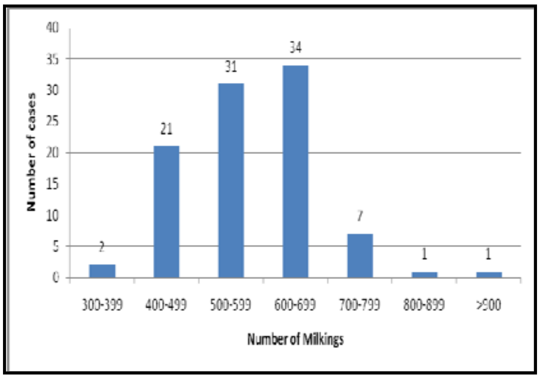

Figure 1. Histogram reflecting the distribution of number of milkings in 305 days.

Table 1. Average, maximum, minimum and standard deviation of the number of milkings in 305 days.

	Number of Milkings	
	In 305 days	**In 24hrs**
Average	579.54	1.90
Maximum	997.00	3.27
Minimum	377.00	1.24
St. Deviation	106.39	0.35

The data showed that 86 out of the 97 cows analysed (88.7% of the cows) had somewhere between 400 and 700 milkings in 305 days. Overall the average number of milkings per day ranged between 1.24 y 3.27 milkings per day per cow across the 305 day lactation. This showed that there were some cows that have almost 3 times more milkings across 305 DIM, than others. The total number of milkings was positively related to total milk yield per cow, although this relationship was not strong (Fig 2).

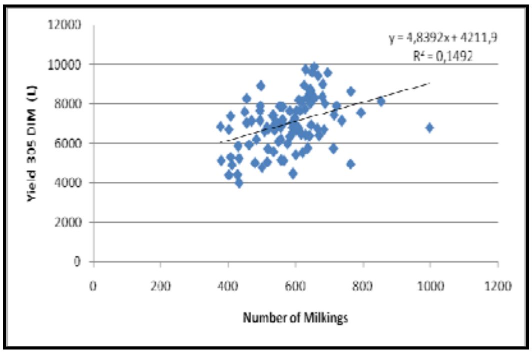

Figure 2. Scatter plot reflecting the relationship between number of milkings and yield in 305 days.

According to this relationship, milk yield increased by 4.84 L for each increase in number of milkings. This is supported by previous research which showed that an increase in number of milkings caused a response in total yield (Stockdale, 2006), yet the effect of this with variable milking intervals has not yet been reported.

As this farm was established under an automatic and voluntary milking regime, cows volunteer themselves to be milked, in search for an incentive (usually the availability of fresh feed – concentrate in the milking unit or a new break of pasture). This creates variable milking intervals across the lactation. Figure 3 and Table 2, reflect the distribution and range of average milking interval of the cows, in the 305 DIM. Figure 3 shows that 73% of the cows had an average milking interval between 10 and 15 hrs.

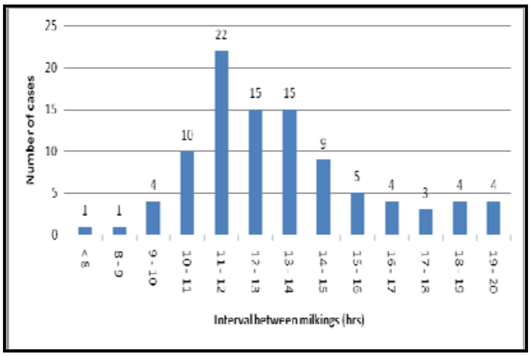

Figure 3. Histogram reflecting the distribution of average interval between milkings in 305 days.

Table 2. Average, maximum, minimum and standard deviation of the average interval between milkings in 305 days.

	Milking interval (hh:mm)
Average	13:09
Maximum	19:26
Minimum	07:18
St. Deviation	02:36

The above reflects average values per cow, but the range is much bigger when analysing all the intervals for every milking of every cow on each specific day, as observed in Table 3:

Table 3. Average, maximum, minimum and standard deviation of the interval between milkings in 305 days.

	Milking interval (dd hh:mm)
Average	00 12:41
Maximum	02 13:03
Minimum	00 00:03
St. Deviation	00 06:00

As the objective was to reflect the effect that variable milking intervals had on total milk yield, Figure 4 shows the relationship for each cow between standard deviation of the milking interval (as a measure to describe the variability of intervals per cow) and the total milk yield, summarised for 305 DIM.

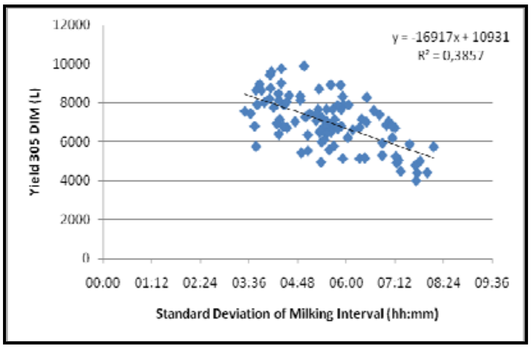

Figure 4. Scatter plot reflecting the relationship between standard deviation of the milking interval and the total yield in 305 days.

As observed in Figure 4, there was negative and linear relationship between standard deviation of milking interval and total milk yield in 305 DIM.

This preliminary analysis shows the detrimental effect of increased milking interval and its variability, on milk yield. However, this is likely to be closely associated with milking frequency and will need to be accounted for in a detailed analysis. Despite this, it seems apparent that aiming to obtain regular milking intervals of cows every day and across the lactation could result in higher average number of milkings, which would reflect a higher lactation yield. It could also result in a higher utilisation of the milking units and may impact on the distribution of visits to the milking stations. Low cost management techniques, which could help to achieve more uniform milking intervals and higher efficiency of robot utilisation, could include:

1) 3 way grazing to provide 3 fresh brakes of pasture in a 24hr period. This could create more frequent cow traffic with more opportunity to be selective about when cows are drafted to the dairy for milking. In this way, extremely long and potentially extremely short milking intervals could be minimised.

2) Changes in the time of opening of new paddocks with a shift in the time of the day that paddocks become available for cows, a change in cows' daily activity pattern could be possible.

3) Changes in the amount of pasture offered per cow in each break.

4) Using different minimum milking intervals. This would allow the farmer to be flexible when the amount of cows in early - late lactation varies throughout the year.

5) Manipulate the amount and physical distribution of supplementary feed. It is believed, that as systems intensify, more supplements could be required. The uncertainty is about the optimum amount (in % related to pasture in the diet) and location to maximise cow movement and production.

Conclusions

This preliminary analysis has shown evidence that cows with a higher dispersion in the milking intervals tend to have a lower yield per lactation. However, a full analysis will be required to account for the confounding impact of milking frequency. This suggests that aiming to manage these intervals, using low cost management solutions, could bring benefits for the cows (higher production, improved welfare and health) and the milking unit and AMS system (higher utilisation, less queuing and less need for fetching cows). Clearly further research is needed to quantify the impact of these management practices on milk yield and AMS efficiency of utilisation.

Acknowledgements

The authors would like to acknowledge the support of all sponsors of the FutureDairy project, particularly Dairy Australia, Industry and Investment NSW, University of Sydney, and DeLaval.

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25 HYDROXYVITAMIN D INCREASES URINARY CALCIUM EXCRETION IN YEARLING STEERS ON A FORAGE DIET

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Abstract

Milk fever is a prominent disease in the dairy industry. Preventative measures for Milk fever include low Ca diets, highly anionic diets, prepartum drenching with Ca supplements and prepartum administration of Vitamin D metabolite and analogues. Responses to the various preventative measures are varied and highly dependent on other mitigating circumstances. Most preventative measures have several negative side effects or restrictions to implementation. Activation of Ca homeostasis mechanisms is critical to reducing the incidence of Milk Fever. Brangus steers were used to test the effect of different levels of dietary cation anion difference (DCAD) on urine pH and urinary Ca excretion. Four levels of DCAD were fed -300, 50, 150, 250 meq/kg. The 50 and 150 DCAD diets were tested with or without supplementation with the Vitamin D metabolite 25 hydroxyvitamin D (25 OHD). Feed intake, Creatinine production and Ca and P balance were analysed. -300 DCAD reduced urine pH and increased urinary Ca excretion. Small reductions in DCAD did not increase urinary Ca excretion unless supplemented with 25 OHD. DCAD or 25 OHD did not affect feed intake, creatinine production, feed digestibility, or Ca and P balance. The results suggest that 25 OHD initiates Ca homeostasis mechanisms with a DCAD range lower than 150 meq/kg. 25 OHD supplementation may allow Milk fever mitigation with small reductions in DCAD.

Introduction

Milk Fever (Parturient Paresis, Hypocalceamia) occurs at the initiation of lactation when Ca is drained from blood for colostrum synthesis and is not replaced rapidly enough from intestinal absorption, bone mobilisation or reabsorption in the kidney (Cunningham 1997).

Paresis and death may occur when the homeostatic mechanisms that replace mammary Ca excretion do not activate quickly enough to maintain blood Ca in its critical range (Horst, Goff *et al*. 2005).

The Vitamin D metabolite 1,25 dihydroxyvitamin D (1,25 OH2D) is the active form of Vitamin D (Goff, Horst *et al*. 1991; Cunningham 1997). Vitamin D is initially synthesised by light in the skin before being hydroxylised in the liver to 25 hydroxyvitamin D3 (25 OHD) and then the kidney to result in the active 1,25 OH2D (Cunningham 1997).

Dietary Cation Anion Difference (DCAD) is the calculation of the ionic balance of a diet expressed in meq/kg. Feeding anionic salts to ruminants reduces urinary pH and increases urinary calcium excretion, thus resulting in hypercalciuria (Kurosaki, Yamato *et al*. 2007). An increase in urinary calcium excretion indicates the activation of one or more of several calcium mobilisation mechanisms, primarily increased intestinal absorption and bone reabsorption (Horst 1986).

Urine pH is an effective indicator of metabolic acidosis (Seifi, Mohri *et al*. 2004). Calcium excretion is increased as a result of anionic salt supplementation (Beauchemin, Bowman *et al*. 2003; Roche, Dalley *et al*. 2007).

Materials and methods

Eighteen rumen fistulated Brangus steers with an average weight of 315kg (+/- 45kg) were blocked by body weight and allocated to one of six treatments.

Steers were fed a forage diet of wheat and lucerne chaff in pellet form. The diet was fed ad lib in the adjustment phase. Four different levels of DCAD were fed. The DCAD levels were achieved by the addition of MgCl2 and the Mg level was balanced with MgO.

Treatments: Control (DCAD 250), 150 OHD (DCAD 150 + 25 OHD3), 150 DCAD, 50 OHD (DCAD 50 + 25 OHD3), 50 DCAD and -300 DCAD.

DCAD was calculated by the equation, Ender (1962).

DCAD (meq/kg) = (meq Na+ + meq K+)– (meq Cl- + meq S--)

Treatment "DCAD -300" was fed at -150 meq/kg for the first 7 days and -300 meq/kg for the last 7 days. 25 OHD was supplemented at 3mg per day, directly injected through the rumen cannulae. Urine spot samples were taken daily, after the adjustment period a five day total collection in metabolism crates was conducted. Urine spot samples were analysed for Ca and Creatinine with an Auto Analyser (Dade Behring Dimension RXL Clinical Chemistry System) and corrections for concentration made. Urine samples from the total collection were analysed with ICP-OES (SAN ++ Continuous flow analyser, Skalar). Urine pH was measured immediately after sample collection (Ecoscan pH 5/6, Eutech Instruments).

The time-series nature of the data was taken into account by an analysis of variance of repeated measures (Rowell and Walters 1976) via the AREPMEASURES procedure of GenStat (2008). A post-hoc t-test was performed on the blocked treatments.

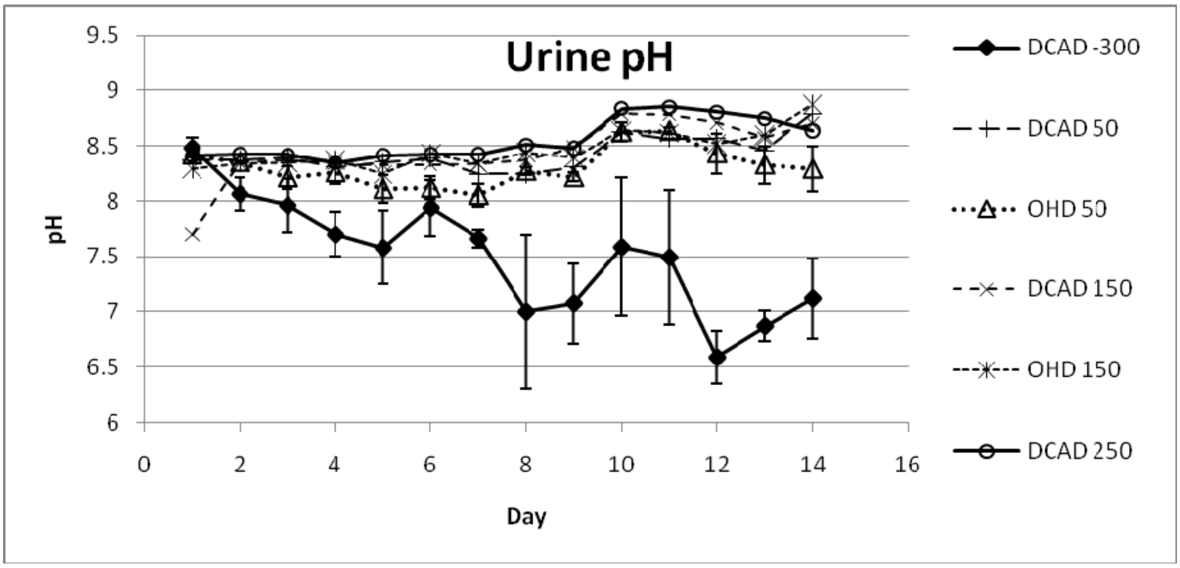

Figure 1. Daily urine pH during the adjustment (days 1-9) and the collection period (10-14).

Results and Discussion

Urine pH was reduced for treatment "DCAD -300" on both the -150 meq/kg and -300 meq/kg diet ($P<0.05$). Urine pH is an effective indicator of metabolic acid-base balance (Tucker, Harrison *et al.* 1988). Urine pH was not affected by DCAD of 50 or 150.

Urine Ca excretion was increased by -300 DCAD but not by -150 DCAD diet. Urine Ca excretion was significantly different for 25 OHD supplementation when analysing spot samples over the collection period but not during the total collection procedure. When the 50 and 150 DCAD treatments ICP total collect data was blocked according to 25 OHD supplementation, the 25 OHD group excreted more urinary Ca. Urine Ca excretion was increased by anionic salt addition and 25 OHD supplementation. The initiation of Ca excretion in urine is important as it indicates that the Ca mobilisation mechanisms of Ca homeostasis have commenced, resulting in excess Ca in the blood, which results in Ca excretion (Cunningham 1997). The experiment demonstrates that diets of 50 and 150 meq/kg only increase urinary Ca excretion if supplemented with 25 OHD at 3mg per day. There was no effect on feed intake, feed digestibility, creatinine excretion or Ca and P balance.

Analysis of 25 OHD and anionic salts in periparturient prepartum cows is required.

A combination of 25 OHD3 and low levels of anionic salts may result in the same reduction in incidences of milk fever as aggressive anionic salt feeding regimes without the reduced feed palatability associated with anionic salts.

Table 1. Urine Ca excretion g/120 hours (total collection period)

	Treatment									
Collection	DCAD 300	DCAD 50	OHD 50	DCAD 150	OHD 150	DCAD 250	DCAD Blocked	OHD Blocked	SEM	P Value
Urine Spot Sample	19.5±2.4a	4.8±1.3cd	11.7±4.5b	3.9±1.1d	10.0±2.4bc	2.9±0.5d			2	<0.001
Urine Total Collect	20.9±1.8a	4.4±0.6	11.1±4.7	4.3±0.7	9.8±1.4	5.0±1.7			2.29	0.002
Urine Total Collection							4.3±1.6	10.4±1.6a		<0.05

Values with subscripts are significantly different at P<0.05

Acknowledgements

This work was supported by Dr. R. Elliott, DSM Nutritional Products Australia Pty Ltd, 6/13 Princeton Street, Kenmore, Qld, Australia 4069.

As well as the dedicated staff in the animal house and laboratories at the University of New England. Notably Les Anderson, Jenny Hegarty, Neil Baillie, Leanne Lisle and Kate Metcalfe.

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DEVELOPING A HEAT LOAD INDEX FOR DAIRY COWS

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Abstract

The temperature humidity index (THI), originally developed as a discomfort index for humans (Thom, 1958), and has been used in various forms as an indicator of livestock stress since the mid 1960's. The THI lacks the ability to accurately describe the total heat load (HL) on an animal as it does not account for the effects of solar radiation or air movement. Both of these variables play a role in an animals' ability to maintain homeostasis. The beef heat load index (HLI) was developed in an attempt to account for both of these climatic factors. The aims of this study were to (1) outline climatic and animal factors that affect milk production, and (2) assess the ability of THI and HLI to accurately predict heat load effects on milk production. Data was collected over the 2008/2009 and the 2009/2010 summers (December to March), using n=150 Holstein-Friesian cows each summer. The cows were housed in an open "feedlot" with limited shade. Individual MP data were recorded daily. Daily observations of cow location and panting score were conducted at 0800, 1200 and 1400 h. For statistical analysis cows were categorised by age, days in milk (DIM), milk production (MP) and parity. Climatic data were collected at 10 minute intervals. The HLI and THI were good predictors ($P<0.0001$; $r^2=0.56$) of changes in monthly MP, but less reliable predicting day effects ($P<0.01$; $r^2=0.15$). This was due to cow variations in DIM ($P<0.001$) and MP ($P<0.001$). MP from cows with <20 kg/d was not affected ($P>0.05$) by high HL. Reductions ($P<0.001$) were seen for cows with MP>20 kg/d. Further studies are underway to develop a model that will allow prediction of the effects of HL on a daily basis.

Introduction

Climatic indices have been used to predict/measure the effect of heat load on animals since the 1960's. The index used by the Australian Dairy industry is the THI (see below). This index utilises ambient temperature (T_A) and relative humidity (RH) to provide a guide to the severity of heat stress and is a reasonable measure of heat load on the animal. However, the THI does not account for air movement or solar radiation. Furthermore the THI provides a blanket value that does not consider individual variation, such as genetic MP, DIM or cow age.

The HLI, which is currently used in Australian feedlots, utilises T_A and RH as well as solar radiation (SR) and wind speed (WS). The HLI equation (see below) uses black globe temperature (BGT) as a measure of solar radiation and ambient temperature. It was developed to overcome the perceived deficiencies in the THI. The HLI uses climatic threshold levels to predict the level of HL on different genotypes.

The aims of this study were to (1) outline climatic and animal factors that affect milk production, and (2) assess the ability of THI and HLI to accurately predict heat load effects on milk production. The outcomes will be used to identify deficiencies in the current system which will be used in the development of a heat load forecast system for use by the dairy industry.

Materials and methods

Data was collected over the 2008/2009 and the 2009/2010 summers (December to March). Cows (n=150 Holstein-Friesian) were housed in an open "feedlot" situation approximately 1.4 ha in size, with a covered feed pad and a permanent shade structure. Cows had access to 2.6 m^2/head from the feed pad and 1.68 m^2/head from the permanent shade structure. Cows only utilised the permanent shade as the feed pad had a concrete surface.

Observations were made daily at 0800, 1200 and 1400 h. The data collected were: cow location (shade, no shade, feeding or at water); posture (standing, lying); and panting score (0 = regular breathing, 4 = open mouth, tongue out, excessive drooling) (adapted from Mader *et al*. 2006). Individual panting scores were then combined across the herd to give a mean panting score (MPS) for the whole herd.

Cows were milked twice a day (approximately 0530 h and 1500 h) in a 10/side herringbone dairy. The milking cups were fitted with Westfalia In-Line milk meters and individual MP and DIM was recorded using DairyPlan software (GEA Farm Technologies). MP data included total daily production, and also AM and PM production. Climatic data (T_A, RH, SR, BGT and WS) were collected at 10 min intervals using an automated weather station (EASIDATA MK3, Environdata Australia P/L, Warwick, QLD, Australia) located 40 m from the feedlot. Daily rainfall was also collected. These data were used to calculate the THI and HLI using the following equations;

- $THI = 0.8 \times T_A + RH/100 - (T_A - 14.4) + 46.4$; where RH is expressed as a percentage;

- $HLI_{BG>25} = 8.62 + (0.38 \times RH) + (1.55 \times BGT) - (0.5 \times WS) + [e^{2.4 - WS}]$, and

- $HLI_{BG<25} = 10.66 + (0.28 \times RH) + (1.3 \times BGT) - WS$; where e is the base of the natural logarithm (approximate value of e = 2.71828) (Gaughan *et al*. 2008).

Cows were fed a mixed ration containing sorghum silage, 15% brewers grain, 10% corn cobs, 5% lactating cow pellets (12% minimum total crude protein) at approximately 45 kg/cow.day. Feed was distributed at approximately 0800 and 1400 h with half of their daily allocation fed out in each feed. The cows had access to alfalfa silage round bales in mid March 2009. Cows were provided both native and improved (alfalfa, sorghum, cow pea) pastures for approximately 10 to 20% of their daily ration. Water was available via two 720 L troughs at the feed pad and a 330 L trough at the milking parlour.

All observations were converted from animal numbers to proportion of the herd. Percentage of cows recorded for each panting score was transformed to a normalised distribution using squared root arcsine transformation before being statistically analysed. The mean panting score was then calculated based on the method of Gaughan *et al*. (2008). The THI and HLI were calculated and the means (THI_{MEAN} and HLI_{MEAN}) were computed for corresponding values between 1100 and 1600 h. For statistical purposes THI_{MEAN} was categorised as; Thermoneutral = THI_{MEAN} <72; Moderate = THI_{MEAN} is 72 to 78; Hot = THI_{MEAN} is 78.1 to 86; and Extreme = THI_{MEAN} >86 (adapted from Livestock Conservation Incorporated, (1970)). HLI_{MEAN} was categorised as; Thermoneutral = HLI_{MEAN} <64.0; Moderate = HLI_{MEAN} is 64.1 – 70.0; Hot = HLI_{MEAN} is

70.1 – 76.0; and Extreme = HLI_{MEAN} >76 (adapted from Gaughan *et al*., 2008).

Milk production was categorised by days in milk (DIM): 1 = <56 d, 2 = 57 to 100 d, 3 = 101 to 224 d, 4 = >224 d., and level of milk production: 1 = <12 kg/d, 2 = >12 to 20 kg/d, 3 = >20 to 30 kg/d, 4 = >30 kg/d. Cows were excluded if any anomalies existed in their milk production data.

The data were analysed using PROC GLM and PROC MIXED (SAS Inst. Inc., Cary, NC). Milk production was analysed using repeated measures ANOVA. The model included the effects of HLI_{MEAN} and THI_{MEAN} categories, DIM category, total milk production category, month, time of day and day as fixed effects. The specific term for the repeated statement was cow within day. When significance ($P < 0.05$) was indicated, the means were separated by using Tukey's Studentized range test.

The transformed panting scores, and mean panting scores were analysed using a repeated measures model which included day, time of day, month, HLI_{MEAN} category, THI_{MEAN} category DIM category, and total milk production category as fixed effects and cow as a random effect. The specified term for the repeated statement was day. The between month differences in the climatic variables were analysed using PROC GLM. Chi Square analysis was used to determine the differences between months for the number of cows lying or standing. This type of analysis was undertaken due to variation in herd size from month to month.

Results

Both THI and HLI were used to assess the effects of climate on MPS and MP.

A month effect was seen in MPS (P<0.0001); being highest during February (1.46 ± 0.05). When assessed on a daily basis against HLI and THI the R^2 for MPS were low (0.1701). This indicates that the use of spot measures of panting score may be an inappropriate measure of heat load on dairy cattle.

Time budgets were not assessed in this study; however cow posture and location data gave an insight into possible areas of MP loss. The proportion of cows standing was highest in December, as were THI and HLI values (P<0.0001). Total cows standing followed a similar trend as the THI and HLI; as the weather cooled; fewer cows were observed standing (Table 1).

Table 1. Total proportion of cows standing and THI and HLI monthly averages (2008/09)

Month	TS[1]	THI[2]	HLI[3]
December	83.2[a]	81.45 ± 0.40[a]	94.32 ± 1.20[a]
January	79.6[a]	76.97 ± 0.32[b]	86.5 ± 0.97[b]
February	66.2[b]	76.19 ± 0.36[b,c]	84.12 ± 1.09[b]
March	67.3[b]	75.50 ± 0.40[c]	84.41 ± 1.20[b]
June/July	69.4[b]	53.70 ± 5.91[d]	46.30 ± 5.88[c]

[1]Where TS is proportion of cows standing,

[2]*THI = 0.8 x T_A + RH/100 – (T_A – 14.4) + 46.4; where RH is expressed as a percentage;*

[3]*$HLI_{BG>25}$ = 8.62 + (0.38 x RH) + (1.55 x BGT) – (0.5 x WS) + [$e^{2.4 - WS}$], and $HLI_{BG<25}$ = 10.66 + (0.28 x RH) + (1.3 x BGT) – WS; where e is the base of the natural logarithm (approximate value of e = 2.71828) (Gaughan et al. 2008)*

[abcd] *Means within a column with the same superscript are not significantly different (P > 0.05)*

There was considerable variation in MP between cows. Milk production also showed a regression value of 0.35 between two successive days. This suggested that there are a number of other factors affecting MP which cannot be explained by either THI or HLI.

There was an inverse relationship between HLI category and daily MP; i.e. MP was highest at TNC and lowest at EXE. There were inconsistencies in the relationship between THI category and MP. As expected MP was lowest during EXE, however it was higher during MOD and HOT than during TNC (Table 2).

Table 2. HLI_{MEAN} and THI_{MEAN} category and average daily MP (kg) on a herd basis (2008/09)

Climate index category	Daily milk production HLI_{MEAN} (kg)[1]	Daily milk production THI_{MEAN} (kg)[2]
TNC	21.85 ± 0.09^{a}	20.66 ± 0.30^{a}
MOD	21.75 ± 0.09^{a}	21.43 ± 0.16^{b}
HOT	21.34 ± 0.09^{b}	21.55 ± 0.16^{b}
EXE	21.18 ± 0.06^{b}	19.22 ± 0.65^{a}

[1] Thermoneutral (TNC), HLI_{MEAN} <64.0; (2) moderate (MOD), HLI_{MEAN} 64.1 – 70.0; (3) hot (HOT), HLI_{MEAN} is 70.1 – 76.0; and (4) extreme (EXE), HLI_{MEAN} >76.

[2] Thermoneutral (TNC), THI_{MEAN} <72.0; (2) moderate (MOD), THI_{MEAN} 72.1 – 78.0; (3) hot (HOT), HLI_{MEAN} is 78.1 – 86.0; and (4) extreme (EXE), HLI_{MEAN} >86.

Means within a column with the same superscript are not significantly different (P > 0.05)

The relationship between MP categories of TNC and EXE for the HLI_{MEAN} are presented (Table 3). Similar results (not shown) were obtained using THI_{MEAN} categories. The data indicates that higher producing cows are more susceptible to extreme climatic conditions.

Table 3. Milk production (MP) (kg/cow/d) of cows classified as high or low production cows under thermoneutral (TNC) and extreme (EXE) HLI_{MEAN} categories (2008/09)

MP category[2]	TNC[1]	EXE[1]	SE	P-value
1	$9.97^{a,c}$	$9.86^{a,c}$	0.16	P>0.05
2	$16.88^{a,d}$	$16.63^{a,d}$	0.14	P>0.05
3	$24.04^{a,e}$	$23.35^{b,e}$	0.12	P<0.0001
4	$36.14^{a,f}$	$34.38^{b,f}$	0.22	P<0.0001

[1] Thermoneutral (TNC), HLI_{MEAN} <64.0; (4) extreme (EXE), HLI_{MEAN} >76. [2] Milk Production Categories; 1 = < 12 kg milk/day, 2 = > 12 & < 20 kg milk/day, 3 = > 20 & < 30 kg milk/day, 4 = > 30 kg milk/day.

[ab]Means within a row with the same superscript are not significantly different (P > 0.05); [cdef]Means within a column with the same superscript are not significantly different (P > 0.05)

Discussion

The HLI and THI provided an adequate assessment of the thermal load on the cows under TNC and EXT conditions. However, THI did not accurately predict the change in MP when cows were exposed to moderate and hot conditions. The low R^2 values for the prediction of MP suggest that neither index is ideal for dairy cows housed outside. Therefore there is a need for a new index to be developed or the existing indices to be modified.

Time budget is another area that may explain MP losses. Highest number of total cows standing was in December and standing in shade was January. THI and HLI values were highest in December. This is an area that will be further investigated.

It is also evident that there is a need to assess cows individually (e.g. on the basis of days in milk, level of milk production). A whole herd approach is not sufficient as mean values will not adequately account for cows on the extremes, i.e. those with some heat tolerance compared with those with limited tolerance. The HLI (beef cattle) accounts for animal variation (level of production, days in feedlot, health status, breed, coat colour) (Gaughan *et al*. 2008), and a similar approach is necessary for dairy cows. However, the HLI seems to better account for MP losses as conditions move from TNC to EXE.

The HLI in addition to relative humidity and ambient temperature incorporates wind speed and solar load (black globe temperature). These two factors are known to have major effects on the animals' ability to dissipate heat. Berman (2005) noted that increased air velocity increased intermediate heat stress threshold temperatures; whereas humidity decreased threshold temperatures. This may explain some of the differences in the predictive abilities of HLI and THI on MP.

However there are inconsistencies between studies. For example, Verwoerd *et al*. (2006) concluded that an increase in body temperature (T_B) could not be explained using THI. Legates *et al*. (1991) concluded that T_A had the biggest influence on respiration rate and T_B, followed by solar radiation and, to a lesser extent, air movement and vapour pressure. In addition Eigenberg *et al*. (2005) found that T_A and solar radiation had the largest contribution toward respiration rate, with 51.4% and 32.2% respectively, followed by dew point temperature (8.9%), WS (5.7%) and body weight (2%). A decline in MP and reproductive performance of Holstein cows was reported by Berman *et al*. (1985) when T_A reach 25 to 26°C. In the current study, T_A was greater than 26°C throughout the summer. This would indicate that even at TNC (in the current study), cows were likely under some degree of heat load.

The lack of a response of MP to increased heat load in the current study was unexpected. West *et al*. (2003) established that on a given day DMI and MP were affected by both THI and mean T_A over the 2 days prior. It is possible that by analysing the present study from this perspective; i.e. removing the physiological time lag; a greater correlation between MP and the climatic variables may be seen. Calculation of accumulated heat load (AHL) (Gaughan *et al*. 2008) and THI hours (Hahn & Mader 1997) may improve our understanding of the cumulative effects of continuous heat load on dairy cows. The accumulative effects of heat load will need to be accounted for in the development of a new model.

This study outlined that neither the THI nor HLI are good indicators of MP losses in their current form. It would seem that both of these indices are able to explain cow behaviour to an extent. However the HLI appears to be a better indicator given its use of solar radiation and wind effects.

Acknowledgements

We would like to acknowledge the Department of Agriculture, Forestry and Fisheries for funding the current research and the UQ Gatton Dairy staff.

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ENVIRONMENTAL IMPACT OF INCREASING STOCKING RATE OR MILK YIELD PER COW OF ON A PASTURE-BASED DAIRY FARM SYSTEM

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Abstract

The comparative environmental impact of increasing stocking rate or milk yield per cow on Australian pasture-based dairies is of interest. To investigate this, data from a 2-year farmlet study conducted as a complete randomized design with 2 levels of stocking rate (2.5 and 3.8 cows/ha) and 2 levels of milk yield per cow (initial target of 6,000 and 9,000 kg/cow.lactation) were used. A "farm gate" N balance (N outputs – N inputs) and the total amount of greenhouse gas emissions (t CO_2 eq) were estimated at the whole farm level. The control (lower stocking rate and milk yield per cow), high stocking rate, high milk per cow and high stocking rate and milk per cow systems produced 444, 517, 485 and 663 kg of N surplus and 20.3, 28.8, 21 and 30.5 t CO_2 eq per ha, respectively. All systems showed a higher environmental impact per ha than the control. Increasing stocking rate or milk yield per cow caused similar N pollution, whereas only increasing milk yield per cow decreased greenhouse gas emissions per unit of milksolids.

Introduction

The rising costs of land and water, and declining terms of trade are increasing the pressure on dairy farmers in Australia to increase milk per ha from home-grown feed. Fariña *et al.* (2010) conducted a pasture-based farmlet study and found that an increase in stocking rate proved to be a more effective way to increase milk production per ha than an increase in milk yield per cow, both in terms of animal response and efficiency of use of supplements. However, the intensification of pasture-based dairies can cause a potential environmental impact, mainly through greater nutrients pollution and greenhouse gas emissions (Basset-Mens *et al.* 2009). There are no studies that have compared the effect of increasing stocking rate or milk yield per cow on the nitrogen (N) balance or greenhouse gas emissions of a farm. The potential N pollution on a farm is determined by the balance between N inputs and N outputs, which has been defined as the farm-gate N balance (Oenema *et al.* 2003; Gourley *et al.* 2007). In terms of greenhouse gas emissions, a recent review of 20 metabolic studies with dairy cows has found that methane emissions per unit of milk production and energy intake can be reduced by increasing milk yield per cow (Yan *et al.* 2010). However, it is still unclear if this relationship holds for pasture-based whole farm systems, and how it is affected by an increasing stocking rate.

The objective of this study was to conduct a whole farm comparison, using data from a previous farmlet study, of the environmental impact of increasing milk production per ha by increasing either stocking rate, milk yield per cow, or both, in terms of N balance and greenhouse gas emissions.

Materials and methods

A brief description of the farmlet study is provided here, and details have been presented by Fariña *et al.* (2010). The experiment was undertaken at No. 9 dairy, Elizabeth Macarthur Agricultural Institute, Department of Primary Industries, Menangle, NSW, Australia between March 2006 and March 2008. The experimental area was sown to perennial ryegrass (*Lolium perenne* L.) and kikuyu grass (*Penisetum clandestinum* Hochst. ex Chiov.), which were both oversown (direct drill) with short-rotation ryegrass (*Lolium multiflorum* Lam.) every autumn. All the area was under full irrigation, except during summer, when less than 25% of the total farm area was irrigated. The study was conducted as a complete randomized design with 2 levels of stocking rate (2.5 and 3.8 cows/ha) by 2 levels of milk yield per cow (initial target of 6,000 and 9,000 kg/cow.lactation) treatments. The treatments (farmlets) were control (**C**), high stocking rate (**HSR**); high milk yield (**HMY**); high stocking rate and high milk yield (**HH**). The four systems comprised 30 cows each, and were compared under the same management and grazing decision rules. The diet was grazed pasture, supplemented with pellets and conserved fodder as required to achieve the target milk yield. Results of the 2 years of study are presented in Table 1.

The N balance at the farm-gate level was estimated following the international guidelines proposed by Oenema *et al.* (2003), and revised for Australian conditions by Gourley *et al.* (2007). Nitrogen imported to the farm in supplements was estimated from the mean crude protein (CP) from analysis of samples. Nitrogen inputs from applied fertiliser were calculated from their N content. Nitrogen in irrigation water was obtained from analysis of N in seasonally pooled water samples, obtained during a parallel study that used the same irrigation water (Kabore 2008). The value of 8 kg N/ha.year was used for the N input from rainfall based on the results of a multiple year field study from a region in Australia with similar rainfall (Eckard *et al.* 2007). The N input from replacement heifers introduced to the herd and N output from cull cows was estimated assuming 0.024 kg N/ kg live weight (Humphreys *et al.* 2008). Nitrogen removed in milk was estimated by multiplying milk yield by milk protein and by 6.25 (16% of N in protein) and milk urea content. Milk protein was analysed from fortnightly samples. Milk urea was estimated from measurements obtained from the same herd during the whole previous lactation (Pedernera *et al.* 2008).

For the estimation of farm greenhouse gas emission, the Dairy Greenhouse Gas Abatement Strategies (DGAS) calculator, developed by Christie *et al.* (2009) in Tasmania, was used. The model is based upon the methodology established by the National Greenhouse Gas Inventory Committee in 2007. Carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) - are multiplied by 1, 21 and 310, respectively, to convert them to tonnes of CO_2 equivalents. Data were fitted with linear mixed models and all parameters were estimated using the Restricted Maximum Likelihood (REML) procedure of GENSTAT for WINDOWS version 11 (Payne *et al.* 2008). Where possible, the year was considered a random effect, as the environmental conditions are assumed to vary randomly from year to year.

Table 1. Mean annual milk yield (L per ha and per cow), pasture yield (t DM/ha), farm-gate N balance (kg N/ha) and greenhouse gas emissions(t CO2 eq) for the control (C), high stocking rate (HSR), high milk yield per cow (HMY) and high stocking rate and milk yield per cow (HH) systems

	Treatment					
	C	HSR	HMY	HH	s.e.d.	*P* -value
Milk per cow (L / 305 days)	6,991b	6,895b	7,759a	7,501a	0.3	<0.05
Milk per ha (L)	20,895c	31,143b	22,975c	34,583a	1.1	<0.001
Pasture utilised (t DM/ha)	11.1	11.1	11.2	11.2	0.8	1.00
N inputs (kg N/ha)						
Supplements	144d	265b	195c	437a	18	<0.05
Fertilisers	380	380	380	380	0	1
Irrigation	27	27	27	26	0.5	0.5
Rainfall	8	8	8	8	0	1
Heifers	7	10	7	10		
Total	566d	691b	617c	862a	18	<0.05
N outputs (kg N/ha)						
Milk protein	111d	161b	123c	182a	6	<0.05
Milk urea	1.4d	2.0c	2.2b	3.3a	0.1	<0.001
Culled cows	9	14	9	14		
Total	122d	176b	134c	199a	6	<0.05
N surplus (kg N/ha)	444c	514b	483b	663a	17	<0.05
Greenhouse gas emissions (t CO_2 eq)						
Pre-farm	331d	566b	404c	754a	30	<0.05
On-farm CO_2	240	240	240	240	0	1
On-farm CH_4	1,594c	2,388b	1,610c	2,442a	12	<0.001
On-farm N_2O	684c	851b	690c	859a	5	<0.001
Total per farm	2,848d	4,045b	2,944c	4,294a	36	<0.001
Total per ha	20.3	28.8	21.0	30.5		
Total per t milk	0.97	0.93	0.92	0.88	0.03	0.18
Total per t milksolids	12.9a	12.6ab	12.0bc	11.9bc	0.4	0.05

Results

The main source of differences in N inputs was the supplementary feed, which was 84, 33 and 197% higher ($P < 0.05$) for the HSR, HMY and HH systems, respectively, than the control (Table1). The N outputs were in direct proportion to the milk produced per hectare. Stocking rate and milk yield per cow (HSR and HMY) caused a similar increase ($P < 0.05$) in N surplus, whereas HH reached a higher ($P < 0.05$) value than these (Table 1). The HSR system produced 0.22 kg N surplus/kg of milksolids, and the control, HMY and HH system produced 0.28, 0.27 and 0.29 kg N surplus/kg of milksolids, respectively, although no significant differences were detected.

Increasing stocking rate (HSR), milk yield per cow (HMY) or both (HH) resulted in 42, 3 and 51% higher (P < 0.001) total greenhouse gas emissions, respectively, than the control (Table 1). These differences were mainly driven by the differences in total on-farm emissions of methane (P < 0.001) and, to a lesser extent, in pre-farm emissions (P < 0.05), with HH having the highest value due to the high use of brought-in feeds. The on-farm N_20 emissions were only higher (P < 0.001) than control for the farm systems with high stocking rate (HSR and HH) (Table 1). Compared to the control, the total emissions per unit of milksolids decreased (P = 0.05) when milk yield per cow was increased, either at a low (HMY) or high (HH) stocking rate, but not when only stocking rate (HSR) was increased (Table 1).

Discussion

All intensification systems produced a significantly higher total N surplus and greenhouse gas emissions than the control in absolute terms, with HH showing the highest values, followed by HSR and HMY. For all systems, further reductions in N surplus could have been achieved by reducing the amount of supplements used and replacing them with more home-grown feed, which could have been utilised from the same amount of N fertilizer used. Although, this pathway was restricted in this study by the limited access to irrigation during summer.The range of farm-gate N surpluses in this study (444 to 663 kg N/ha.year) was higher than in other farm studies (Table 2). However, all studies shown in Table 2 maintain a consistent ratio of N surplus to N input, which is similar to the systems evaluated in this study. The N surplus per unit of milk reported in the present study (0.22 to 0.33 kg N/kg milksolids) is above studies with N inputs below 180 kg N/ha.year (0.07 to 0.09 kg N/kg milksolids) (Ledgard *et al.* 1999; Haas *et al.* 2001) but similar or below other studies with N inputs above 180 kg N/ha.year (Table 2). The differences between systems in terms of total emissions per ha were in direct proportion to their milk yield per ha. On the other hand, systems with higher milk yield per cow (HH and HMY) showed lower emissions per kg of milksolids. These cows were able to dilute more the "fixed" amount of methane produced to cover maintenance requirements. In line with these findings, Christie *et al.* (2009) and Basset-Mens *et al.* (2009) have shown for Australian and New Zealand pasture-based dairies, respectively, that farm intensification tended to reduce the greenhouse gas emissions per unit of milk produced. The range of total greenhouse gas emissions per unit of milk achieved in the present study (0.88 to 0.97 kg CO_2 eq/ kg of milk) was similar to the average reported for pasture-based systems in New Zealand (0.85-0.93 kg CO_2 eq/ kg of milk) (Basset-Mens *et al.* 2009; Beukes *et al.* 2009) but lower than studies in dairy farms in Sweden (Cederberg 1998), Germany (Haas *et al.* 2001) and the Netherlands (Thomassen *et al.* 2008) which reported 1.1, 1.3 and 1.4 kg CO_2 eq/ kg of milk, respectively. All intensification strategies evaluated here increased the environmental impact at the farm level, notwithstanding that the control system represented a dairy farm well above the industry average level of intensification. It is possible to conclude that increasing either stocking rate or milk yield per cow on Australian pastured-based dairies could cause similar potential N pollution.

To determine the actual risk of impact on the environment, the distribution of that surplus within a farm-system will need to be assessed. This study also demonstrated that less greenhouse gas emissions per unit of milk can be achieved by increasing milk yield per cow.

Table 2. Farm-gate N balance components (kg N/ha.year) as average of treatments from farm studies

	Kg N/ha.year				
Country	**Input**	**Output**	**Surplus**	**Surplus / input**	**References**
Australia	684	158	526	0.77	Fariña *et al.* (present study)
Netherlands	415	107	308	0.73	Aarts *et al.*(1992); Hanegraaf and den Boer (2003); Onenema *et al.* (2003)
Belgium	367	131	236	0.64	Mulier *et al.* (2003)
England	337	67	270	0.80	Jarvis (1993)
New Zealand	336	99	237	0.67	Ledgard *et al.*(1999); Ledgard and Luo(2008)
Ireland	286	83	203	0.70	Humpreys *et al.* (2008)
Australia	263	87	176	0.64	Eckard *et al.* (2007)
Switzerland	184	43	141	0.77	Thomet and Pitt (1997)
Germany	128	48	80	0.63	Haas *et al.* (2001)

Acknowledgements

The authors would like to acknowledge the assistance of Mrs. Amy Rogers and the EMAI N$^{o.}$9 dairy staff.

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QUANTIFYING THE FREQUENCY OF SUCCESSFUL REATTACHMENT (AFTER 1 vs. 3 HOURS) OF UN-MILKED QUARTERS WITH A PROTOTYPE AMS

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Abstract

During 2009 and early 2010 FutureDairy has been testing a new prototype AMS. This new prototype is expected to be capable of carrying out in excess of 480 milkings per day. In the event of an incomplete milking (1st attempt) there is an opportunity for cows to be automatically drafted back for re-milking (1hr treatment), or to draft cows to a feeding area (3hr treatment) to extend the interval between the 1st and 2nd attempt at milking (1st attempt milking incomplete, milking incomplete cows at 2st attempt). To propose a solution about how best to manage incompletely milked cows and ideal dairy layouts this work was designed to measure the percentage of incompletely milked cows in the 1st attempt which had a successful milking in the 2nd attempt. During the 4 day trial 100 cows were fetched daily to the dairy for an observed milking. There was no significant difference found between the frequencies of successful attachment in the 2nd attempt between the 1hr and 3hr treatment. In this study it was found that cows with a higher average 7-day production level had a higher proportion of completed milkings at the 2nd attempt. It was concluded that there was no measurable performance differences between the 1hr and 3hr treatments. These results indicated a potential level of flexibility with management of incompletely milked cows and dairy layout designs.

Introduction

In 1992 the first Automatic Milking System (AMS) was implemented in The Netherlands. The first systems were installed on family farms, with 50-150 dairy cows as a response to the high labour cost (Svennersten-Sjaunja and Pettersson 2008). At the end of 2003, worldwide some 2,200 commercial farms were using one or more AMS to milk their cows (Koning and Rodenburg 2004). Currently, there are approximately 8,000 AMS units on 5,000 farms worldwide (Svennersten-Sjaunja and Pettersson 2008; Andre *et al*. 2010). This shows the rapid increase in the number of farms with AMS. However the first installations were designed for small family farms. These days with continuous technological advancement and increased management skills of AMS, larger farms with more than 500 cows are adopting the system (Svennersten-Sjaunja and Pettersson 2008). It is known that a greater investment is needed when installing AMS on farm (Bijl, Kooistra and Hogeveen 2007; Andre *et al*. 2010). From the economic efficiency point of view, maximizing the milk production per unit would make the system more viable (Davis *et al*. 2008; Andre *et al*. 2010). Milk yield, milking frequency, inter-milking interval, teat-cup attachment success rate, and length of the milking procedure are important functional efficiency aspects of AMS (Gygax *et al*. 2007). When a teat cup is not attached to an intended teat, the cow can leave the AMS unmilked in that quarter. A study with an average attachment failure rate of 7.6% showed that, when accounting for the effect of an extended milking interval, milk production for the affected quarter was 26% lower than the regular milkings (Bach and Busto 2005). This shows the importance of accurate attachment.

During 2009 and early 2010 FutureDairy has been testing a new prototype AMS. This new prototype is expected to be capable of carrying out in excess of 480 milkings per day. For a herd of cows milking twice a day this would equate to at least 240 cows per robot. In addition, it is expected that this new prototype will be priced comparably with conventional milking equipment. While using this system one question needs to be answered in regard to the frequency of incompletely milked cows. In the event of an incomplete milking there is an opportunity for cows to be automatically drafted back to the waiting area for another milking. Depending on the dairy layout there may be an opportunity to draft cows to a feeding area to extend the interval between the 1st and 2nd attempt at milking. The subsequent success rate of reattachment after an incomplete milking in these two different situations has not yet been quantified. To propose a solution about how best to manage incompletely milked cows and ideal dairy layouts the results of this proposed study will be beneficial. Without observations no conclusion can be made whether or not it is better to attempt attachment for one or more unmilked quarter right after the incomplete milking (within an hour) or to send the cows first into a feed area before returning them, back to the system, after 3 hours.

Materials and methods

During the 4-day trial the cows were managed and grazed as the standard procedure. They were allocated an accurate allowance of pasture/feed over each 12-hour period. For the 4 day trial there were 4 allocations of pasture grazed during each day and 4 allocations of feed made available each night on a sacrifice feeding area. Pelleted concentrate was available to cows upon entry to the system which encouraged voluntary cow traffic and correct cow positioning. During the 4 day trial cows were fetched to the dairy for milking. Each day approximately 100 cows were milked, this was not necessarily the same 100 cows each day but many cows were common to at least 2 days of data collection. For the purpose of this document the "observed milking" will be called **1st attempt** and any cows that did not have all cups successfully attached at the **1st attempt** will be called **incomplete** (conversely if all cups were attached the milked is termed **complete**). Any cows that were incomplete at 1st attempt were then returned for a **2nd attempt** after either a 1 or 3 hour waiting period. In the first 2 days (May, 24 and 25 2010; "**1hr**" treatment) cows were milked in batches of 50 cows. This allowed us to return incomplete cows back to the system within an hour simulating an automatic drafting system that could generate a similar result with voluntary cow traffic. In the last 2 days (May, 26 and 27 2010; "**3hr**" treatment) of the trial, all cows received their first milking in 1 batch. The incomplete cows were returned from the feedpad to the waiting yard at around 3 hours after milking (minimum 2 hours). This treatment was designed to simulate the situation where cows gain access to a feeding area before being drafted back to the waiting yard as they exit the feeding area. Between the observed milking sessions cows were able to voluntarily milk themselves through one of 2 VMS (Voluntary Milking System; DeLaval AMS units).

Key responses measured in this study were the percentage of cows incomplete at 1st attempt which were subsequently complete at 2nd attempt. The 2 treatments were compared and statistically analysed at the success rates of attachments. Electronic data collected by the VMSClient management program was used to generate milking interval time after an incomplete milking and the success of reattachment after been sent back to the AMS. Analyses were carried out to investigate the relationship between treatment and success rate at 2nd attempt to make a decision on what to do with cows that were incomplete after 1st attempt. Beside this main objective data is electronically collected to investigate the relation in incompletes with, stage of lactation (days in milk; DIM), parity (lactation number), cow production, yield per milking and milking interval leading up to 1st attempt. This part of the investigation may help us to determine different management strategies that might be most suitable for different groups of cows. For example, success at 2nd attempt may be greater for an early lactation cow if she is returned to the waiting yard immediately, prior to her udder starting to become engorged with milk again.

Data was analysed with GenStat 12th Edition. The impact of interval between attempts on the number of success/failures, was compared by a two by two contingency table and analysed following the Chi-Square or Fishers exact test. The impact of different variables on the success rate was analysed with the following generalized linear mixed model (GLMM) P (complete milking): Fixed (Constant + Treat + Days in milk + Interval incomplete + Lactation number + Average milk yield 7 days) + Random (Animal number) as also: P (complete milking): Fixed (Constant + Treat + Days in milk + Lactation number + Milking interval + Milk yield of observed milking) + Random (Animal number)

Results

The actual interval between 1st and 2nd attempt averaged 1 hour and 3 minutes and 3 hours and 30 minutes for the 1hr and 3hr treatments respectively. The results of the study show in Table 1, shows that when sending cows directly back to the waiting area (1hr treatment), on average 47.5% of the quarters that were incomplete at 1st attempt were successfully attached at 2nd attempt. When cows were subject to the 3hr treatment, 39.1% were successfully reattached at the 2nd attempt. The 8.4% difference was not significant (P=0.330). Including the results of both the 1st and 2nd attempts the total proportion of cows which were milked completely was not different between the two treatments (P=0.262). During the study it was found that when the robot did not attach the teat cup to the target teat, which is recognized as a mixed action, the number of complete milkings was impacted significantly (P=0.001). The unequal number of cows and number of incomplete milkings between the 2 different treatments was, as expected, not significant.

Table 1: Proportion of incomplete at 1st attempt, successfully reattached quarters at 2nd attempt and total of completely milked cows after 2nd attempt

Treat	*Incomplete[1]*	*Reattachment of incomplete[2]*	*Successfully attached[3]*
1 hr	18.87	47.50	90.09
3 hr	21.30	39.13	87.04
Total	20.09	43.02	88.55

When taking a closer look at the results it was noticed that a higher proportion of the incomplete teats at 1st attempt were rear quarters (68% vs. 32% front quarters; P< 0.001). Table **2** shows that with the 1hr treatment, at the 2nd attempt the rear quarters (that were incomplete at 1st attempt) were more likely to be attached than the front quarters 52% and 47.1% for the left rear (LR) and right rear (RR) quarters respectively. Only 18.2% and 28.6% of the left front (LF) and right front (RF) quarters respectively were attached at the 2nd attempt. The difference between complete at 2nd attempt between the front and rear quartes, was significant ($P<0.05$) for the 1hr treatment but not the 3hr treatment. There was no significant ($P=0.063$) treatment effect on the proportion successful attachment of combined rear teats (LR and RR) in the 2nd attempt (difference in combined rear teats 1hr vs. 3hr treatment 17.05%).

Table 2: Reattachment success rate after an incomplete milking per quarter

Treat	*LR*	*RR*	*LF*	*RF*
1 (1 hr)	52.0	47.1	18.2	28.6
2 (3 hr)	28.6	36.4	25.0	40.0

When having a closer look at successful attachment at 2nd attempt in different situations, for example days in milk (DIM), average 7 day production, parity, milking interval (before 1st attempt) and treats (1hr and 3hr treatment) some significance was found. The milking interval between the 1st and 2nd attempt as also the parity of the cow, DIM and milking interval before the 1st attempt did not have a significant influence on the number of cows completely milked after the 2nd attempt. The average 7 day production however did affect the model significantly ($P<0.001$). As already expected by results of the non significant effect of milking interval between the 1st and 2nd attempt, the 1hr and 3hr treatment did not effect the model significantly ($P=0.344$). See Figure 2 for the fitted logistic regression model.

When analyzing the data of all the milked cows for the total number of successful milkings after the 2nd attempt, in relation to the situation(s) described above, milk yield at 1st attempt, milking interval before 1st attempt and days in milk were all significant factors ($P<0.05$) in the model.

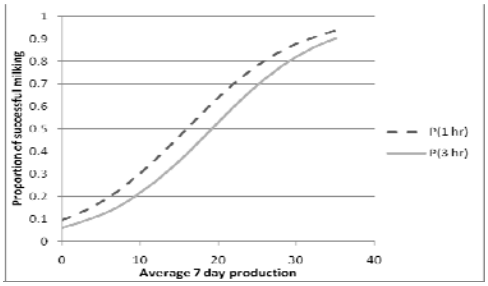

Figure 2: Fitted logistic regression model for proportion of complete at 2nd attempt related to 7 day average production level and 1hr and 3hr treatment

With an increasing stage of lactation and milk yield per milking the proportion of successful milkings after the 2nd attempt increased, but an increasing initial milking interval before the 1st attempt was incline to result in a lower proportion of successful milkings after the 2nd attempt.

Discussion

It first needs to be concluded that the data shown in this study are based at a new prototype AMS. Due to ongoing upgrades of the system towards a commercial product, it is anticipated that the capabilities and accuracy of the technology will improve. This means that the outcomes of this study may become redundant as improvements are recognised.

There was no significant difference found between the the frequency of successful attachment at 2nd attempt in the 1hr and 3hr treatment in the prototype AMS. It is possible that the lack of difference found between the 1hr and 3hr treatment was that the additional 2.5 hour waiting period (for the 3hr treatment) was not long enough to cause any dramatic changes in udder conformation. Additional information regarding udder conformation and its impact on both 1st and 2nd attempt attachment success has not been presented here but will be investigated. It was shown that the back quarters were more likely to be not attached which may be due to a number of cows that had very close back teats which makes automatic cup attachment more difficult. The results showed that the prototype AMS was more likely (although not significant) to successfully attach the back teats compared to the front teats at the 2nd attempt.

In this study it was found that cows with a higher, 7 day average production (rolling average), had a higher total proportion of complete milkings after the 2nd attempt. The higher production level would likely be associated with a fuller and more distended udder which would likely make it easier for any automatic cup attachment device to locate the teats easier. The significant impact on the model of milk yield per milking, milking interval before 1st attempt and days in milk on attachment success was somewhat surprising. It was found that with an increasing stage of lactation and milk yield per milking the proportion of successful milkings increased. Beside this, an increasing initial milking interval was inclined to result in a lower proportion of successful milkings. It makes sense that a higher production level per milking results in a more distended udder, making attachment easier. However, in contrast the results also showed that the proportion of complete milkings decreased with higher initial milking intervals. It would be expected that these longer intervals should be associated with higher level of udder fill and therefore a higher likelihood of successful attachment. This data requires further investigation. It would also be expected that attachment difficulty would increase with higher days in milk due to the udder being more flaccid. This data also requires further investigation.

It can be concluded that the system showed no “success” differences between milking cows in the 1hr or 3hr treatment at the 2nd attempt. This suggests that there is a level of flexibility available in designing the dairy layout. Cows can either be sent back to the pre-milking waiting yard directly after an incomplete milking, or after visiting a feedpad, without any significant impact on the chance of subsequent attachment success. However, it is also recognised that the initial success level of approximately 80% of cows is expected to improve with software and hardware upgrades of the prototype technology imminent. For this reason the direct results of this work may become redundant but have been important to allow further development and understanding of the application of the technology on farm.

Acknowledgments

This work was carried out within the FutureDairy program. We wish to acknowledge the funders Dairy Australia, DeLaval, Industry and Investment NSW and The University of Sydney. We would also like to thank Mikael Karttunen for his technical support of the new prototype AMS and the FutureDairy team for their assistance.

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EFFECTS OF CARBOHYDRATES AND HISTIDINE ON RUMINAL PH AND FERMENTATION PRODUCTS DURING AN INDUCED ACIDOSIS PROTOCOL

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Abstract

This study investigated the effects of grain, fructose and histidine on ruminal pH and fermentation products in dairy cattle. Thirty Holstein heifers were randomly allocated into 5 treatments; i) Control (no grain), ii) Grain (1.2% liveweight (LW) rolled triticale)(GR), iii) Grain (0.8% LW) + fructose (0.4% LW)(FR), iv) GR + histidine (6g/hd) and v) FR + histidine in an incomplete factorial design. All heifers were fed 1kg of grain daily with ad lib access to silage and lucerne hay prior to challenge date. Feed was withheld for 14 hours immediately before challenge date, on which heifers were fed 200g of lucerne hay, and immediately after their treatment in the intent of inducing a subclinical acidosis. Rumen samples were collected 5 minutes after treatment ingestion, 60 minutes later and at 3 further 50 minute intervals. Samples were analysed for ruminal pH immediately and later for ammonia, histamine, volatile fatty acids and D- and L-lactate concentrations. The substitution of fructose for some grain resulted in a marked drop in ruminal pH. Ruminal histamine and volatile fatty acid concentrations increased with the addition of grain and grain plus fructose, irrespective of the presence of histidine. D- and L-lactate concentrations were greater in the FR (9.2 and 4.9 mM) compared to the GR (0.2 and 0.1 mM) and control groups (0.1 and 0.1 mM). The addition of histidine did not have a marked affect on ruminal fermentation. In summary the substitution of some fructose for grain altered ruminal fermentation products in dairy heifers.

Introduction

Ruminal lactic acidosis and lameness are two of the most important challenges facing the Australian dairy industry. Acidosis is commonly associated with the consumption of large amounts of readily fermentable carbohydrates (Bramley *et al* 2008). The clinical form can result in rumenitis, metabolic acidosis, lameness, hepatic abscessation, pneumonia and death (Lean *et al* 2000). Of greater economic importance are losses that result from subclinical acidosis in dairy cattle, particularly those fed on pasture (Lean *et al* 2000). Bramley *et al* (2008) found that herds with a high prevalence of acidotic cows also had a high prevalence of lameness (28% of cows).

Histidine is an amino acid present in high concentrations in kikuyu and ryegrass (Reeves 1998). When ruminal pH is low, histidine is decarboxylated by the bacteria *Allisonella histaminiformans*, to histamine (Garner *et al* 2002). Ruminal histamine accumulation has long been suspected to be related to the onset of laminitis (Nocek 1997) and has been suggested to be an indicator of acidosis (Rabiee *et al* 2009).

Plants store excess carbohydrates as either starches or fructans. The majority of tropical (C4) pasture plants such as kikuyu store carbohydrates in the form of starch; whilst, most cool season (C3) pasture plants such as ryegrass, store carbohydrates as fructans (Pollock and Cairns 1991). Fructans are polymers of β-D-fructose (Roberfroid and Delzenne 1998) and can form up to 70% of the water soluble content of grasses (McGrath 1988). Thoefner *et al* (2004) showed fructan administered as an oligofructose bolus induced laminitis and acidosis in dairy cattle. The aim of this study was to provide insights into the role of forages in acidosis and laminitis, through examining the effect of the amino acid histidine, and fructose in dairy cattle in the presence of increased starch access. The hypothesis was that administered fructose and histidine concentrations representative of those of pasture would increase the risk of subclinical acidosis in dairy heifers fed a grain ration.

Materials and methods

Thirty non-pregnant Holstein heifers less than 18 months of age (359.3 ± 47.3 kg liveweight (LW)) were randomly allocated into 5 treatment groups; i) Control (no grain), ii) Grain (1.2% LW rolled triticale *cv* Berkshire)(GR), iii) Grain (0.8% LW) + fructose (0.4% LW)(FR), iv) GR + histidine (6g/hd) and v) FR + histidine in an incomplete factorial design (n = 6 heifers/group). The fructose (Melbourne Food Depot, East Brunswick, Vic) was mixed through the grain; whilst, the histidine (Merck KGaA, Darmstadt, Germany) was dissolved in 50 mL of water and administered via a stomach tube. The heifers were fed 1kg of grain daily and had *ad lib* access to mixed silage and lucerne hay for a 10 day adaptation period. Feed was then withheld for 14 hours prior to challenge. On the day of challenge each heifer was fed and ate 200g of lucerne hay, immediately after heifers were fed their allocated treatment. Rumen samples were collected 5 minutes after treatment ingestion, 60 minutes later and at 3 subsequent 50 minute intervals via a stomach tube and assessed for saliva contamination as described by Bramley *et al* (2008). Rumen samples were analysed for pH immediately after collection and fermentation products following storage at -20^{o}C within four weeks of collection. Ammonia and D- and L-lactate concentrations were analysed using a Boehringer Mannheim kit (Arrow scientific, Lane Cove, N.S.W.) and spectroscopy. Volatile fatty acid (VFA) concentrations were analysed by gas chromatograpghy. Histamine concentration was analysed using a human histamine ELISA kit (IBL International, Hamburg, Germany) modified for bovine ruminal histamine. The kit was validated for bovine ruminal histamine by comparing the slopes between human and bovine serially diluted rumen fluid standard curves, which were not significantly different (Rabiee *et al* 2009). A repeated measures ANOVA with *heifer* as a random effect was used to analyse all parameters except D- and L-lactate (Stata v11, StataCorp LP, College Station, Texas, U.S.A). *Day* was used as a co-variate. A generalized estimated equations (GEE) model was used to analyse D- and L-lactate data. For statistical analysis the GR and GR + histidine treatment groups were collectively termed the GR group. The FR and FR + histidine treatment groups were collectively termed the FR group. $P < 0.05$ was defined as the level of significance.

Results

Ruminal pH was significantly lower in the GR and FR groups (6.9 ± 0.0 and 6.5 ± 0.0) compared to the control group (7.1 ± 0.0) and lowest in the FR group. The effects of grain, fructose and histidine were not significant, but the interaction of grain and histidine decreased ruminal pH. The effect of time and time by grain, fructose and histidine interactions were significant for ruminal pH, decreasing ruminal pH over the total time (Figure 1A). All contrasts between the control, GR and FR groups were significant for ammonia concentrations with the GR group (13.1 ± 1.0 mM) producing the highest ammonia concentration and the control group the lowest (7.5 ± 1.1 mM). The effect of grain increased ammonia concentration. In all treatment groups ammonia concentration decreased up to 115 minutes after feed consumption before increasing to 215 minutes. Ruminal D- and L-lactate concentrations were significantly higher in the FR group (9.2 ± 1.4 and 4.9 ± 0.9 mM) in comparison to the control (0.2 ± 0.7 and 0.1 ± 0.4 mM) and GR groups (0.2 ± 0.7 and 0.1 ± 0.3 mM). The effect of fructose was highly significant ($P < 0.001$), increasing D- and L-lactate concentrations. Fructose decreased D-lactate concentrations over time (Figure 1B). The fructose by histidine interaction was significant for L-lactate. Ruminal histamine concentration was significantly lower in the control (61.3 ± 6.1 ng/mL) compared to the GR (117.9 ± 4.3 ng/mL) and FR (111.2 ± 4.3 ng/mL) groups; which did not differ. The interaction of fructose and histidine resulted in an increase in ruminal histamine concentration ($P < 0.01$). Histamine concentration increased in all treatment groups up to 65 minutes after treatment consumption before decreasing over time (Figure 1C). The time by grain interaction was significant for ruminal histamine concentrations with grain decreasing histamine concentration after 65 minutes from treatment consumption. The fructose and histidine by time interactions were not significant. All contrasts between the control, GR and FR groups were significant for the volatile fatty acids analysed which included: acetate, butyrate, caproate, iso-butyrate, iso-valerate, propionate and valerate. The lowest volatile fatty acid concentrations occurred in the control group, with the exception of iso-butyrate and iso-valerate. Grain increased propionate and valerate concentrations; while, fructose increased acetate, butyrate and propionate concentrations. Concentrations of all analysed volatile fatty acids increased over time and grain increased concentrations over time. Fructose increased butyrate (Figure 1D), caproate, propionate (Figure 1E) and valerate (Figure 1F) concentrations over time. Histidine increased iso-valerate and propionate concentrations over time.

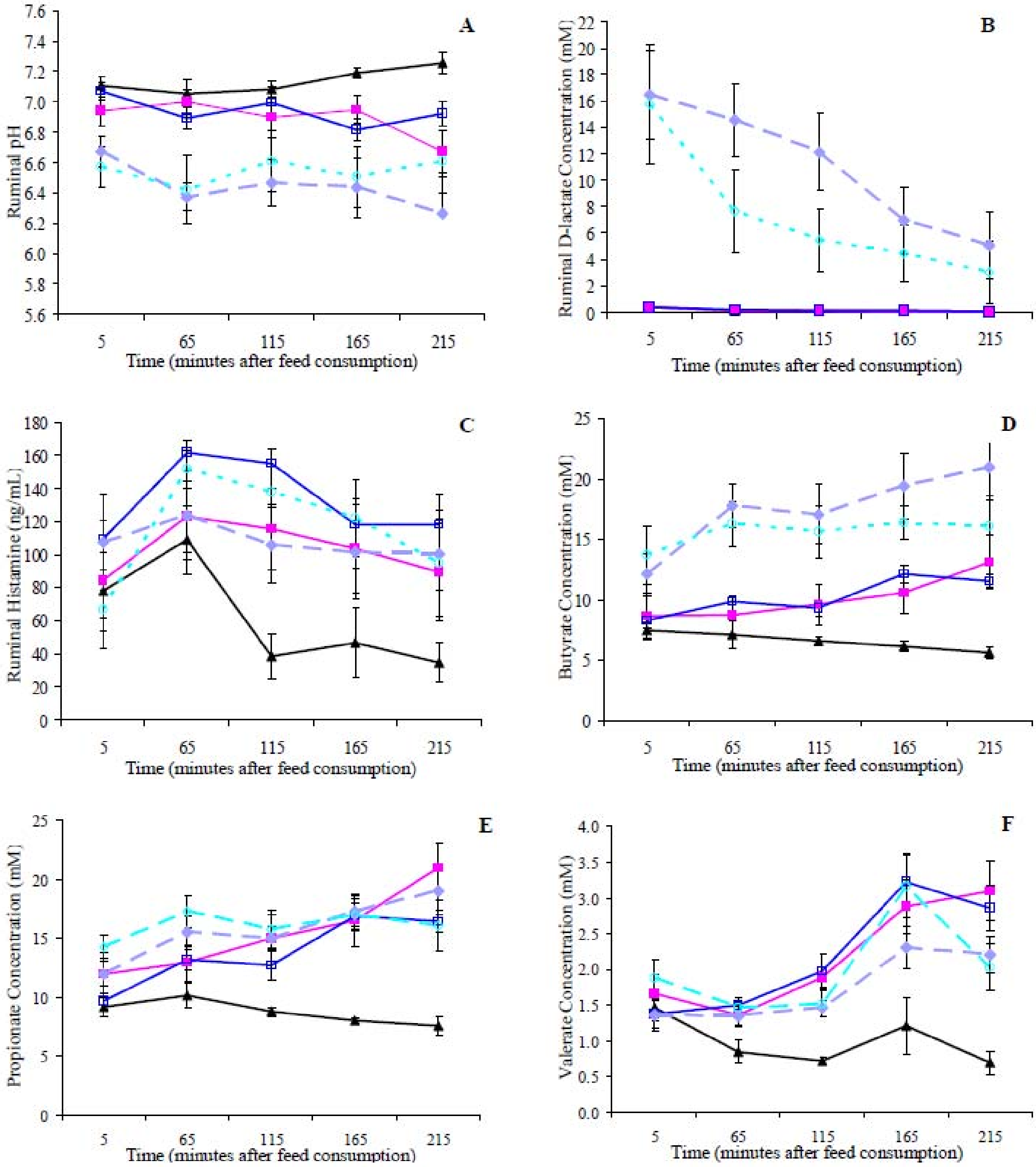

Figure 1A. pH; B. D-lactate concentration; C. Histamine concentration; D. Butyrate concentration; E. Propionate concentration; F. Valerate concentration. All values are means ± SEM from ruminal fluid taken at 5, 65, 115, 165 and 215 minutes after completion of treatment consumption.

Control GR GR + HIS FR FR + HIS

GR = 1.2% LW rolled triticale; FR = Grain (0.8% LW) + fructose (0.4% LW); HIS = histidine (6g/hd) (n = 6 heifers/group).

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Discussion

This experiment was designed to induce subclinical acidosis as defined by Bramley *et al* (2008) to test if fructose and histidine concentrations increase the risk of acidosis. Despite this, rumen pH in this trial was relatively high throughout the experimental period. However, as there were significant declines in pH in the GR and FR groups it was concluded subclinical acidosis was induced. Rumen pH is largely influenced by VFA and lactic acid concentrations (Schwartzkopf-Genswein *et al* 2003). The observed increase in VFA concentrations in the GR and FR group was probably ascribable to the stimulation of ruminal bacteria in these groups as a result of feeding readily fermentable carbohydrates in the form of grain and fructose. Hence, this VFA increase is likely to account for the drop in pH observed in the GR group and a proportion of the pH decline in the FR group. The fructose utilisers *Streptococcus bovis* and lactobacilli, which are favoured as pH declines produce lactic acid as a fermentation product (Hungate 1966). As lactic acid is 10 times stronger (pKa = 3.1) than VFA (average pKa = 4.8) the accumulation of lactate in the FR group may be responsible for a large percentage of the decline in pH in this group (Schwartzkopf-Genswein *et al* 2003). Marked drops in pH of dairy cattle administered with 13, 17 or 21 g/kg LW of oligofructose have also been observed by Thoefner *et al* (2004).

Histidine did not appear to have a significant impact on any of the parameters analysed, including histamine concentration. While the clearance rates of histamine were not measured in this study, elevated histamine levels in the GR and FR group in comparison to the control group support preliminary findings by our research group that histamine concentrations may be an indicator of acidosis (Lean unpublished).

In summary the substitution of 0.4% LW fructose for grain had marked effects on ruminal fermentation products in dairy cattle induced with subclinical acidosis. The addition of histidine did not have significant effects on ruminal fermentation.

Acknowledgements

This work was supported by Dairy Australia and SBS*cibus.*

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QUANTIFICATION OF THE EFFECTS OF INACCURATE PASTURE ALLOCATION IN A PASTURE-BASED AUTOMATIC MILKING SYSTEM

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Abstract

Pasture allocation is necessary to maintain high levels of pasture utilisation, feed conversion efficiency and animal health. But it is much more critical in an AMS as it is the key incentive to encourage cow traffic ultimately resulting in milkings.

The aims of this study were to quantify the affects of inaccurate pasture allocation within an existing pasture based AMS. There were eight trial runs that consisted of half the run being accurate pasture allocation and the other half simulated inaccurate pasture allocation with each treatment being alternated for each trial run. The results for 24 h milk production showed that on average was 21.37 l/cow for the accurate (ACC) treatment and 21.37 l/cow for the inaccurate (INACC) treatment.

The milking interval and frequency averaged 15.13 h/cow and 1.79 (milkings/cow/day) for ACC and 14.81 (h/cow) and 1.80 (milkings/cow/day) for INACC. Daily pasture intake was higher for INACC with an average of 14.8 (kg DM/cow.d) compared with ACC of 13.8 (kg DM/cow.d). This resulted in a higher total daily feed intake for INACC of 22.4 (kg DM/cow.d) compared with ACC of 21.9 (kg DM/cow.d). The association between total daily feed intake and 24 h milk production was much stronger for INACC than ACC.

The post graze residual was significantly lower for INACC than for those achieved with the ACC or OVER allocation treatments. This resulted in a higher daily feed intake for inaccurate treatment but at a lower pasture quality when grazing below the desired post-graze residual. The impacts on the whole system would be evident through prolonged periods of inaccurate pasture allocation (under-feeding or over-feeding).

Introduction

As on-farm adoption of Automatic Milking Systems (AMS) is increasing in Australia, it is of increasing importance that a full understanding of the impact of pasture management and allocation within a pasture-based AMS is generated. This will ensure that current and future installations are well equipped to achieve high levels of system performance. Regardless of the milking system, in Australia, pasture utilisation levels are closely linked with farm profitability due to the fact that pasture is the cheapest form of feed. Pasture allocation on conventional farms is often based on farmer instinct, desired grazing rotation length and historical practices. In reality the average farmer allocates the desired quantity of feed with an error rate of plus/minus 50% target (Fulkerson *et al.,* 2005). On any farm inaccurate pasture allocation will likely impact on wastage levels, subsequent quality, regrowth and ultimately milk production (all at a cost to profitability). The purpose of this study was to quantify the importance of accurate pasture allocation within an AMS.

Materials and Methods

The project was carried out at the AMS research farm (DPI NSW, Elizabeth Macarthur Agricultural Institute). The study involved the milking herd of around 160 pre-trained, mixed aged lactating cows milked through two DeLaval Voluntary Milking systems (VMS). The trial grazing area consisted of around 16ha of kikuyu and ryegrass based pasture. Cows were allocated two grazing strips of pasture a day and trafficked through a set of automatic drafting gates to get to fresh pasture after depleting the previous strip. At the drafting gates cows were drafted to the dairy if milking permission was granted or to the paddock if milking permission was denied. Accurate and inaccurate pasture allocations were alternated within each grazing run.

Accurate pasture allocation: Cows were allocated 50% of their daily pasture allocation in each of the day and night paddocks (normal practice for AMS pasture-based farm using 2-way grazing). Prior to each of the 8 grazing run (over a period from 6/8/08 to 18/4/09; each run comprised 6-10 days) pasture was measured using a C-Dax Rapid Pasture Meter to determine pre-grazing pasture masses (kgDM/ha). From this information a grazing plan was generated for the following seven days based on pre-grazing covers and an anticipated daily pasture growth rate. The FarmWorks P-Plus software was used to map the grazing strips for the ensuing week.

Inaccurate pasture allocation: A similar method was used to simulate inaccurate pasture allocation. It was important that this was simulated rather than allocated randomly to ensure that total pasture intakes were similar across the two treatments for each trial run. Over each 48 hour period the sum of the each inaccurate allocation (two allocations/day = four in total) equaled the total 48 hours requirement/cow.

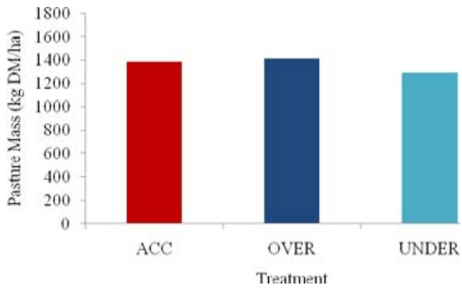

Figure 1. Average post graze-residual (ACC = accurate allocation)

Results and Discussion

The post grazing pasture residual (figure 1) achieved in allocations that were lower than the requirements (under allocation) were significantly lower (P>0.05) than those achieved with accurate treatment and the allocations that were higher than required (over allocation). There was no difference in the post grazing residuals achieved with the accurate and over allocation breaks.

Results presented in Figure 2 show that there was no significant difference in milking frequency between the two treatments. This suggests that although there was variability between breaks (especially inaccurate treatment) the frequency evened out over the whole trial. This was possibly the result of ensuring cows were allocated their daily feed requirements over a 48h period.

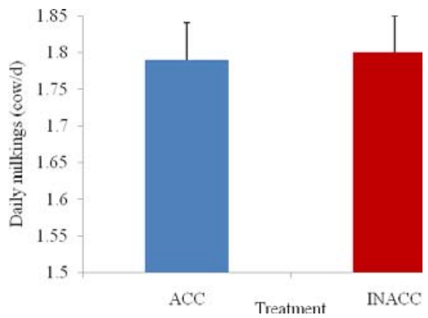

Figure 2. Average daily milking frequency

Results presented in figure 3 show that there was no significant difference in average daily milk yield with accurate vs. inaccurate pasture allocation (21.23L/cow.d and 21.37L/cow.d (P=0.361) for accurate and inaccurate respectively).

Conclusions

This study pointed out that through accurate pasture allocation did not have a severe negative impact on milking frequency or milk production when cows were achieving their target intakes over a 24-hour period. This indicates that if AMS farmers can get the allocation accurate (on average) then the system the negative impacts of over or under allocation are likely to be minimised. However, the potential still exists for severe impacts on milking frequency (and therefore milk production) if a farmer consistently over or under allocates pasture.

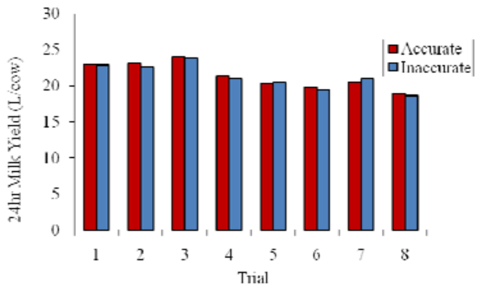

Figure 3. Average daily milk yields for each trial run

Accurate pasture allocation enables cows to achieve target daily feed requirements whilst also maintaining desirable post-graze residuals therefore a higher utilisation of pasture.

Inaccurate pasture allocation on a commercial farm could result in cows generally being (a) under allocated, (b) over allocated or (c) averaging target allocation levels with a higher level of variability (as in this study).

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AN INVESTIGATION INTO THE FLEXIBLE USE OF DIFFERENT FORAGE SYSTEMS IN NORTHERN VICTORIA – A SYSTEMS ANALYSIS APPROACH

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Abstract

Future Dairy is conducting a project into the flexible use of different forage systems in Northern Victoria as a continuation of the project in the Hunter Valley and the research on Complementary Forage Systems. The dairy industry in Northern Victoria relies heavily on irrigation for forage production. Irrigation water is considered the main limiting resource for pasture-based dairy systems in the region.

The aim of the project in Northern Victoria is to work with farmers to increase the production of milk from each mega litre of irrigation water. It is envisaged that this will be achieved through the more efficient use of irrigation in growing and utilising more feed on farm. The project will use several commercial farms in the region as case study to understand how decisions make at the forage system level affect the business as a whole.

Introduction

Future Dairy has conducted on-farm monitoring of dairy farms in the Hunter Valley. The purpose of this monitoring was to extend the results of the research work that was conducted at Camden in the area of Complementary Forage Systems into a commercial situation.

The project in Northern Victoria is a continuation of this research extension into a different dairying region with different limiting resources. In Northern Victoria the main limiting resource is irrigation water, most of the region has between 400-500mm annual rainfall and so there is a reliance on irrigation for forage production. The most recent best estimate for average water availability for dairy farming in the Goulburn-Murray Irrigation District is 767 gigalitres which is 64% of historic water availability (Dairy Australia, 2010).

Materials and methods

The investigation will use case study methodology as a research method to analyse different dairy business systems. Case study methodology has been chosen because it is a method that allows a complex system to be analysed effectively. The forage system of a dairy business is such a complex system that other research methodologies were considered to be limited in being able to achieve a true systems analysis.

Murray Dairy is working with Future Dairy to identify farmers in the region who would be suitable to participate in the on-farm monitoring. The aim is to have 6-7 farmers participate in the project. Each farm will be an individual case study of how decisions made at the forage system level affect the business as a whole.

The farmers will be monitored on a fortnightly basis to gather information on forage production, milk production and other business data.

A process of bio-economic modelling will also be used to look at different scenarios for each farm. This will help the farmer with decision making about what forage to use in their system and when certain forages will be most beneficial.

On-farm monitoring

On-farm monitoring has been chosen as a data collection method as it enables the pathway of development to be described. A starting point data set for each farmer will be established and they will each set targets for the end of the project. The on-farm monitoring will allow the capture of data that is influenced by actual operating conditions as the project progresses rather than by modelling assumptions. The pathway the farmer has taken to achieve the target aims will then be able to be analysed in full rather rather than just with to data sets.

The on-farm monitoring will also establish a feedback loop for the farmer during the project. This will enable them to monitor their progress and make changes as necessary.

Modelling will be used to analyse the data collected from each of the farms. The data from the farms will enable the modelling of different forage system scenarios. The use of on-farm monitoring will allow information to be shared across the farms in the project for use in modelling different scenarios. The process of analysing each farms data will begin with raw data from farm production records. Data from each of the participating farms will be able to be used to model different scenarios on the other farms. This sharing of information The modelling process will be to use DairyMod and APSIM to model the forage production, this will be followed by using UDDER and RedSky to allow a thorough economic analysis of the system.

It is envisaged that on-farm monitoring will be conducted over 18months and cover various dairying forage systems including pasture based to feedlot based dairies.

Acknowledgements

This work is proudly supported by Dairy Australia and Future Dairy

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EFFECT OF IMPROVED EXTENSION SERVICES ON DAIRY PRODUCTION OF SMALL-HOLDER FARMERS IN PAKISTAN

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Abstract

A benchmark and longitudinal study was carried out with the objective to demonstrate the effect of improved extension services on dairy production for small holder farmers. Benchmark data was collected on the whole farming system from 121 and 107 farmers in the two environmentally contrasting districts, Okara and Bhakkar respectively. Improved extension services as well as veterinary services were provided to these farmers in the form of access to quality vaccines and by presenting "improved farming techniques" in farmer discussion groups. Farmers recorded farm production data on a weekly basis including records of milk production from each milking cow and buffalo. Results indicate that farmers greatly overestimate the daily production of their milking animals. Furthermore, preliminary results of the uptake of "improved farming techniques" indicate an average increase in production per animal of up to 0.93 kilograms per animal per day. This research suggests that if simple improvements to the extension methods carried out in Pakistan are implemented, there is potential for increases in milk production throughout the country. This is likely to have positive ramifications relating to food security and the socio-economic status of small-holder dairy farmers in Pakistan.

Introduction

Pakistan like many developing countries has an agrarian rural based economy. Livestock is a major contributor to the national (12%) and agriculture (50%) economy (GOP, 2006). In the recent past the livestock sector has been declared as one of the fastest growing sectors and which provides livelihoods for more than 35 million people and these farmers/households derive 30 to 40% of their income from their livestock (GOP, 2006).

Milk is the major contributor of livestock produce to the incomes of these small farmers. The value of milk alone exceeds the combined value of wheat, rice, maize and sugarcane in the country (GOP, 2006). Milk is produced under different production systems namely, rural subsistence, rural market oriented, rural commercial farms and peri-urban dairying. It is estimated that around 70% of the dairy households in Pakistan still operate under conditions of subsistence by maintaining herds of three or four animals (Burki, Khan & Bari, 2005). The productivity of livestock for meat and milk is low, due to the lack of extension services.

The role of extension has been to provide research-based education and information to the production sector. Some of the most important areas on a dairy farm management are feeding and forages, udder health, reproduction, calf rearing and herd health (Dahl *et al*., 1991a). Problem solving in these areas requires a broad base of knowledge and expertise, and in some cases multidisciplinary teams of extension specialists are needed to assist producers (Dahl *et al*., 1991b). Services to the dairy sector in Pakistan are being provided by government agencies and a range of NGOs. Virtually all service providers who interact with farmers are veterinarians who are mainly concerned with performing vaccinations, animal treatment and artificial insemination. This is common for agricultural and livestock ministries in many developing countries (McDowell, 1981). Limitations in the extension service and the research/extension interface are considered to be bottlenecks in the development of the dairy sector. In particular, the limitations are; the style of communication between farmers and extension staff, the information available to extension staff and a failure to consider farm problems and solutions in a whole-of-farm systems context.

Considering these details, the major objectives of this study were to (1) define the current field milk production levels of dairy cattle and buffalo and (2) to demonstrate the improvements in milk production through the implementation of improved extension services to smallholder dairy farmers in Pakistan.

Materials and Methods

Dairy Project Background

In August 2007, a 3 year dairy project "Improving dairy production in Pakistan through improved extension services" was started in the two contrasting environments of the districts Okara (more affluent with good access to services) and Bhakkar (a less affluent desert region with less access to services). The objectives of this study were to increase dairy production through improved extension services. Veterinary services are well established in both these regions with the provincial government agency working throughout the province and non-Government organizations and co-operatives working in selected districts. Throughout this study the project utilized the networks and staff of these agencies as the driver for its field activities of data collection and extension services. These included the provincial Livestock Department of Punjab in both districts, as well as the National Rural Support Program (NRSP) in Bhakkar and Idara-e-Kissan, in Okara.

Small-holder dairy farmers maintaining 5-10 (buffalo and/or cattle) for production were the target group of the project. Generally, it is considered that there are four types of dairy systems in Pakistan (FAO, 1987) which are:

- Rural subsistence farmers –up to 3 animals with one or two in milk. Milk is used in the household and milk product surpluses are seldom sold into the market.
- Rural market-oriented farmers – generally have few than 6 animals with two or three in milk. Milk is used in the household and surplus is regularly sold to the market. These farmers make up the bulk of the market supply.
- Rural commercial farms – larger herds (>40 animals) which are well organised, with direct links to milk processing plants.
- Peri-urban commercial farms – are settled in the outskirts of cities with herd sizes of about 20 animals marketing milk directly into urban areas.

Data Collection

Production data were collected using a questionnaire based survey on the whole-farming system. These surveys were conducted by two trained field staff and took approximately ten to fifteen minutes to complete. A total of 228 farmers were surveyed with 121 farmers from Okara and 107 farmers from Bhakkar. These farmers came from eleven villages in Okara and eight in Bhakkar with between six and thirteen farmers in each village. Farmers were asked to give estimates of production per animal as well as details about their farm management such as animal housing, feeding practices and marketing options for sale of their milk.

Following the initial survey, a longitudinal survey was implemented where farmers recorded the milk production from each milking cow and buffalo on a weekly basis. Milk was measured with weight scales and recorded in kilograms into a herd book by trained extension workers in each village. Other information recorded included changes to feeding management, animal husbandry or the adoption of any recommendations by extension staff. The longitudinal survey commenced on the 1st of January 2008 and was completed on the 31st of December 2009.

Farmer and extension workers trainings

Improved extension services were provided to the farmers that were involved in the longitudinal survey. The project emphasized on an interdisciplinary educational program of farmer discussion groups where farmers were engaged in both technical discussions with extension workers and practical demonstrations. Farmers were provided with simple pictorial fact sheets in their local language which outlined the key messages of each session. The topics covered in the discussion groups were; animal husbandry/housing, nutrition, fodder and forages, preventative health and calf management.

Data Comparisons

Preliminary results are reported in this paper. These relate to the responses to the benchmark survey relating to estimated milk production and actual milk production recorded throughout the longitudinal survey. These questionnaire results have been compared to the actual milk production results from the longitudinal data as this was considered to be the true benchmark of milk production in the study areas.

Table 3. Farmer survey questionnaire responses to the "average milk production per animal" for milking buffalo and cattle.

Dairy Production System	Buffalo kg/day	Cow kg/day
Subsistence	12.33	5.00
Market Oriented	12.12	5.89

To determine the effect of the improved extension services on farm milk production, farmers were grouped depending on their responsiveness to the uptake of new practices. Farms that made a management change and adopted recommendations were considered to be "adoptive farmers" whereas those that continued to manage their farms without change were considered "traditional farmers". As farmers adopted recommendations they were grouped into the "adoptive farmers" category and their milk production data was pooled and compared with the "traditional farmers".

Results

Small-holder dairy farmers were asked to categorize themselves into the "Subsistence" or "Market Oriented" dairy production system. Farmers that considered their farm to be a commercial or peri-urban system were disregarded for the purposes of this study as the focus of this project was on small-holder production systems. Table 1 shows the responses of the farmers to the survey questionnaire about the average milk production of their milking buffalo and cattle. It can be seen from these responses that the farmer's perception is that the milk production is significantly greater in buffalo than in the cow. It can also be seen that there is no real difference between the two dairy system categories.

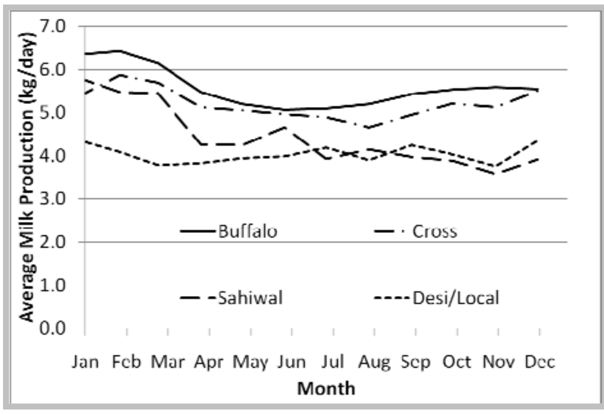

Figure 1. Longitudinal survey results for average recorded milk production per day (kg/day). Comparisons between three categories of cattle (sahiwal, cross and desi/local) and buffalo.

The longitudinal survey data collected milk production data from each individual milking animal on a weekly basis. Other information recorded at this time was the farmer's species or breed description of that animal. Figure 1 shows the average monthly milk production over the two year longitudinal survey for four of the most common species and breeds seen in Pakistan. From this graph although it is difficult to determine whether the questionnaire responses are significantly different from the actual milk production measurements. It can be seen that the estimate of the average cow milk production per day from the questionnaire is similar to that of the the cattle breeds depicted in the graph (desi/local, sahiwal and cross). However, in the buffalo, farmers overestimated, by approximately double the recorded production in the longitudinal survey.

Preliminary results on adoption rates of recommendations from extension workers were generally low with only 25% of farmers making any significant management change. The changes that were generally made included providing 24-hour access to water, providing shelter or shade to animals throughout the day or changes to feeding practices (for example feeding more frequently). Although adoption rates were low, positive impacts in milk production were still apparent. Figure 2 below compares the average milk production of farmers in 2008 (benchmark year) to farmers in 2009 that were considered either "traditional farmers" or "adoptive farmers".

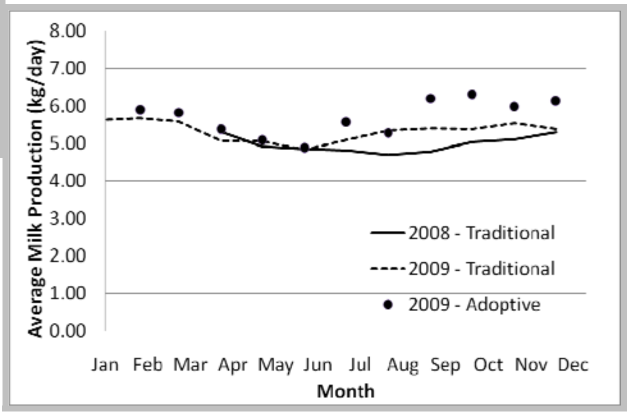

Figure 2. Average milk production of animals in the longitudinal survey from farms that were categorized into "adoptive" and "traditional" farmers.

Although results are preliminary, it can be seen that in the 2009 data, adoptive farmers did have a slight increase in production compared to that of the traditional farmers. In October there was an average increase of 0.93 kilograms per animal per day, which is an increase in production by over 17%. However, this was not consistent throughout the year which was 6.75%. Note that data collected in the first three months of 2008 has been omitted due to the unreliability of the data collection process at this time.

Discussion

Responses to survey questionnaires can be unreliable at times and can vary significantly depending on the way in which questions are structured and asked as well as in the way in which the survey is carried out. Despite this, they are a useful tool to help field staff to interact with farmers and gain an understanding of the farming system that they are working in.

The results of this questionnaire show, in general, that there is an overestimation of milk production per animal. This is especially the case with milking buffaloes. Farmers estimated their buffalo milk production to be on average over 12 kilograms per animal per day. This production is what can be expected of elite dairy buffaloes producing 3000-5000 kilograms per lactation (Moioli, *et al.*, 2006). The longitudinal survey data however shows that the recorded average measurement is less than 7 kilograms per day throughout the entire year. This data is interesting not only because it is different to the farmer's perceptions, but it is also different to the figures that have been found in previous studies carried out in Pakistan. Khan, Ahmad and Khan (2007) reported on the Livestock census completed in Pakistan in 2006 and other review reports. They found that the average total milk yield was 2100 kilograms for a lactation of 290 days which means an average milk production of 7.24 kg/day. These results are similar to those reported on by Moioli *et al.* (2006) on yield data collected in Pakistan in 2000 which show that the average milk production was 7.09 kg/day.

Similarly in cattle, farmers have overestimated their milk production per day. However, the differences are not as great. Papers reporting on cattle milk production in Pakistan are limited and generally only report on Sahiwal cattle and other common local breeds. Bajwa *et al* (2004) reported that the average milk production of Sahiwal cattle in 2000 was 5.93 kg/day, whilst Khan *et al* (2008) found it to be 6.59 kg/day.

It is difficult to compare directly between the results of this longitudinal survey and the findings of other experiments and surveys. This is due to differences in year, environment and the herds from which the data was collected. Despite this, the average milk yields depicted throughout the year in Figure 1 suggest that the field recorded animals tested in the villages of this survey have lower yields than those which have previously been recorded. This could imply that during the years 2008 and 2009 the environmental conditions for milk production was less favorable. However, it is more likely that the differences between the findings are due to the management and overall productive capacity of the animals that were being recorded. It then follows that estimates of the country's milk production is lower than that which has been extrapolated in the past.

Improved Extension Outcomes

In the initial questionnaire survey it was observed that the majority of farmers in Okara and Bhakkar kept their animals restrained to a fence, tree or pole throughout the day and night. Animals were only untied to be taken to water, feed or shelter. This was considered to be a factor in the low milk production of the animals. Water is one of the most significant nutrients for dairy animals and a sufficient supply of clean water is generally accepted as essential to prevent negative effects on performance (Beede, 1991; Murphy, 1992; LeJeune *et al*., 2001). It has been shown that by reducing the voluntary intake of water by 50% in cows yielding 15kg/day, you can reduce the milk yield by 26% (Little, *et al.,* 1980). Keeping in view this basic husbandry principle farmers were educated, among other things, regarding the free access to water and feeding.

The graph in Figure 2 shows little difference between the "adoptive" and "traditional" farmers. However, a 6.75% increase in milk production throughout the year is a positive step to increase the productive capacity of some of these farms. The majority of the “adoptive” farmers made the change of providing their animals with free-access to water 24-hours per day. Therefore, it seems like a simple change in management to benefit the health of the animal as well as the milk production per day.

Conclusion

It is difficult to evaluate the impact of “the improved extension services” that this project provided to the farmers. This is because there are many other factors that could have contributed to changes in milk production. However, the preliminary results of this longitudinal survey suggest that there has been a slight positive increase in milk production of the farmers who have adopted recommendations from our field extension workers. Following from these results it will be important to analyse the available data in greater detail to determine other possible effects or outcomes of this research. An important aspect to look into will be the economic benefit of any increases in milk production at an animal and farmer level. Furthermore, case studies of individual farms will be important to determine why management changes were adopted so that improvements to extension and communication methods can be implemented in future projects.

Acknowledgements

The authors sincerely thank the cooperating small-holder dairy holder farmers and their families, extension workers and research assistants for participation and contribution to this project. Furthermore, the authors thank ACIAR for funding the project No. LPS/2005/132.

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SUSTAINABLE NUTRITIONAL MANAGEMENT OF THE MODERN DAIRY COW: STRATEGIES TO MITIGATE GREEN HOUSE GASES ON-FARM

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Abstract

Ruminants are one of the most widely distributed groups of mammals on earth, having adapted to arctic, temperate and tropical environments. This global distribution is possible because of the unique ability of ruminants to digest a wide variety of temperate and tropical vegetation. It is the portion of the digestive tract known as the rumen, and its distinctive population of microorganisms that provides ruminants with the genetic potential to derive energy from widely varying fibrous feeds. Global warming, caused by increasing atmospheric concentrations of greenhouse gasses (GHG), is a major worldwide environmental, economic and social threat. It is well documented that livestock production contributes to this problem (Steinfeld et al 2006). Of primary concern for livestock production is the methane (CH_4) generated by ruminant livestock during the normal process of feed digestion (i.e., enteric CH_4). Many governments have implemented policies to reduce GHG emissions and significant efforts are now being directed towards developing animal husbandry methods that lower CH_4 emissions from ruminants including dairy cattle. A number of mitigation options have been proposed (e.g., vaccines, chemical additives, animal breeding, CH_4 capture, and so forth; reviewed by Johnson and Johnson 1995; Boadi et al 2004; McAllister and Newbold 2008), but diet manipulation is the most direct, and arguably the most effective, means of lowering CH_4 emissions from ruminants in most systems. The development and implementation of research on livestock diet manipulation to reduce CH_4 is becoming a focus of an increasing number of research organizations around the world.

Introduction

The microflora of the rumen is exceedingly diverse consisting of bacteria, protozoa and fungi. Bacteria are responsible for the majority of feed digestion in the rumen and are by far the most numerous of these organisms, at 10^{10} to 10^{11} cells per gram of digesta. While over 200 species of bacteria have been isolated from the rumen, cloning of 16S genes from the rumen has revealed that these represent less than 15% of the diversity of the rumen bacterial population. Of these cultivated species, only about 20 occur in numbers exceeding 10^7 per gram of digesta. Other cultivated species form a small part of the total population, but the relative importance of a microbial species cannot be defined on population density alone, as complex microbial consortia are required for efficient feed digestion (McAllister *et al* 1994).

Protozoa are the second most populace microorganisms in the rumen present in the rumen at 10^3 to 10^6 cells/mL of ruminal fluid, with over 100 species identified that represent over 25 genera. Protozoa are thought to be responsible for one-quarter to one-third of the fibre digestion in the rumen (Williams and Coleman, 1988). Although protozoa are often associated with ruminal fluid, large numbers may also attach to the surface of feed particles.

As a result of predation by protozoa on ruminal bacteria, the number of bacteria in the rumen fluctuates inversely with the number of protozoa (Teather *et al* 1984). Ruminants can survive, and in fact prosper, without any protozoa in the rumen (Lindsay and Hogan 1972), and protozoa may reduce the availability of dietary and microbial protein to the animal (Leng and Nolan 1984; Ushida *et al* 1986). Protozoa are thought to have a symbiotic relationship with ruminal methanogens, as the hydrogenosomes of the protozoa produce hydrogen that is used by methanogens to reduce carbon dioxide to methane (Finlay *et al* 1994).

Ruminal fungi are the most recently recognized group of ruminal microorganisms. Although the motile zoospores of these organisms occur in relatively low numbers (10^3 to 10^4/mL of ruminal fluid) it has been estimated that fungi may contribute up to 8 % of the total microbial biomass (Orpin 1983). Fungi are thought to be involved in the digestion of the most resistant forages such as barley straw. Ruminal fungi also possess hydrogenosomes and likely participate in a symbiotic relationship with methanogens through electron transfer. The relationship of methanogens with ruminal fungi is less well characterized than that with ruminal protozoa. Recent work in our laboratory in which we have measured messenger RNA production in the rumen suggests that the ruminal fungi may play an even bigger role in fiber digestion in the rumen than previously proposed.

Methanogens occur in the rumen at approximately 10^7 to 10^{10} cells per gram of digesta and are generally more prevalent with a forage diet than a concentrate diet. All ruminal methanogens utilise H_2 and CO_2 and play a key role in the microbial ecosystem as scavengers of the hydrogen produced during fermentation. This prevents the accumulation of reducing equivalents, allowing digestion to proceed efficiently. Only five species of ruminal methanogens have been successfully cultured with the majority of methanogens being associated with Methanobrevibacter, Methanomicrobium and an uncultured group Rumen Cluster C (Attwood *et al* 2010). Early research on ruminal methanogens was aimed at recovering the metabolisable energy lost from ruminants as methane but now, because of increasing concern with global warming, they are under study with a view to controlling methane emissions from ruminants (Joblin 1996; Mathison *et al* 1998).

Both lytic and temperate bacteriophage have been identified within the rumen (Lockington *et al* 1988), but their biology and population dynamics are poorly understood. Interest in the study of rumen bacteriophage has been growing in response to recognition of phage therapy as a potential means of favourably altering ruminal ecology (Ambrozic *et al* 2001). Tarakanov (1994) demonstrated that the *Streptococcus bovis* population in the rumen was reduced following the addition of *S. bovis*-specific bacteriophage to the diet. Although bacteriophage with activity against methanogens have also been described (McAllister and Newbold 2008), work to identify bacteirophage that could potentially lower methane production has yet to be undertaken.

Rumen Environment

The volume of the rumen contents in mature beef cattle ranges from 60 litres to 90 litres with increasing levels of forage in the diet. Solid feed particles undergoing digestion by rumen microorganisms may account for 7 to 14% of the total rumen weight. Ruminal fermentation requires strictly anaerobic (without oxygen) conditions and in fact oxygen is toxic to most rumen microorganisms. Oxygen that enters the rumen either across the rumen wall or with the feed is quickly consumed by microbes adherent on the rumen wall or by oxygen tolerant anaerobes in the rumen. During fermentation, rumen microorganisms produce volatile fatty acids (i.e., acetate, propionate and butyrate) which are subsequently used as an energy source by the ruminant. Production of these acids tends to lower the pH (acidify) of rumen fluid. Generally, rumen fluid pH is high (6.0 -7.2) when forages are fed but can decline below 5.0 when the percentage of concentrate in the diet is increased. If the pH stays at 5.0 for an extended period the animal can develop acidosis or exhibit laminitis. Most often the regulatory systems in the rumen return the pH of the rumen to 6.0 - 6.2 and this cycling of pH levels can occur in the rumen on a daily basis. Thus, the rumen is a dynamic system, in which all resident species, bacterial or otherwise are required to adapt to a continuously changing environment.

Changes in the Rumen Environment

The ruminant's diet is the major influence on the nature of the rumen environment. Factors such as composition of the feed, the degree of physical processing and the presence of feed additives all affect the numbers, proportions and digestive activity of rumen microorganisms and the amount of CH_4 produced. Probably the most profound change in the rumen environment occurs during the transition from forage to a concentrate diet. During this transition, the principal substrates for microbial fermentation change from the components of plant cell walls (ie. cellulose, hemicellulose, pectin) to cereal starch. Fermentation of concentrates is often extremely rapid and the excessive production of acid can cause the rumen pH to decline to below 5.0. Cellulolytic bacteria and protozoa are inhibited at pH values below 6.0 and consequently, feeding mixtures of concentrate and forage often causes a decline in the ruminal digestion of fibre.

Since the microorganisms that digest cell wall components are different from those that digest starch, one might expect a substantial difference in the species composition of the rumen bacteria between concentrate and forage diets. Although this is true during transition from forage to concentrate, the major species in the climax microbial population are remarkably similar between these two types of diets. In one experiment using sheep as a model, cellulolytic bacterial species present were unchanged after the diet was shifted from roughage to a 70 % corn diet. Conversely, we have found that despite the absence of starch in the diet, 50 % of isolated bacterial species were still capable of digesting starch in steers fed alfalfa. Thus, the component species of the adapted microbial population are inherently stable. This stability ensures that ruminants receive a continuous, uniform supply of volatile fatty acids and microbial protein even with moderate changes in diet.

The development of a stable microbial population upon transition from a forage to a concentrate diet is not an immediate process. Usually the numbers of bacteria that produce lactic acid (the acid involved in lactic acidosis) increase with the introduction of concentrate into the diet. Simultaneously, the numbers of bacteria that metabolize lactic acid also increase and the accumulation of lactic acid in the rumen is avoided. With time, the numbers of lactic acid producing bacteria decrease and the rumen ecosystem returns to a stable condition. However, if the transition from forage to a concentrate diet is too abrupt or if the particle size of the grain is too small, the microbial population may become unstable. Under these conditions lactic acid accumulates in the rumen and acid tolerant bacteria predominate. The pH of the rumen drops below 5.0 and the ruminant suffers from lactic acidosis. Additionally, the rumen contents may become viscous with the formation of stable foam in the rumen. The foam prevents eructation, gas accumulates in the rumen and feedlot bloat develops. These conditions are largely avoided if coarse particle size concentrates are fed and microorganisms are given time to adapt to concentrate over a 3 to 4 week period during which increasing amounts of concentrates are substituted for forage at 5- to 7- day intervals.


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The inherently stable nature of rumen populations makes it extremely difficult to alter the rumen environment through the use of feed additives. Probiotics, methane inhibitors, proteolysis inhibitors, buffers, microbial enzymes and ionophores have all been used in an attempt to manipulate the rumen environment. Although some of these additives may cause short term changes in the rumen environment, microbial adaptation often results in the rumen environment reverting back to pretreatment conditions. Ionophores are an exception, in that their introduction into the diet usually improves feed efficiency from 5 to 10 %. All bacterial species can be classified into two distinct groups based on the structure of their cell walls, and ionophores are found to selectively inhibit the growth of one group (Gram-positive species), which leads to a corresponding enrichment of the other (Gram-negative) group. As a result propionate production is increased, methane and lactic acid production are depressed and protein degradation is decreased in the rumen. These combined responses are likely responsible for the positive effect of ionophores on ruminal fermenation.

Greenhouse gas emissions from ruminant production

The GHG emissions from ruminant production comprise CH_4, N_2O, and CO_2. The CH_4 arises primarily from enteric fermentation and to a lesser extent, from manure storage. In confinement dairy systems in which manure is stockpiled, approximately 80% of the CH_4 is from enteric fermentation and only 20% from manure management (Vergé *et al* 2007). Nitrous oxide emissions originate largely from denitrification of N in soils arising from fertilizers and urinary deposits, and to a lesser extent from sources of N resulting from leaching, runoff and volatilization. Energy-based CO_2 emissions result both from on-farm (e.g., cropping, feed processing, transport) and off-farm (e.g., fertilizer, herbicide manufacture) sources, but these usually account for a relatively small portion of total emissions related to ruminant production.

Methane is the main source of GHG in most ruminant production systems. Methane from manure and enteric fermentation accounts for 40–70% of total GHG emissions in beef production systems (Vergé *et al* 2008; Johnson *et al* 2003), and 48–75% of the total GHG emissions on dairy farms (Vergé *et al* 2008; Eckard *et al* 2002; de Boer 2003). Emissions of CO_2 are typically 5–10% of total GHG emissions, and the remaining emissions (20–55% beef; 15–47% dairy) are N_2O. The total GHG emissions associated with producing meat and milk under various production systems have been estimated using whole systems modeling approaches that include farm life cycle analysis (Johnson *et al* 2003) and industry-wide analyses based on IPCC methodologies (Vergé *et al* 2007; Vergé *et al* 2008). Estimates of GHG emission intensity are calculated by expressing the total GHG produced (in CO_2 equivalents, CO_2 eq) per kilogram of meat (expressed on a liveweight or on a carcass basis) or milk produced.

For dairy farms in developed countries, the emission intensity of GHG is estimated at 1.0 to 1.6 kg CO_2 eq/kg milk. This range in emission intensity is due partly to methodology, including differences in definitions of boundaries of the farming system between studies. Differences in emission intensity also reflect differences in farming systems, including differences in diet composition, management practices, and level of productivity of the cows.

Dietary options for methane mitigation

Feeding diets with higher grain content

It is well established that feeding grain-based diets gives rise to less enteric CH_4 (g/kg of DMI) as compared to feeding forage-based diets (Johnson *et al* 1995). Starch fermentation promotes propionate production in the rumen and lowers ruminal pH, which inhibits the growth of rumen methanogens (Van Kessel and Russell 1996). Rumen protozoal numbers are also often lower in cattle fed high-grain diets, which also decreases the transfer of hydrogen from protozoa to methanogens (Williams and Coleman 1988).

Although increased use of grains in ruminant diets reduces enteric CH_4 emissions, the net impact on the whole-farm GHG budget will depend upon the particular farming system. Consequently, there is considerable debate as to whether intensification of ruminant production (i.e., feeding higher concentrate diets, decreased grazing) increases or decreases net farm GHG emissions (Mills *et al* 2003, Avery and Avery 2008). Feeding grain can reduce enteric CH_4 but can also result in increased CH_4 emissions from manure because the volatile solid content of manure increases with increased digestible energy content of the diet (Hindrichsen *et al* 2006). As well, feeding grain can increase N_2O and CO_2 emissions arising from increased use of fertilizers and fossil fuels for machinery and transport (Lovett *et al* 2006). Even so, several studies have reported that feeding less forage generally decreases total farm GHG emissions because of the decrease in enteric CH_4 production. Johnson *et al* (2002a) compared whole-farm GHG inventories for dairy farms in California, Wisconsin and New Zealand, where forages made up 43, 61 and 96% of diet DM, respectively, and found that total farm GHG emissions increased with forage proportion. This is in agreement with the findings of Lovett *et al* (2006) who compared dairy farms in Ireland with cows at varying levels of milk production potential. Those studies, however, did not consider that methanogenesis from manure can increase with grain feeding (Hindrichsen *et al* 2006), nor did they account for carbon sequestration in soil organic matter. If credit is given for the preservation of carbon in grazed pasture, ruminant production systems often revert from being a net emitter to being a sink for CO_2 as compared to cropped land. This scenario is especially evident if cropped land has recently been seeded to pasture as organic matter deposition leads to an accumulation of carbon which gradually reaches a plateau over a period of up to 25 years.

Increased feeding of grains should be promoted as a CH_4 mitigation strategy only after careful assessment using a life cycle analysis. The scope for using higher grain diets in dairy production in many areas of the world is limited because milk quality and animal health are negatively affected if concentrates in the ration exceed approximately 55%. Furthermore, grain feeding ignores the importance of ruminants in converting fibrous feeds, unsuitable for human consumption, to high-quality protein sources (i.e., milk and meat). This issue will likely become more critical if climate change impairs agricultural production and grains become even more important for human sustenance.

Forage type and quality

Although CH_4 production (expressed as g CH_4/kg of DMI) is usually higher from forage-based than from grain-based diets, considerable variation remains in CH_4 production among forage types. Cereal forages can contain significant quantities of starch, which favors production of propionate over acetate and can reduce CH_4 production in the rumen. Furthermore, intake of conserved cereal forage is often greater than that of grass forages. This reduces ruminal residence time and hence, restricts ruminal fermentation and promotes post-ruminal digestion. Cereal forages, however, usually require fertilization, harvest and preservation prior to feeding and these practices also contribute to GHG emissions through the burning of fossil fuels. With grazing of grass forages, these emissions are avoided and the opportunity for carbon sequestration in the soil is enhanced. These points illustrate the importance of using a life cycle approach in assessing the contribution of forages to total GHG emissions.

There is evidence that CH_4 emissions per kilogram of DMI are lower from ruminants fed legumes than from those consuming grass forages (McCaughey *et al* 1999; Waghorn *et al* 2002). For example, CH_4 emissions were lower in cattle fed clover (losses of 7% GEI) compared with perennial ryegrass (8.5% GEI) at similar levels of intake (Beever *et al* 1985). This difference may be associated with the rapid fermentation of plant cell contents that is well documented with legume forages (Coulman *et al* 2000). As well, differences in CH_4 production among forages may also arise from the presence or absence of various plant secondary compounds such as tannins, saponins or essential oils (see below).

Although differences in CH_4 output among forages may reflect compositional differences, plant maturity at the time of harvest can confound the impact of forage type on CH_4 emissions. Advancing maturity, with concomitant reductions in soluble carbohydrate content and lignification of plant cell walls, promotes the production of acetate and reduces the production of propionate in the rumen, thereby increasing the amount of CH_4 produced per unit of forage digested (Pinares-Patiño *et al* 2003; Pinares-Patiño *et al* 2007). Higher enteric CH_4 emissions in cattle grazing alfalfa as compared to grass pastures has been observed with this anomaly being attributed to the advanced maturity of the alfalfa (Chaves *et al* 2006). However, because reductions in forage quality are frequently accompanied by a reduction in intake, it may be that the amount of CH_4 produced per unit of DMI, or as a percentage of GEI, is not influenced by forage quality (Pinares-Patiño *et al* 2003; Molano and Clark 2008). Nonetheless, improvements in forage quality are believed to lower lifetime emissions or emissions per kilogram of milk or meat as a result of enhanced animal productivity (O'Mara *et al* 2008).

Lipid supplementation of diets

Supplementation of diets with lipids (excluding those that are protected from ruminal digestion) is one of the most effective ways of lowering enteric CH_4 emissions by ruminants. The challenge, however, is to lower CH_4 emissions without impairing animal production, given that adding unprotected fats to the diet can have negative effects on feed intake, carbohydrate digestion, protein and fat content of milk, and organoleptic quality of milk (Doreau and Chilliard 1997). Furthermore, feeding animal fat is prohibited in many countries leaving more costly vegetable-based sources as the only means of fat supplementation. As a result of increased diet cost, animal performance must improve to offset the higher feeding costs associated with using fat as a means of CH_4 mitigation. Despite these constraints, fats high in polyunsaturated fatty acids (PUFA) are attracting increasing interest not only for their ability to reduce methane emissions but also due to their ability to cause favourable alterations in the fatty acid composition of meat and milk, including increasing the proportions of mono- and PUFA, and the concentrations of conjugated linoleic acid *cis*-9,*trans*-11 isomer (Bu *et al* 2007) and omega-3 fatty acids (Hu and Willet 2002).

The mechanism by which feeding lipids reduces CH_4 production is multi-faceted (Johnson and Johnson 1995). Replacing dietary carbohydrates with lipid decreases the amount of organic matter that is fermented in the rumen, leading to less enteric methane production. In addition, lipids decrease numbers of protozoa and associated methanogens (Ivan *et al* 2004), and free fatty acids and medium-chain fatty acids (C12, C14) can be directly toxic to rumen methanogens (Machmüller *et al* 2003). In the case of PUFA, bio-hydrogenation of the unsaturated double bound can serve as a hydrogen sink, but stoichiometric calculations suggest that this sink only accounts for a small proportion of the hydrogen produced in the rumen (Casey *et al* 2006; Beauchemin *et al* 2007b; McGinn *et al* 2004). The greater energy density of lipids can also lead to a decline in DMI (Casey *et al* 2006; Jordan *et al* 2006a; Jordan *et al* 2006b; Cosgrove *et al* 2008), further decreasing the ruminal digestion of organic matter to the point that milk or meat production can be compromised. To prevent these negative effects, the amount of lipid added to the diet must be limited to 3–4%, such that total lipid content does not exceed 6% of dietary DM (National Research Council 2001). These responses to lipid supplementation also differ among plant sources and are particularly manifested for plant sources that have high concentrations of short-chain saturated fatty acids such as coconut and palm oil.

In a meta-analysis of published findings on cattle and sheep, Beauchemin *et al* (2008) calculated that CH_4 (g/kg DMI) was reduced by about 5.6% for each percentage unit of lipid added to the dietary DM. In a more recent analysis of data from studies using dairy cows, Eugène *et al* (2008) reported a 2.3% decrease in CH_4 (g/d) per 1% addition of lipid, but no decrease in CH_4 when corrected for intake (g/kg DMI), indicating that the CH_4 suppression in those studies was due to a reduction in DMI as opposed to a direct effect of the fat on ruminal methanogenesis. It appears that feeding lipids can be an effective CH_4 mitigation practice in some situations, but responses are highly variable. Factors such as level of supplementation, fat source and associated fatty acid profile, the form in which the fat is administered (i.e., as refined oil or as full-fat oilseeds), and the type of di*et al*l impact the net effect of lipids on CH_4 production.

Refined oils high in medium-chain fatty acids (i.e., C12:0 and C14:0), such as coconut oil, palm kernel oil, high-laurate canola oil, and pure myristic acid, can be extremely effective in lowering CH_4 (g/kg DMI) production (e.g., 64% reduction in sheep with 7% added fat from coconut oil (Machmüller and Kreuzer 1999); 55% reduction in sheep (Machmüller *et al* 2003) and a 31% reduction in dairy cows (Odongo *et al* 2007b) with 5% added fat from myristic acid). Medium-chain fatty acids are particularly effective in reducing CH_4 because of their toxic effects on the rumen methanogens (Machmüller *et al* 2003), but these responses are also frequently accompanied by a dramatic decline in diet digestibility. The effects of supplementing diets with long chain fatty acids on reducing CH_4 emissions appears to be more variable than has been observed with medium-chain fatty acids. Adding whole cottonseed (to supply 3.3% added fat) or a mixture of sunflower and fish oils (3.75% added fat) to dairy cow diets reduced CH_4 (g/kg DMI) by 26 to 27% (Grainger *et al* 2008b; Woodward *et al* 2006). Other researchers have reported no effects of added fat on CH_4 production in dairy cows, in studies involving adding 5.6% of DM as fat from canola seeds and whole cottonseed (Johnson *et al* 2002b) or 2% fat from blended flaxseed and fish oils (Woodward *et al* 2006). Reasons for the lack of CH_4 reduction in some studies are not clear, but may arise from differences in secondary ingredients in the diet or compositional differences in the microbial populations among animals.

Pure oils are usually more effective against CH_4 than the same amount of lipid supplied via unprocessed and/or processed oilseeds. For example, Martin *et al* (Martin *et al* 2008) fed various forms of flaxseed (5.7% added fat to the diet) to dairy cows and reported a 10% reduction in CH_4 (g/kg DMI) for unprocessed seeds, a 26% reduction for extruded seeds, and a 49% reduction for crude oil. However, a substantial part of the CH_4 reduction was caused by negative effects on feed intake and digestion, given that all of the flaxseed treatments lowered neutral detergent fiber (NDF) digestion in the total tract by approximately 14%, and feeding extruded seeds or crude oil also reduced DMI (by 16% and 26%, respectively). In general, oilseeds are preferred over refined oils because of lower cost and the fact that they evoke fewer adverse side effects on intake and fiber digestibility. Oilseeds that are not substantially damaged during mastication (e.g., canola seed, flaxseed) require mechanical processing whereas seeds that release their contents in the rumen such as sunflower can be fed without processing.

Studies have show that the lipid-mediated reduction in CH_4 is retained after 1 to 2 months (Ivan *et al* 2004; Grainger *et al* 2008b) of fat feeding. Studies to confirm continued mitigation past this point have yet to be conducted.

Distillers' dried grains

The recent worldwide increase in ethanol production from grain has resulted in increased availability of distillers' grains. The ruminant livestock industry has adapted by including these co-products in beef and dairy cattle diets. Dried distillers' grains (DDG) from corn contains approximately 30% crude protein and 10 to 15% fat (DM basis). The potential of feeding DDG for CH_4 mitigation was confirmed recently by McGinn *et al* (2009) in beef cattle and as far as we are aware, similar responses have yet to be confirmed in dairy cattle. In growing beef cattle fed a diet in which barley grain (35% of diet DM) was replaced by dried corn DDG (adding 30 g fat/kg diet DM), CH_4 emissions (g/kg DM) were reduced by 16%. While incorporating DDG in ruminant diets can reduce CH_4 production, a limitation to using DDG is that it contributes a substantial amount of crude protein to the diet, which could increase nitrogen excretion and ammonia emissions in some situations (Todd *et al* 2006). Atmospheric ammonia is a precursor to the formation of atmospheric aerosols that are linked to human health challenges (Popendorf *et al* 1985) and the deposition of ammonia to land increases the release of N_2O (Loubet *et al* 2006). Further research using a life cycle approach is necessary to calculate the net effects on the GHG budget associated with using DDG in ruminant diets.

Micro-algae

Micro-algae have been proposed as valuable organisms for industrial-scale production in the future (Rosenberg *et al* 2008). Like fish oil, micro-algae are rich in eicosapentaenoic acid (EPA, C20:5 *n*-3) and docosahexaenoic acid (DHA, C22:6, *n*-3). However, fish oils are costly and fish supplies are limited, and their commercial use in ruminant diets is declining. The new cultivation techniques available for algae coupled with possibilities for genetic manipulation (Rosenberg *et al* 2008) make micro-algae an attractive possibility for CH_4 mitigation. Inhibitory effects of micro-algae on CH_4 *in vitro* appear to be similar to those of fish oils (Fievez *et al* 2007). Fish oils can be potent inhibitors of CH_4 in the rumen, with CH_4 inhibition proportional to the amount of PUFA and the rate of lipolysis (Fievez *et al* 2003). Supplementing micro-algae *in vitro* resulted in incomplete biohydrogenation of linoleic and linolenic acids, and the accumulation of hydrogenation intermediates was associated with a decrease in the rumen protozoal populations (Boeckaert *et al* 2007) and a reduction in CH_4 production (Fievez *et al* 2007). However, when the same product (43 g/kg of DMI) was offered to dairy cows in the diet (Franklin *et al* 1999) or via ruminal cannula (Boeckaert *et al* 2008), DMI of the cows was drastically reduced (by 21 to 46%), as was the concentration of fat in the milk. While the *in vitro* results with this algae product appear promising, substantially more research is needed in animals to define the optimum dose of micro-algae for CH_4 reduction and the potential effects on animal production. The practicality of producing micro-algae as a feed (i.e., drying, transportation, yield, production facilities etc.) would also have to be considered before such an approach would be practical as a means of mitigating enteric methane emissions in ruminants.

Ionophores

In North America, ionophores (e.g., monensin) are used in beef and dairy cattle husbandry to improve efficiency of meat and milk production, although the use of ionophores in animal production is not permitted in Europe. Ionophores reduce methanogenesis by increasing the proportion of propionate relative to acetate and by decreasing ruminal protozoal numbers (McGuffey *et al* 2001; Duffield *et al* 2008). They do not, however, target the rumen methanogen population directly, as shown in a recent long-term (180 days) feeding study using lactating dairy cows in which monensin was fed at 24 mg/kg (Hook *et al* 2009).

The effectiveness of monensin for lowering CH_4 production appears to be dose-dependent, as reviewed by Beauchemin *et al* (2008). At dosing levels less than 20 mg/kg, monensin had no effect on CH_4 production (g/kg DMI) in dairy cows (Van Vugt *et al* 2005; Grainger *et al* 2008a, Waghorn *et al* 2008), whereas higher doses (24 to 35 mg/kg) reduced CH_4 production in beef cattle and dairy cows by 4 to 13%, measured as g/d. However, when expressed on the basis of DMI (g/kg DMI), effects ranged from no effect to a 10% reduction (McGinn *et al* 2004; Van Vugt *et al* 2005; Sauer *et al* 1998; Odongo *et al* 2007a). The inhibitory effects of ionophores on methanogenesis do not always persist. For example, Guan *et al* (2006) reported that in beef cattle, monensin (33 mg/kg) lowered CH_4 emissions by 27% in the first 2 weeks, but the original emissions were restored within 6 weeks. When a high-forage diet was fed, emissions were lowered by 30% for 4 weeks, but levels were restored by week 8. The change in CH_4 production corresponded to changes in protozoal populations, which exhibited adaptation to ionophores over time. However, there are other studies (e.g., Guan *et al* 2006) in which adaptation to ionophores did not occur, and to date the factor(s) enabling the persistence of the monensin effect are not clear. Tedeschi *et al* (2003) proposed that, even in the case of microbial adaptation, ionophores are an effective CH_4 mitigation practice because of their potential to improve feed conversion efficiency and consequently CH_4 production per kilogram of meat or milk. However, this response is not always consistent (i.e., especially with forage-based diets) and increasing public pressure to reduce the use of antibiotics in livestock production may curtail its use in the future.

Organic acids

Organic acids, such as malic acid and fumarate, have the potential to decrease CH_4 emissions by acting as an alternative hydrogen sink in the rumen (McAllister and Newbold 2008). Organic acids have reduced CH_4 output in numerous *in vitro* studies in a dose dependant manner (e.g., Carro *et al* 2003; Kolver *et al* 2004). However, *in vivo*, relatively high levels of supplementation (> 2% of the diet) are required to reduce CH_4 output (Bayaru *et al* 2001). For example, a 42% reduction in CH_4 output (g/kg DMI) was observed when 10% fumaric acid was added to the diet of sheep (Wallace *et al* 2006). However, high levels of organic acid supplementation reduce DMI and cause rumen pH to drop with negative consequences on fibre digestion. Encapsulation of organic acids with fat to slow their release in the rumen can overcome these limitations (Wallace *et al* 2006), but the cost of this approach is uneconomical. It appears that this approach is unlikely to be economically viable in the near future.

Condensed tannins

A wide variety of biologically active compounds in plants have been explored for their ability to mitigate ruminal CH_4 production. Condensed tannins (CT) are secondary phenolic compounds in plants that may play a role in discouraging herbivory and concentrating nitrogen both in terrestrial and in aquatic environments (Waghorn 2008; Wang *et al* 2008).

Condensed tannins vary widely in chemical structure, but in general share a common property in that they have a high affinity for protein. Tannins bind with proteins forming tannin – protein complexes, reducing degradation of plant protein to amino acids and the rumen ammonia concentration. Consequently, the flow of feed protein to the small intestine is increased when CT are added to the diet. For diets containing excess nitrogen, the protein-binding effect of condensed tannins could be beneficial for the environment as reduced nitrogen digestion reduces the excretion of ammonia in urine and leaves it in a more slowly degradable form in the feces.

As with other plant extracts, most studies that examine the effects of CT on CH_4 have been conducted *in vitro*. Tavendale *et al* (2005) reported that CH_4 yield in batch cultures was about 30% lower with the CT-containing legume *Lotus pedunculatus* as substrate than with *Medicago sativa*. *Calliandra calothyrsus*, a legume shrub rich in CT has also been reported to lower CH_4 production in the artificial rumen (Hess *et al* 2004). In both of these studies, however, reductions in CH_4 emissions were accompanied by a decline in DM digestibility, a response that likely reflects the negative effects that CT can have on carbohydrate digestion (Tiemann *et al* 2008a).

Reductions in CH_4 emissions with CT appear to depend on the tannin source and on ruminant species. Feeding Sulla (*Hedysarum coronarium*) to provide 27 g CT/kg DMI, as opposed to unsupplemented perennial ryegrass pasture, resulted in lower (19.5 *vs.* 24.6 g/kg DMI) CH_4 emissions by dairy cattle (Woodward *et al* 2002). Similarly, CH_4 emissions by goats were reduced substantially (6.9 *vs.*16.2 g/kg DMI) by feeding *Sericea lespedeza* forage that contained 177 g CT/kg DM, as compared to a crabgrass/tall fescue mixture (Puchala *et al* 2005). Little difference in CH_4 emissions was observed among goats fed *S. lespedeza* and/or *Kobe lespedeza* forages that contained 140 and 151 g CT/kg DM, respectively (Animut *et al* 2007), but CH_4 emissions were more than doubled when the forage CT were deactivated by feeding 25 g/d of polyethylene glycol. Adding CT from quebracho onto the *K. lespedeza* forage (50 g CT/kg forage DMI) further reduced CH_4 emissions by the goats, but our research team found that including quebracho CT extract at 2% of diet DM had no impact on CH_4 emissions by cattle (Beauchemin *et al* 2007a). High-tannin sorghum silage was also found not to alter CH_4 emissions in beef cattle (de Oliveira *et al* 2007) although in that study, the biological activity of CT may have been neutralized by the ensiling process. Frequently, CT-mediated reductions in CH_4 are observed without a shift in fatty acid production towards propionate or without changes in protozoal populations. Consequently, care must be taken to ensure that achievement of CH_4 suppression using CT is not occurring through a general reduction in fermentation activity, as was recently observed when growing lambs were fed *Calliandra calothyrsus* or *Flemingia macrophylla* as sources of CT (Tiemann *et al* 2008b). The fact that the CT concentrations in plants exhibit yearly and seasonal variation may challenge the ability of this approach to achieve consistent reductions in enteric CH_4 emissions through this approach challenging.

Saponins

Saponins are of interest for CH_4 mitigation because they inhibit rumen ciliate protozoa (Makkar *et al* 1998; Wang *et al* 1998; Lila *et al* 2003) by altering their cell-membrane permeability (Klita *et al* 1996), but it appears that saponins do not directly inhibit methanogens. Tea saponins decreased *in vitro* protozoal numbers and CH_4 production, but did not affect methanogen numbers when added to a pure culture of *M. ruminantium* (Guo *et al* 2008). Saponins used in ruminant nutrition are either powdered, dried whole plant material, or liquid extracts. Whole plant products contain polyphenolics, which may account for some of their activity, whereas extracts are low in polyphenolic content. The two major commercial sources of saponins are the desert plants *Yucca schidigera* from Mexico and *Quillaja saponaria* from Chile, although a number of other plant sources are also of interest. The effectiveness of saponins for reducing CH_4 production *in vitro* varies considerably, depending upon the saponin source and dosing level. Many studies report a decrease in CH_4 production *in vitro* when saponins are added (Lila *et al* 2003; Hess *et al* 2003; Hu *et al* 2005; Pen *et al* 2006; Holtshausen *et al* 2009). Lila *et al* (2003) used *Y. schidigera* in mixed hay-concentrate diets and reported a reduction in CH_4 production at dosing levels of 1.2 to 3.2 g saponin/L, whereas Wang *et al* (1998) reported no effect of *Y. schidigera* at a much lower dosing level (0.022 g saponin/L). Holtshausen *et al* (2009) reported a linear reduction in CH_4 of up to 26% with increasing levels of *Y. schidigera* (up to 45 g/kg DM) and up to 7% reduction with similar levels of *Q. saponaria.* The lower effectiveness of *Q. saponaria* compared with *Y. schidigera* was likely due to its lower saponin content (30 g/kg DM compared with 60 g/kg of DM in *Y. schidigera*). Tea saponins included in *in vitro* incubations at up to 40 mg saponin/g substrate DM decreased CH_4 production by 26% (Hu *et al* 2005), whereas an *in vitro* evaluation of saponins from three different forages (*Sapindus saponaria*, *Enterolobium cyclocarpum*, and *Pithecellobium saman*) found CH_4 production decreased only with *S. saponaria* (Hess *et al* 2003).

Holtshausen *et al* (2009) reported that feeding powdered *Y. schidigera* (containing 6% saponin) or *Q. saponaria* (3% saponin) to lactating dairy cows at 10 g/kg diet DM did not affect CH_4 production, even though the same products reduced CH_4 production *in vitro*. Benchaar *et al* (2008b) also fed yucca (10% saponin) to lactating dairy cows (at 2.75 g/kg diet DM) and observed that protozoal populations were unaffected. The differences between results *in vitro* and *in vivo* could arise from adaptation of the rumen microflora to degrade or alter saponins as has been reported in our laboratory (Wang and McAllister 2010). Newbold *et al* (1997) reported a decrease in protozoal numbers in sheep after 4 d of feeding saponins from *Sesbania sesban*, but after another 10 d, the population recovered.

Essential oils

Over 250 essential oils have been described, consisting of mixtures of terpenoids and a variety of low molecular weight aliphatic hydrocarbons, alcohols, acids, aldehydes, acyclic esters and, on occasion, N- and S- containing compounds, coumarins and homologues of phenylpropanoids (Benchaar *et al* 2008a). The antimicrobial activity of essential oils has been recognized for millennia, but their potential to selectively inhibit ruminal methanogenesis has only recently been explored. A large study was undertaken to screen 450 plant species for their ability to decrease ruminal CH_4 production *in vitro* (Bodas *et al* 2008). Of the 450 sources screened, 35 were found to decrease CH_4 production and of these, six were found to decrease CH_4 production by >25% with no adverse effects on digestibility. This extensive screening enabled identification of only three plant sources as showing high promise as methanogenesis inhibitors. These were rhubarb root (*Rheum nobile*), Italian thistle (*Carduus pycnocephalus*) and aspen (*Populus tremula* L.). Although this study did not identify the active essential oils in these plants, others have examined the impact of extracts of essential oils on ruminal CH_4 production. Cinnamon and garlic oil extracts were found to be effective for lowering CH_4 production *in vitro*, but the effect was concentration dependent (Chaves *et al* 2008). Kamra *et al* (2005) investigated methanol and ethanol extracts of various spices, including fennel, clove, garlic, onion and ginger, for their effects on CH_4 production *in vitro*. Among the extracts tested, methanol extract of garlic was most effective, suppressing CH_4 production by 64% without adverse effects on feed digestibility.

To our knowledge, only a single study has been conducted to examine the effect of essential oils on CH_4 production *in vivo*. Feeding Crina® (1 g/d) to beef cattle was found not to affect

CH_4 emissions, even though feed digestibility was decreased (Beauchemin *et al* 2006). Given that the diversity of methanogens was shown to increase in lambs supplemented with essential oils (Ohene-Adjei *et al* 2008), the possibility of rumen populations adapting to these additives can also not be discounted. In fact, we found clear evidence of the microbial population having adapted to the inclusion of cinnamon leaf oil in an artificial rumen (Fraser *et al* 2007). Given the diversity of essential oils, it is highly probable that differences will exist in the rates at which microbial populations adapt to these compounds. It is possible that the favorable responses attained to date *in vitro* may not be as marked *in vivo* as a result of microbial adaptation. Furthermore, many of the concentrations of essential oils that have elicited favorable fermentation responses *in vitro* are too high for *in vivo* applications, due to issues with palatability and possible toxicity.

Yeast

Active dry yeast (*Saccharomyces cerevisiae*) and yeast cultures are often used in ruminant diets to improve animal performance (Robinson *et al* 2009; Chaucheyras-Durand *et al* 2008). Research suggests it is possible to select yeast strains that reduce CH_4 production *in vitro* (Newbold and Rode 2006), although commercial products used in animal husbandry have not been selected for their effects on CH_4 production (Chaucheyras-Durand *et al* 2008). McGinn *et al* (2004) evaluated the effects of two commercially available strains of yeast on CH_4 production in beef cattle and reported one caused a non-significant decrease of 3% (expressed as g/kg DMI). The mechanisms whereby yeast may decrease CH_4 are unclear, but it is possibly related to the increase in bacterial numbers that typically occurs as a result of added yeast (Chaucheyras-Durand *et al* 2008). The partitioning of degraded carbohydrate between microbial cells and fermentation products may alter the production of hydrogen, thereby decreasing CH_4 yield (Newbold and Rode 2006). Alternatively, yeast may promote the growth of acetogenic bacteria capable of using hydrogen in the rumen. At this point, direct evidence to support that yeast lower CH_4 emissions *in vivo* is extremely limited.

Bacterial direct-fed microbials

Bacterial direct-fed microbials (DFM) are being used increasingly in ruminant production to favorably alter the ruminal environment and improve production efficiency. Lactic acid-utilizing bacteria (e.g., *Propionibacterium* spp., *Megasphaera* spp.) promote propionate production and help prevent the accumulation of lactic acid in the rumen, whereas lactic acid-producing bacteria (e.g., *Lactobacillus* and *Enterococcus* spp.) are thought to help prevent ruminal acidosis by facilitating adaptation of ruminal microorganisms to the presence of lactate in the rumen. Animal feeding studies have shown that supplementing with *Enterococcus faecium* EF21 (Beauchemin *et al* 2003) or with a combination of *Lactobacillus acidophilus* and *Propionibacteriun freudenreichii* (Raeth-Knight *et al* 2007) increased propionate concentrations in the rumen, an outcome that is expected to lower CH_4 production. However, no *in vivo* studies have been conducted to verify this expectation. The development of DFM that alter ruminal fermentation in a manner that reduces CH_4 production is a major part of our current research program. However, identifying DFM that can actively adapt and integrate with the rumen microbial population to undertake a consistent and predictable reduction in methane will undoubtedly present a challenge.

Conclusion

Direct manipulation of rumen microbial populations is notoriously difficult because it is the feed that is by far the most powerful factor in determining the nature of the microbial species in the rumen. Strategies that are targeted at lowering CH_4 emissions in ruminants must achieve this goal without compromising meat or milk production. Improving the efficiency of milk and meat production has been an economic driver that has been directing production practices almost since the beginning of livestock domestication. Producers have already adopted several practices that have reduced the amount of CH_4 per unit of product produced by several fold. Future mitigation strategies will only be adapted if they are economically viable and many of the currently proposed approaches lack this key criteria. Adoption of some of these approaches may be promoted by the development of carbon credit programs, but ultimately these increased costs will need to be passed to the consumer. The greatest declines in CH_4 emissions are likely to be achieved through a combination of approaches, including dietary modification, improved farm management, and animal selection for improved feed conversion efficiency. The optimum dietary strategy will depend on the particular farm, its geographic location, the feedstuffs available, and type of animals being fed. It is essential that an array of possible CH_4 mitigation strategies be made available, because creating options that are a best 'fit' for producers' own management situations will help ensure adoption.

Acknowledgments

This work was supported by SAGES and Peer-Review project programs of Agriculture and Agri-Food Canada as well as the Value-Added program between Norway and Canada. The technical assistance of Krysty Munns is also gratefully appreciated.

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Dairy Futures CRC

TRANSITION MANAGEMENT: IMPROVING PRODUCTION, REPRODUCTION AND HEALTH

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Abstract

Recent Australian studies have identified means through which milk fever risks may be reduced by manipulation of concentrations of macro-elements in the pre-calving diets. Diets that control calcium intake to around 0.5% of diet, provide more than 0.45% magnesium and < 0.4% phosphorus and have a DCAD < 0 meq/kg will reduce the risk of milk fever. The results have been integrated into transition feeding strategies designed to optimise calcium and bone metabolism, energy metabolism, protein metabolism, immune function and rumen function. The aims of transition can be summarised in the establishment of four freedoms. Cattle should be; free of macromineral deficiency (conditioned or otherwise); free of lipid mobilisation disorders; free of immune suppression and free of ruminal disruption. Diets that have addressed these principles have lead to marked increases in milk production; greatly improved reproduction and reduced risk of lowered the risk of removal from the herd. There is evidence that transition diets that modify calcium metabolism also alter homeorhetic changes in energy and mineral metabolism. Further research into the role of transition diets in improving reproduction, production and health is required to refine these strategies.

Introduction

The periparturient or transition period is defined as the three weeks before and after calving and is characterised by greatly increased risk of disease (Curtis *et al*., 1985, Shanks, 1981, Stevenson and Lean, 1998). This period is dominated by a series of adaptations to the demands of lactation, a type process termed 'homeorhetic' (Bauman and Currie, 1980). Homeorhetic processes are the long term adaptations to a change in state such as from being non-lactating to lactating and involve an orchestrated series of changes in metabolism that allow an animal to adapt to the challenges of altered state.

Diseases that result from disordered homeorhetic change reflect disorders in homeostasis, in other words, these are failures to adapt that result in shortages of nutrients that are vital for existence. The conditions are often inter-related (Curtis *et al*., 1983, Curtis *et al*., 1985, Curtis, 1997) and include hypocalcaemia and downer cows, hypomagnesaemia, ketosis and fatty liver, udder oedema, abomasal displacement, RFM / metritis, poor fertility and poor production. While there has been, in the past, a tendency to look at metabolic systems in isolation, all metabolic processes are intricately linked. This concept reflects a need for effective homeostatic control of metabolism. A failure of one metabolic process will inevitably impact on the efficiency others. As research progresses, intricate homeostatic links between metabolic processes once thought to be distant and unrelated are continually uncovered. As a result of the increased understanding of homeostatic processes, the concept of transition feeding has evolved from one focused on only control of milk fever to an integrated nutritional approach that addresses optimising calcium and bone metabolism, energy metabolism, protein metabolism, immune function and rumen function.

While addressing any one of these areas in isolation will be of some benefit, developing integrated nutritional strategies based on an understanding of the homoeostatic and homeorhetic processes involved in the transition from a non-lactating to lactating animal will have substantial benefits. Grummer (1995) stated that "If transition feeding is important, then perturbations in nutrition during this period should affect lactation, health and reproductive performance." There is now a substantial body of evidence clearly confirming that the transition period is represents a brief but critically important period of time in a cow's life where careful manipulation of diet can impact substantially on subsequent health and productivity.

Milk Fever Prevention

The early studies conducted by Scandinavian workers (Dishington, 1975, Ender *et al*., 1962) and by Block (1984) established a new direction in research into milk fever. The Dietary Cation Anion Difference (DCAD) theory of milk fever control began with studies by Norwegian workers found that diets high in sodium and potassium and low in chlorine and sulphur tended to increase the incidence of milk fever, while those high in chlorine and sulphur and low in sodium and potassium or containing added anionic salts (AS), decreased the occurrence of milk fever (Dishington, 1975, Dishington and Bjornstad, 1982, Ender *et al*., 1962). Block (1984) found a significant increase in the incidence of milk fever for cattle fed on diets that differed only in their quantities of chlorine, sulphur and sodium. Further studies (Beede *et al*., 1992, Gaynor *et al*., 1989, Goff *et al*., 1991a, Leclerc and Block, 1989, Oetzel *et al*., 1988, Phillipo *et al*., 1994) supported the earlier findings that feeding diets containing higher concentrations of chlorine and sulphur can reduce risk of milk fever. Increasing potassium in the diet causes hypocalcaemia (Horst *et al*., 1997).

Application of DCAD theory to prevent milk fever aims to reduce the plasma pH, resulting in strong ion metabolic acidosis. This is can be achieved by feeding salts of the strong cations ($CaCl_2$, $CaSO_4$, $MgCl_2$, $MgSO_4$, NH_4Cl and $(NH_4)_2SO_4$) or acids of the anions (HCl and H_2SO_4). The strong cations Ca^{2+}, Mg^{2+} and NH_4^+ are absorbed to a lesser extent from the GIT than are the strong anions Cl^- and SO_4^{2-}. This results in a relative excess of absorbed anions compared to absorbed cations lowering the [SID^+] and subsequently plasma pH. Salt (NaCl) and KCl have a net effect of zero on the [SID+], because Na^+ and K^+ are absorbed with near 100% efficiency in the intestine. The efficacy of acidification can be monitored by evaluating the pH of urine. Jardon (1995), based on personal experience and communication with other researchers, suggested that a urinary pH of 6-7 was optimal for Holstein cattle and a pH of 5.5-6.5 was optimal for Jersey cattle to indicate metabolic acidosis. Charbonneau *et al*., (2006) concluded that a urinary pH of 7.0, regardless of breed, may be more appropriate for transition cattle.

The review and meta-analysis of Lean *et al*., (2006) developed the following equation for predicting the milk fever risk based on pre-calving dietary constituents; milk fever risk could be predicated from the dietary levels of calcium, magnesium, phosphorus, DCAD as calculated by (Na^+ + K^+) – (Cl^- + S^{2-}), breed and duration of exposure to the diet [-5.76 + 5.48 (Ca) –5.05 (Mg) + 1.85 (P) +0.02 (DCAD) – 2.03 (Ca^2) + 0.03 (Days of Exposure)]. Importantly, this linear relationship between DCAD and milk fever risk (Lean *et al*., 2006) predicts that any reduction in the DCAD will decrease the risk of milk fever. This linear relationship should not be confused with the curvilinear relationship between DCAD and urine pH with DCAD having little impact on urine pH until it reaches approximately 200 mEq/Kg DM. The curvilinear relationship between urinary pH and DCAD reflects renal buffering systems that maintain an alkaline urinary pH until overwhelmed.

The aim of DCAD manipulation of pre-calving diets must be to reduce milk fever risk and not necessarily manipulate blood or urine pH. A target dietary DCAD of 0 meq/Kg or less is appropriate.

The quadratic effect of calcium present in both the models developed by Oetzel (1991) and Lean *et al*., (2006) supports a hypothesis that either low dietary calcium percentage (Boda and Cole, 1954, Goings *et al*., 1974, Wiggers *et al*., 1975) or high dietary calcium percentage (Lomba *et al*., 1978, Oetzel *et al*., 1988) fed pre-calving reduces milk fever risk.

At present we recommend controlling calcium concentrations in the diet to around 0.6% before calving. The equation developed by Lean *et al*., (2006) predicts that the effect of increasing Mg concentration in the pre-calving diet is a very substantial decrease in the risk of milk fever. Magnesium concentrations in the diet before calving should be in the range of 0.45% and phosphorus concentrations should be controlled to <0.4%.

Aims and applications of integrated transition management

The aims of transition can be summarised in the establishment of four freedoms. Cattle should be; free of macromineral deficiency (conditioned or otherwise); free of lipid mobilisation disorders; free of immune suppression and free of ruminal disruption. A series of studies were conducted to evaluate the impact of transition diets designed to achieve these goals on production, health, reproduction and metabolism of cattle. A prospective cohort study was used to examine the effect of increasing days of exposure to 'optimally' formulated pre-calving diets on subsequent production (DeGaris *et al*., 2004a); reproduction (DeGaris *et al*., 2004b) and health (DeGaris *et al*., 2004c) There were 1008 dairy cows from three herds enrolled in the study. Prepartum transition diets consisted of ryegrass pasture, ryegrass silage, cereal hay, grain, by-products, oilseed meals, BioChlor®, rumen modifiers, $MgSO_4$, minerals and vitamins. Diets provided, on average, 9.9 MJ metabolisable energy per kg dry matter (DM), a metabolisable protein balance of 286 g/day and a dietary cation anion difference of −150 meq/kg DM. Statistical models controlled for herd, calving day, age and gestation period. These inclusions were used to supply the energy density, anions, proteins, macrominerals, vitamins and trace elements required for pre-calving cows. The rumen modifiers were included to control the risk of acidosis and to control the risk of ketosis and other lipid mobilisation disorders. The macro mineral concentrations of the diet were consistent with those required for milk fever prevention as evidenced by the extremely low rate of milk fever across the study period (< 0.5%).

Increasing exposure to the pre-calving diet significantly increased 4.0% fat and 3.2% protein corrected milk (FPCM) yield and milk protein yield as a linear and quadratic effect (Figures. 1 and 2). The increase in production found between minimal exposure (3 days or less) and optimal exposure (22 days for FPCM and 25 days for milk protein) was approximately 3.75 liters FCPM per day and 100 g of milk protein per day (DeGaris *et al*., 2008). The magnitude of this effect is similar to those seen by Corbett (2002) and DeGroot (2004) who used

BioChlor based transition diets. Increasing exposure to the pre-calving di*et al*so significantly improved reproductive measures and lowered the risk of removal from the herd. The risk of breeding per day exposed to the pre-calving diet significantly increased the risk of breeding by 1.015 (95% CI = 1.004 to 1.027). The risk of conception per day of exposure also significantly increased by 1.019 (95% CI = 1.008 to 1.030). This effect is large and is well demonstrated in Figure 3, showing the cumulative pregnancy rate for cows exposed to the diet for less than 10 days, those exposed for 10-20 days and those cows exposed for more than 20 days. The risk of being removed from the herd by day 150 of lactation due to voluntary culling or death per day decreased significantly by 0.047 (95% CI = 0.913 – 0.981) with each day exposed to the transition diets.

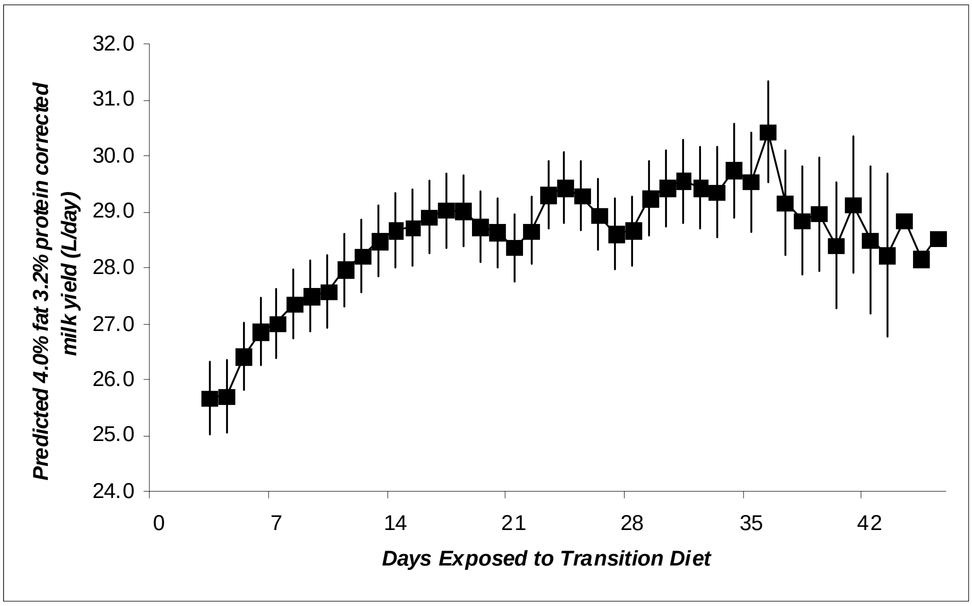

Figure 1. Four-day moving average and 95% confidence interval of predicted FPCM yield with increasing days exposed to the pre-partum transition diets.

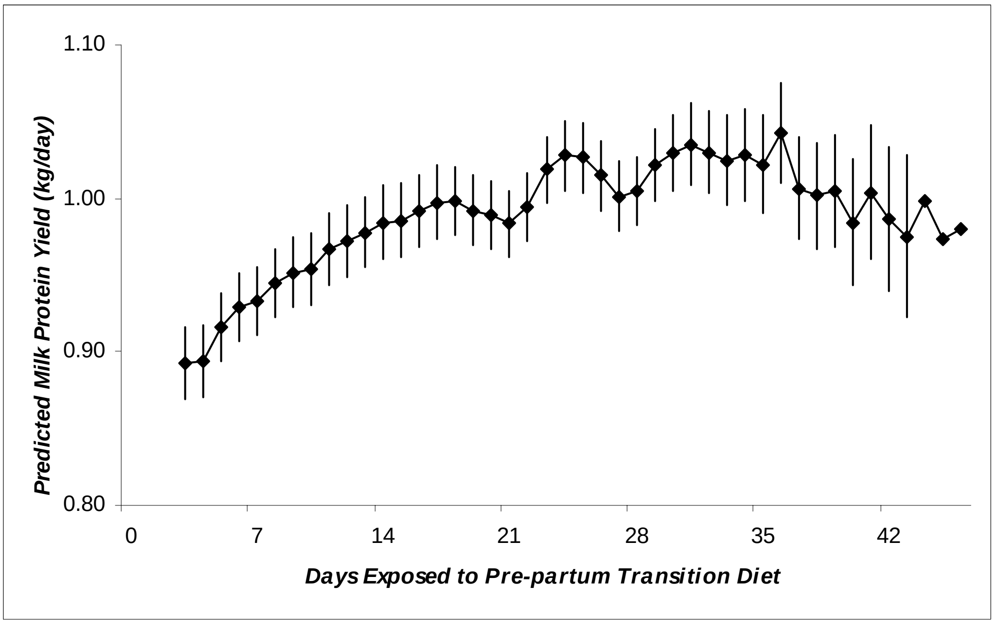

Figure 2. Four-day moving average and 95% confidence interval of predicted milk protein yield with increasing days exposed to the pre-partum transition diets.

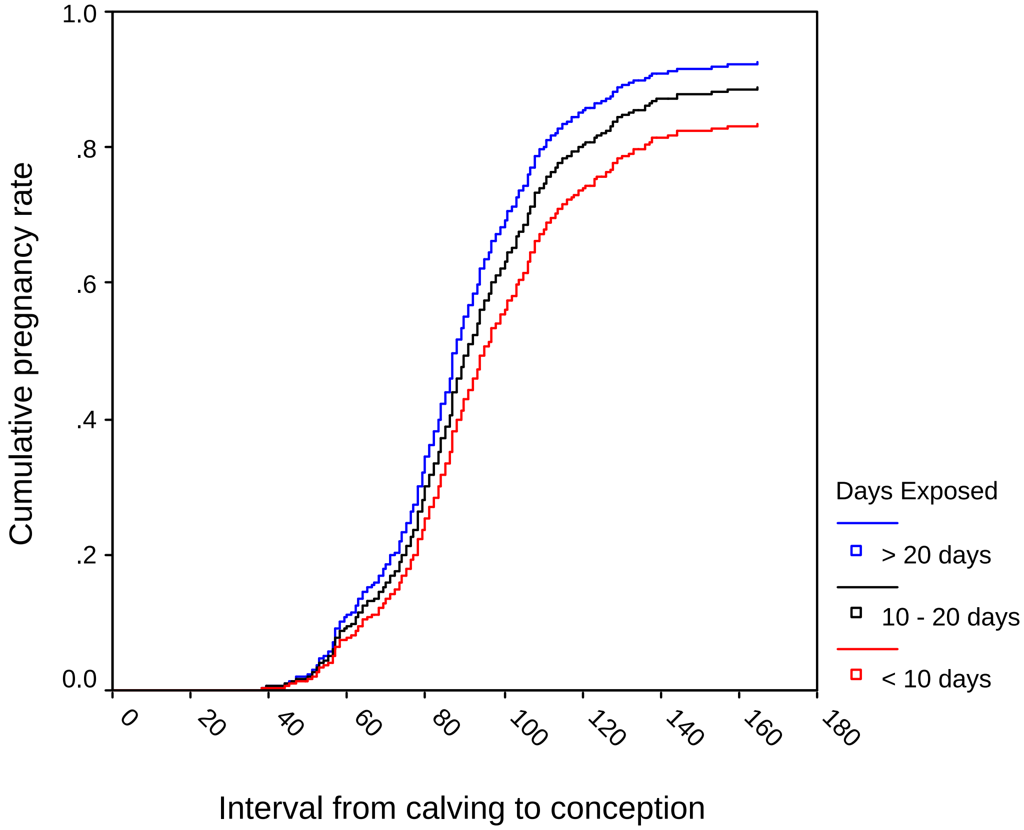

Figure 3. Cumulative pregnancy rate for cows exposed to a BioChlor-based pre-partum transition diet for < 10 days, 10- 20 days and > 20 days.

In a third study, we attempted to understand the metabolic relationships underlying the profound responses to the transition diets. Forty cows were bled bi-weekly from the introduction to the prepartum transition diet until day 35 of lactation. Blood samples were submitted for estimation of a range of metabolites. Cubic smoothed splines were fitted to scatterplots of metabolite concentration as a function of day relative to calving and the area under the curve (AUC) was calculated. Linear regression modelling determined the effect of days exposed, age, body condition score and calving day on AUC. The prepartum AUC of blood phosphorus and beta-hydroxybutyrate increased and the AUC of blood calcium and cholesterol decreased with increasing days exposed to the diet (Figures 4 and 5). The postpartum AUC of beta-hydroxybutyrate and non-esterified fatty acids decreased with increasing days exposed but increased with days exposed × age and days exposed × body condition score (BCS), respectively. The AUC of other metabolites did not vary significantly with days exposed. Increasing exposure to the prepartum diet significantly altered the AUC of blood metabolites associated with mineral, energy and protein metabolism. These homeorhetic adaptations are consistent with improvements in production and reproduction reported in (DeGaris *et al*., 2009) and the result suggests links between energy, protein and skeletal metabolism.

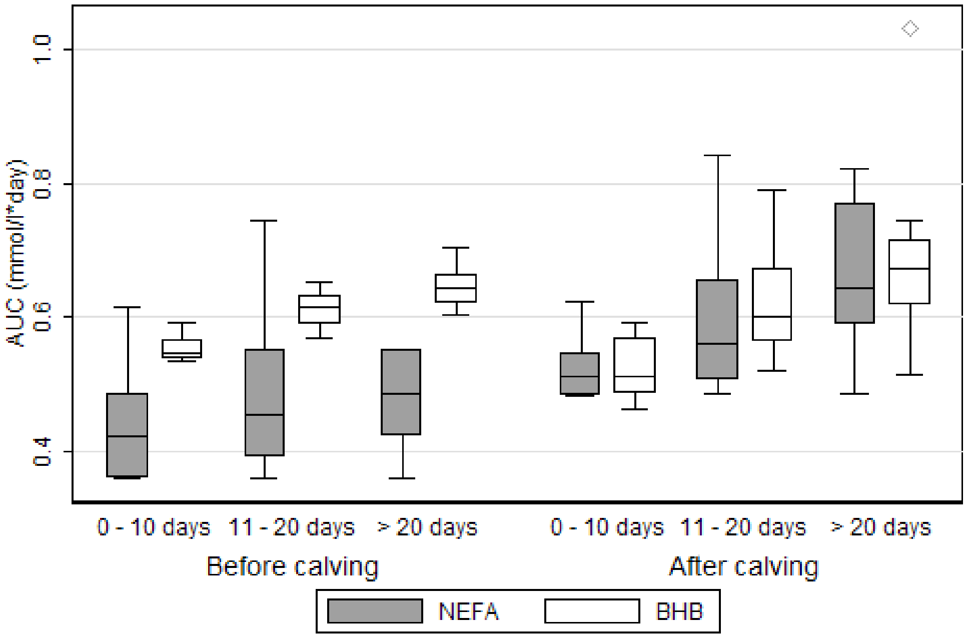

Figure 4. Boxplots of the predicted AUC (mmol/l*day) for the periods day ¯10 to calving (before calving) and calving to day 35 of lactation (after calving) for blood NEFA and BHB for the cows exposed to the pre-partum transition diet for 0 – 10 days, 11 – 20 days and > 20 days.

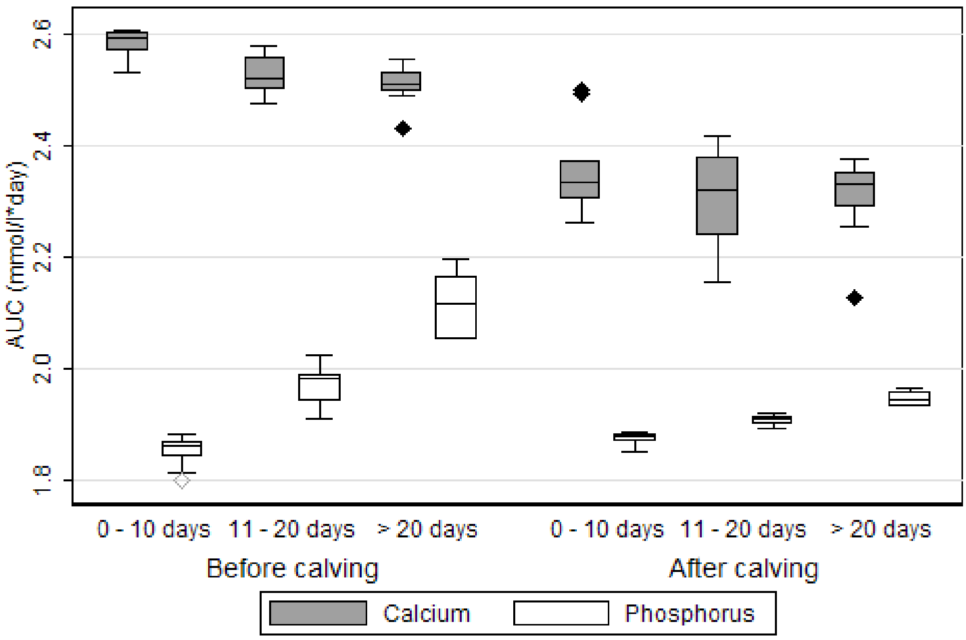

Figure 5. Boxplots of the predicted AUC (mmol/l*day) for the periods day minus 10 to calving (before calving) and calving to day 35 of lactation (after calving) for blood calcium and phosphorus for the cows exposed to the pre-partum transition diet for 0 – 10 days, 11 – 20 days and > 20 days.

A review of transition feeding which includes a series of practical recommendation on the application of transition diets has been commissioned by Dairy Australia (Lean and DeGaris 2010 in press). This document can be consulted for greater detail on the pathophysiology of the transition period and for practical information on feeds and feeding strategies involved.

Our findings, overall, suggest highly integrated up-regulation of metabolism with increased exposure to the transition diet. This increase in metabolic activity is reflected in increased concentrations of metabolites, glucose, free fatty acids, cholesterol and ketones, which reflect energy and protein metabolism, and also in increased milk production. Whether this up-regulation is mediated through the somatotropic (growth hormone) axis or bone-related mechanisms or both need to be examined in further studies. Indeed, the observed up regulation of metabolism raises many questions that are critical to answer; How much further can we up-regulate production by pre-calving nutrition? Can we even more markedly improve reproductive performance? What are the effects on the calf of the transition diet either directly or indirectly? Lastly, the pathways through which these effects are mediated require further understanding. Investigating these questions and others should provide exciting directions for research and better outcomes for farmers and cattle.

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FARMING FOR A HEALTHY FUTURE – THE CLOVER HILL DAIRIES STORY

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Abstract

Our milk business produces 5 million litres per year from 400 cows milked 3 times daily on two farms. The farm and the 12 rural residential landholders have formed an incorporated landcare group to work together to protect and enhance the unique community environment of farming land, rainforest and waterways and ensure the dairy farm is a long term thriving commercial enterprise. The farm is one of Australia's most water efficient milk production systems producing 125,000 litres of milk per mega litre of captured water compared to the industry average of 3,500 litres. Optimising pasture ground cover allowing us to run 4 to 5 cows to the hectare, produce 50,000 litres milk/ha and reduce nutrient runoff in high rainfall events. This not only increased milk production by 20% and litres of milk/megalitre of captured water to water use efficiency of 35x industry average, it simultaneously reduced greenhouse gas emissions by 30% per litre of milk produced. As a result, 50% of Clover Hill farm is fenced off from the cows and is now protected high conservation value rainforest which has benefits to the wider catchment and the community it supports. We protect our right to farm by actively involving local communities, communicating our journey and involving them in on farm natural resource management activities. Of particular value is our dedication to showcasing sustainable farming practices to government agencies, regional NRM bodies, schools and local government. Beyond the farmgate Clover Hill Dairies team work closely with the local communities and industry stakeholders to build industry and community understanding of the benefits of implementing practices that improve both productivity and environmental outcomes. An example of this is the highly successful Picasso Cows Natural Resource Management Program. Participating students, schools and their communities all rated the program highly. Encouraging and furnishing opportunities for young people to enter food value chain career pathways.

Introduction

Sadly Australia is complacent about the challenges to food security. There is a lack of appreciation by society in general of the interdependence of environment, agriculture, food and health. If we are to progress and fuel the mushrooming food needs of the cities while meeting the community's expectations for environmental sustainability, then both rural and urban communities must have greater mutual empathy. Farmers today see themselves equally as dedicated to the health and sustainability of the land on which they work and live, as to the production of food and fibre. Meanwhile urban consumers often purchase their food and fibre with some innate suspicion or little knowledge of the value chain that provides it. This is a dilemma for modern farmers. More and more communities and governments are showing a lack of confidence and questioning our ability to make sensible decisions. They are adding red and green tape for primary producers on issues such as workplace safety, pesticide use, noise and odour management, land use planning and animal welfare regulations, all in the apparent interest of the wider community. This challenges our right to farm and imposes costs and stressors that are difficult to pass on when social license moves to social control. What affects farmers, affects every-one as a healthy agriculture sector is important for all businesses and service providers along the food value chain. This is the challenge – how do we fix it? At Clover Hill Dairies we started with a mission to “be” the image we want our customers to see. Our customers want to purchase from farmers who practice the things they value – whether it be animal welfare or environmental protection. They want food produced in a way that is consistent with their own personal values and our aim has been to develop a highly efficient dairy system on a small acreage that meets or exceeds those consumer expectations. We know that building trust with consumers will be what sets apart the successful primary producers of the future.

The milk business

Clover Hill Dairies is a 7th generation family-operated business located at Jamberoo on the NSW South Coast. Our milk business produces 5 million litres per year from 400 cows milked 3 times daily on two farms. We (myself, husband Michael and son Nicholas) have developed a highly efficient, sustainable and profitable farming enterprise that supports agricultural production, biodiversity and minimises the contributions of climate change. Although our two farms are located within two kilometres the topography is very different.

The home farm Clover Hill (Farm 1) is situated on the northeast face of Saddleback Mountain at Jamberoo NSW. Located at the headwater of three major tributaries of the Minnamurra River, a sensitive wetland and mangrove environment, Clover Hill is 100 ha in total, of which only 50ha is farmed. The remaining 50ha contains large areas of important high conservation value remnant rainforest and is fenced off to prevent stock access. Clover Hill is unique not only is it located in very steep rainforest country it is also part of a dairy-centric rural residential subdivision of blocks ranging from 0.4ha to 40ha. The farm and the 12 rural residential landholders have formed an incorporated landcare group to work together to protect and enhance the unique community environment of farming land, rainforest and waterways and ensure the dairy farm is a long term thriving commercial enterprise. At Clover Hill we milk the fresh herd of 180 cows (up to 150 days in milk) three times daily. The farm is one of Australia’s most water efficient milk production systems producing 125,000 litres of milk per mega litre of captured water compared to the industry average of 3,500 litres (Dairy Australia). The herd holds numerous milk production records. Our commitment to stewardship starts from the ground up. We focus on maintaining good soil fertility and structure and grass cover with pastures based on kikuyu and Italian ryegrasses. This has helped avoid the problems of erosion, soil loss and plugging associated with other high-intensity farms.

Cow Nos	200 milkers
Effective Area	50ha
Stocking rate	4cows/ha
Breed	Registered Holsteins– Nth American Genetics
Production	170,000 kgMS/yr trend is
	34000 kgMS/ha trend is
	850 kgMS/cow trend is
Somatic Cell	$<200 \text{ X}10^{3}$ trend is
Lactation No Average	4.5
Feed conversion Efficiency	1.7
Water Use Efficiency	125,000 litres milk/mega litre of captured water/ year
Pasture Management System	Zero tillage and herbicide
	Kikuyu base overplanted with annual rye/oats
Supplements Fed	3.6tonne/cow/yr trend is
Rainfall	1500mm to 2000mm/yr No irrigation
Soil type	Clay loam
Soil Carbon %	Variation is 5 to 12% with upward trend
Farm nutrient balance for NPKS	Biannual nutrient mapping and annual nutrient budget
Topography Gradient	Steep 5-6
Effluent Disposal	1 portable sprinkler
Fertiliser Use	300kgN/Ha/yr trend and manures to provide maintenance P and K, liming as necessary

Lemon Grove Research Farm PL (Farm 2) was established in 2008 to diversify our enterprise. It is 60ha of alluvial river flats at the head of the sensitive Minnamurra River flood plain. We milk a further 220 cows (150 days in milk plus) 3 times daily here and also undertake agronomic and pharmaceutical milk trials. This farm also has a high urban interface being located adjacent to the Jamberoo Township and receives 33% less rainfall than Clover Hill. Our business has experienced phenomenal growth in the past 10 years that has seen us increase milking cow numbers from 80 to 400, milk production from 800,000 litres to 5 million litres per year and simultaneously reduce green house gas emissions per litre of milk produced by 30% (Greenhouse in Agriculture) on just twice the amount land.

Cow No's	Target 240 in milk
Effective Area	60 ha
Stocking rate	4 cows/ha
Breed	Holsteins – Nth American Genetics
Production	Target 12000L 840kgMS/cow,
Somatic Cells	<200 x 10^3 trend is
Pasture Management System	Zero tillage 50% Kikuyu base overplanted with annual rye/oats and 50% perennial legumes, herbs and brassicas over planted with annual rye/oats
Supplements Fed	3.6 tonne/cow/yr (on pro rata basis per farm)
Rainfall	1300mm to 1500mm
Soil type	Clay loam
Soil Carbon %	Varying between 5-12% with upward trend
Farm nutrient balance for NPKS	Biannual nutrient mapping and annual nutrient budget
Topography Gradient	Alluvial river flats and flood plain
Effluent Disposal	Solids trap and traveler irrigator
Fertiliser Use	Nitrogen as urea, effluent manures to provide maintenance P and K, liming as necessary

Clover Hill Dairies climate change strategy is to minimise emissions per unit of milk produced by:

- having an efficient system so we can adapt and minimise our footprint
- using less resources and using them smarter so we can minimise the impact on our business of Climate Change legislation and any costs associated with that legislation

On farm changes in the last 10 years to improve on farm energy efficiency include:

I. Increasing milk production by selecting cows that can more efficiently convert pasture to milk and supplementing their pasture diet with energy dense grains and nutrients that improve cow health and increase milk production.

II. Optimising pasture ground cover (17- 20 tonnes DM/ha/year) allowing us to run 4 to 5 cows to the hectare (2x industry average; Dairy Australia), produce 50,000 litres milk/ha (5x industry average; Dairy Australia) and reduce nutrient runoff in high rainfall events.

III. Optimising the productivity of the cows and the land by moving from twice-a-day milking to milking three times a day in 2005. This not only increased milk production by 20% and litres of milk/megalitre of captured water to water use efficiency of 35x industry average, it simultaneously reduced greenhouse gas emissions (GHGE) by 30% per litre of milk produced

IV. Improving farm efficiency and productivity of pastures enabled us to lock-up less productive land for conservation purposes. As a result, 50% of Clover Hill farm is fenced off from the cows and is now protected high conservation value rainforest which has benefits to the wider catchment and the community it supports.

V. Recycling 50% of our captured water has allowed us to achieve water use efficiency/ha of 10 times the industry average.

VI. Improving overall business productivity and profitability allowing us to increase staff numbers from 1 full time equivalent (FTE) in 2000 to 4 FTE and 4 part-time which both actively supports the local economy while also improving our farm management effectiveness and quality of life.

And at Lemon Grove Research Farm PL :

I. Researching and planting new water and nutrient efficient perennial pasture mixes that are:

- Accessing moisture and nutrients leached into the deeper soil profile by our high rainfall events.
- Improving our drought resilience.
- Responding well to nutrient supplied by our dairy effluent and also recycling this valuable pool of nutrients.
- Providing high quality fodder and improving milk production during autumn and winter when this is traditionally challenging in our region.
- Delivering sustainable triple bottom line outcomes by efficiently using effluent nutrients while reducing deep leaching losses into the water table and allowing us to take advantage of higher milk prices paid by our processor in autumn and winter.

Cow to Consumer

Clover Hill Dairies dedication to, and promotion of sustainable farming practices extends well beyond the farmgate. We seek to enhance, enrich and promote the whole food and fibre chain from paddock to plate

Beyond best farming practices the Clover Hill Dairies team is committed to:

I. Forging cross community partnerships to secure our social licence to operate and right to farm

On farm a key success factor in the development and implementation of Clover Hill Dairies sustainability plan is our commitment to remain ahead of the curve by examining closely where society is heading and the environmental challenges arising and moving into that space with clear goals and areas of expertise. We protect our right to farm by actively involving local communities, communicating our journey and involving them in on farm natural resource management activities. We speak to their children in our locals schools and employ their youth on our farm. We actively seek information from industry experts, natural resource management agencies and research scientists about new technologies and concepts that can improve resource use efficiency whilst enhancing environmental outcomes. We work closely with the landholders on our rural residential subdivision at Clover Hill. Together we have engaged a bush regeneration officer who has an honours degree in environmental science and formed a partnership with Landcare Illawarra to collect seed from our remnant Illawarra Lowlands Grassy Woodlands and Sub-Tropical Rainforest Endangered Ecological Communities to ensure local provenance is maintained. The seed is grown by local nurseries that have the skills and capacity for this work and the seedlings are planted with the assistance of Conservation Volunteers Australia and local youth groups to increase the biodiversity and climatic adaptability of our high conservation value landscape areas

The Clover Hill Dairies Farm Management Plan ties into Southern Rivers CMA targets and the South Coast and Tablelands Dairy Industry projects on neighbouring dairy farms. Our farm management plan complements work conducted in the catchment on dairy and beef farms by Southern Councils Group and Small Farms Network

Our commitment to pursuing environmental excellence whilst improving productivity outcomes is highly valued by the Australian community as witnessed by our recent 2010 National Landcare Primary Producer Award. Of particular value is our dedication to showcasing sustainable farming practices to government agencies, regional NRM bodies, schools and local government.

Our sustainable practices and innovations are transferable to the wider farming community and to facilitate this we are sharing our learnings with internal and external stakeholders via field days, the media and a series of case studies and fact sheets on our website www.cloverhilldairies.com.au/resources.html

Beyond the farmgate Clover Hill Dairies team work closely with the local communities and industry stakeholders to build industry and community understanding of the benefits of implementing practices that improve both productivity and environmental outcomes. An example of this is the highly successful Picasso Cows Natural Resource Management Program. Partner Lynne has been successful in designing and attracting over $100,000 sponsorship to pilot 'Picasso Cows' an award winning agricultural and environmental education and awareness program which saw primary schools students paint life size fibreglass cows in one of three environmental themes “Healthy Landscapes” “Clean Water” and Energy Efficiency” and participate in on-farm landcare projects .

Outcomes from Picasso Cows were monitored by entry and exit surveys. In terms of creating greater awareness and understanding about environmental issues this program was an outstanding success. Participating students, schools and their communities all rated the program highly. The program has delivered a much greater appreciation of dairying as an industry and the environmental considerations that are necessary to have a sustainable dairy industry. Through public displays both regionally and at the Sydney Royal Easter Show the students’ Picasso Cows and the program’s key messages have been viewed by over tens of thousands of people. This program has now been handed over to Dairy Australia who are rolling it out to 400 schools across Australia over the next three years

II. Encouraging and furnishing opportunities for young people to enter food value chain career pathways

Clover Hill Dairies works with a number of local and international universities in the UK and Canada, opening the farm for work experience, as a case study for honours and PhD theses and as a research facility. Clover Hill Dairies also provides a wide range of opportunities for school students including traineeships and work experience. The Clover Hill Dairies team are active participants in the Cows Create Careers initiative providing their time and services as industry advocates and mentors. Through Cows Create Careers students, teachers and parents are more aware of the variety of careers that the dairy industry has to offer and more students are entering dairy education pathways and careers.

III. Building lifelong relationships between city consumers and rural providers.

The farm team are passionate industry advocates dedicated to bridging the urban/rural divide and promote programs showcasing the people and places behind the food we eat encouraging students into farming and strengthening ties between the city and country. Recognising that farming practices are moving much faster than educational resource development, Clover Hill Dairies has developed and implemented agriculture education and awareness programs that build partnerships with teachers, students and the community and show them the science and technology, animal welfare and environmental stewardship commitment of farmers in 2010 and beyond. Over 5000 children have been involved in our campaigns in NSW over the past three years. Our programs are fun, genuine and full of hope for a sustainable future and have attracted considerable support from funding partners across the food value chain. Partner Lynne is chairman of, and mentor to Dairy Youth Australia Inc. Lynne is also funding seeker for Dairy Youth Australia Inc and has recently accessed $150,000 from stakeholders including large corporates such as Woolworths and the GPT group to design and deliver community events that are a true celebration of the diversity, sustainability, creativity and progress of primary industries, their people, place and produce

Dairy Youth Australia programs include:

I. The **Cream of the Crop** Competition

Find further information at www.dairyyouthaustralia.com.au/creamofthecrop . The 2009 winning entries are loaded on the web and have attracted over 9,000 hits in 4 months, proving the community is interested in contemporary authentic, positive and popular stories about agriculture and the environment written by young people for young people.

II. The Archibull Prize

Find further information at www.dairyyouthaustralia.com.au/archibull - our 2010 signature program.

Currently 1500 students in 14 western Sydney schools are involved in this program which invites students in suburban high schools to learn with hands on experience about the challenges of housing and feeding the world and the competition for natural resources. Once again we use art to explore current issues in Australian agriculture. The finished artworks and curriculum activities must explore and communicate contrasting stories about the future of agriculture in their local area under the theme "Love it Or Lose It".

Conclusions

In the past 30 years we have become acutely aware from our neighbours and visitors that we (as farmers) have to dramatically improve our efforts to build trust with the wider community - our customers. This takes time and commitment. We found that generally people are wary of modern farming methods and technology. Equally engaging with the community on so many levels has opened our eyes to the passion they do share for agriculture and their thirst for knowledge. To change perceptions we need ``grass roots'' action; Farming men and women who can get out there and sell the message that agriculture is alive and well. Farmers today have to be out in their communities, committed to ``walking the talk'' so to speak from paddock to plate, from cow to consumer, building TRUST between rural and urban communities. We must engage with the urban communities now so they feel connected with the bush and understand the efforts taken by farmers to protect the natural resource base. They must see responsible agricultural production as a legitimate use of land, water and other resources. We need to show them that agriculture has a future and is a great career for their children. A profitable and sustainable healthy future for the farming sector is achievable - the health and welfare of all Australians, and many people around the world depends on it.

References

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RECENT ADVANCES IN THE MANAGEMENT OF PRODUCTION DISEASE IN DAIRY COWS

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Abstract

While there will always be more to learn about individual diseases of production, a significant body of knowledge already exists which should allow us to control and prevent these diseases in dairy cows. This paper presents a practical, on-farm approach for the monitoring and prevention of production disease in dairy cattle with a focus on the transition period. It is an integrated approach, which can be used in an interdisciplinary way by farmers, veterinarians, nutrition advisors and other relevant professionals for the improvement of animal health and welfare and producer profitability. The key areas that form the basis for this approach are negative energy balance including body condition score management, hypocalcaemia, rumen health (SARA) and trace element status. Monitoring criteria are described for each of these key areas, which when considered collectively, will facilitate the assessment of dairy cow health with regard to clinical and sub-clinical disease.

Introduction

The European Commission recently requested expert scientific opinion on the welfare of dairy cows (Annex to the EFSA Journal 2009). This report highlighted production diseases as indicators of poor welfare in dairy cows and stressed that **'**long term genetic selection for high milk yield is the major factor causing poor welfare, in particular health problems'. The report stated that 'there is an urgent need to promote changes in the criteria used for genetic selection in the dairy industry' and that greater 'weight should be given to fitness and welfare traits when these may conflict with selection for milk yield. Genetic selection for improved fertility, health and longevity is likely to improve welfare and lead to greater profit for the farmer'. Specifically, in the context of production diseases, the report stressed that all dairy cattle should be fed a diet that provides sufficient energy, nutrients and dietary fiber to meet the metabolic requirements in a way that is consistent with digestion. The report underlined the importance of controlled transition feeding as well as the provision of continuous access to drinking water independent of diet.

Reduced longevity in modern dairy genotypes reflects the impact of production disease (Knaus 2009) and sustainably competitive systems of agricultural production in the future will require optimal animal health and welfare as key features, Figure 1 (Downey *et al* 2008). While significant advances have been made in our understanding of infertility and animal health in the dairy sector, the incidence of production-related diseases in many herds remain similar to those published decades ago and infertility problems are being experienced in virtually all major dairying countries. The production diseases of the transition dairy cow reflect the cow's inability to cope with the metabolic demands of high production and internationally they continue to be a cause of economic loss to the dairy industry and an animal welfare concern (Mulligan and Doherty 2008). While, traditionally regarded as encompassing the significant metabolic disorders of dairy cows (hypocalcaemia, hypomagnesaemia and ketosis), the term production disease has been broadened to include conditions such as retained placenta, left displaced abomasum (LDA) and laminitis.

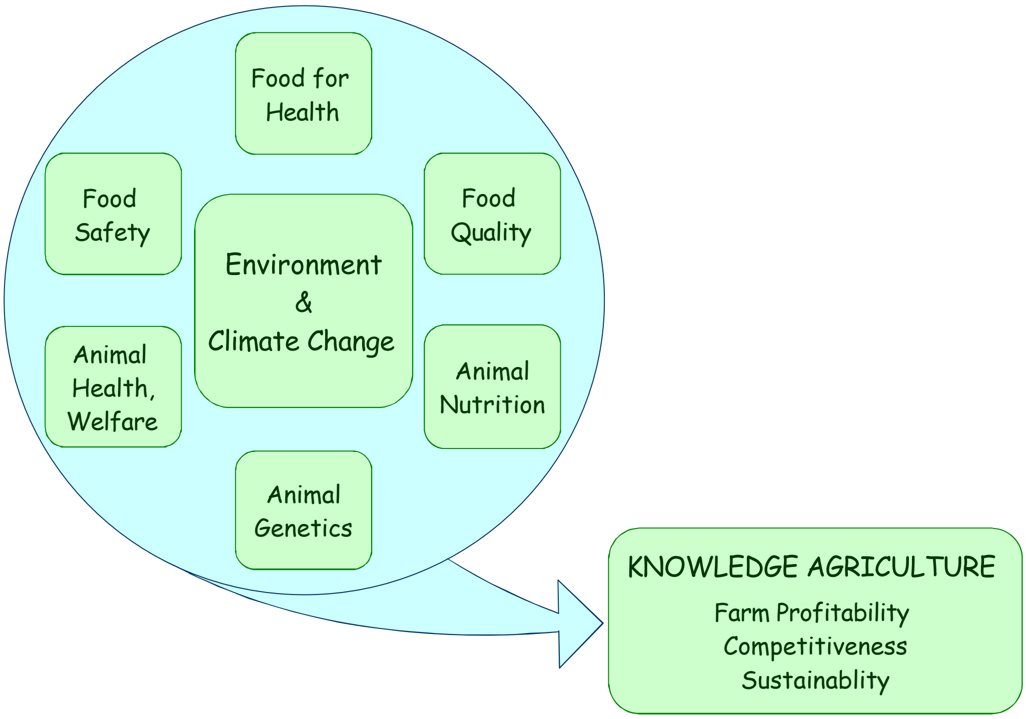


Figure 1. Sustainable Production Systems

(*Downey et al. 2008)*

The recent 14th International Conference on Production Diseases of Farm Animals at the University of Ghent in June 2010 included presentations on a possible immune-mediated basis for post-partum calcium mobilisation in the cow (Jonsson *et al* in press), tissue insulin sensitivity in the pathogenesis of negative energy balance (Van Saun in press) and an examination of the role of lipopolysaccharide in the context of the rumen 'microbiome' in sub-acute ruminal acidosis (Krause in press). However, while there will always be more to learn about individual diseases of production, a significant body of knowledge already exists which should allow us to control and prevent these diseases. In the challenging milieu of the modern dairy farm, veterinarians are rarely presented with uncomplicated herd-level problems of conditions such as hypocalcaemia. Thus, cows in negative energy balance are more likely to develop clinical ketosis, mastitis, retained fetal membranes and left displaced abomasum with obvious implications for herd health and welfare, milk production and fertility. It is the complex interaction of these diseases, their relationship with nutritional strategy and housing environment, their ability to impact on the expression of infectious disease such mastitis and the fundamental influence of social and attitudinal factors that make prevention and control of these diseases such a herd health challenge. This paper provides an update on the management of the production diseases as they relate to the transition cow and presents approach based around the experience of the Herd Health

Group at University College Dublin with dairy farmers participating in herd health programmes. This approach has been developed in the context of the Irish dairy industry with its seasonal emphasis on calving in spring and the production of milk from pasture. The approach adopted is an interdisciplinary professional one, relying upon teamwork involving the farmer, veterinarian, nutritionist and other agricultural advisors as appropriate.

The Transition Period

Grummer (1995) described the transition period as the period from 3 weeks pre-calving until 3 weeks post-calving. The transition period is characterised by marked changes in the endocrine status of the animal that are much more dramatic than at any other time in the lactation–gestation cycle, and a reduction in feed intake when nutrient demand for the developing conceptus and the impending lactogenesis are increasing (Grummer 1995). The initiation of milk production has the direct effect of increasing calcium (Ca) output from the cow at a time when input of calcium cannot be increased in the short-term in many dairy cattle, while the reduced feed intake at this time creates an imbalance of energy yielding inputs relative to energy outputs.

Generic Herd Health Approach

Before attempting to implement a preventative strategy for production disorders of transition cows, it is important to understand farm performance in the context of a range of targets for the most common transition cow disorders (Table 1). Subsequently, careful monitoring of clinical data, production data, dietary analysis and environmental/management factors is used to try and identify risk factors for the occurrence of particular diseases (Figure 2).

Table 1. Target incidence rates for clinical production diseases (Adapted from Mulligan *et al* 2006)

Clinical condition	Target incidence rate
Milk fever	0–5%
Downer cow syndrome	< 10% of milk fevers
Hypomagnesaemic tetany	0%
Ketosis	0–5%
Left displaced abomasum	0–3%
Right displaced abomasum	1%
Low milk fat syndrome (milk fat < 2.5%)	< 10%
Retained placenta	< 10%
Lameness	< 10%

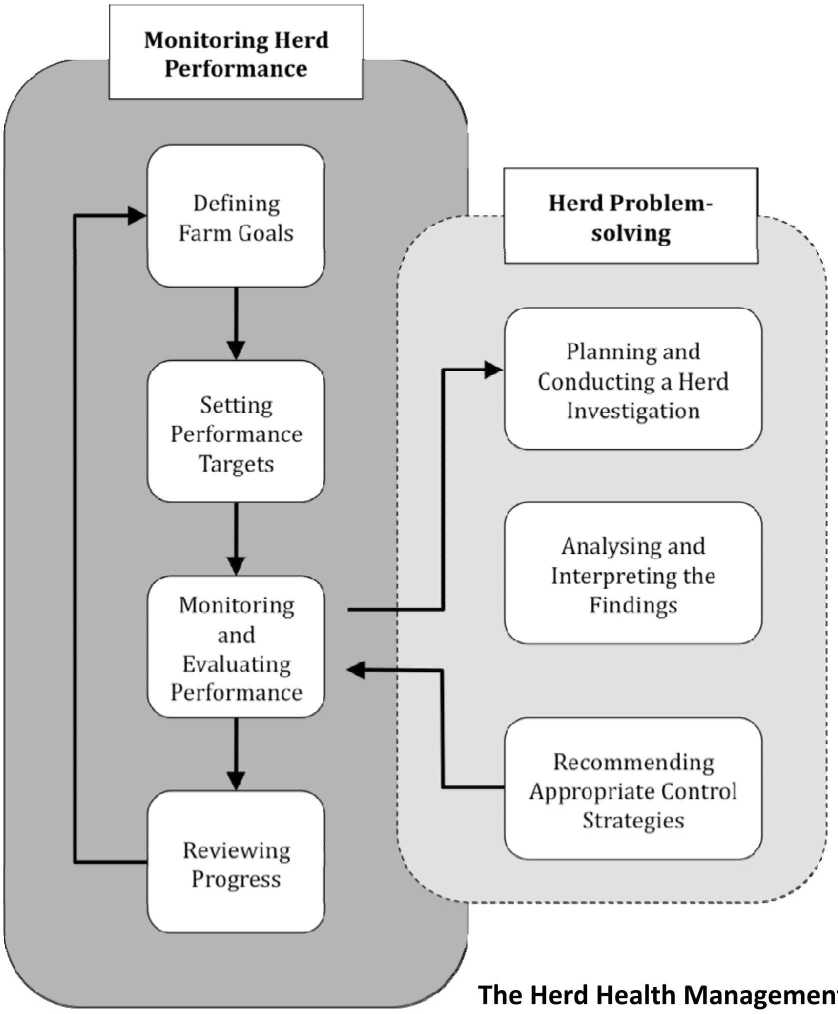


Figure 2. The Herd Health Management Cycle

Monitoring and evaluation of performance depends completely on accurate data recording and analysis. In the context of those dairy farms involved with the University College Dublin (UCD) Herd Health Group, monthly milk records (including Somatic Cell Counts), fertility events, feed analysis, transition cow health events, body condition scores, locomotion scores, treatment records and results from selected sampling for beta-hydroxybutyrate (BHB) and non-esterified fatty acids (NEFAs) are downloaded to a UCD Herd Health database for analysis and interpretation from the central national Irish Cattle Breeders Federation (ICBF) website and farmer management software packages.

Negative Energy Balance (NEB)

There are numerous consequences of a poorly managed dry and/or transition cow period that may reduce dairy cow fertility. The greatest severity of NEB experienced by early lactation dairy cows is in weeks 1 and 2 after calving. Therefore, it is important that poor husbandry practices, which may limit feed intake in early lactation dairy cows, are eliminated. For example, abrupt dietary change from the dry to lactating cow diet is very common and may have very little effect on early lactation cow milk yield. However, this practice has been shown to cause sub-clinical laminitis in some situations (Donovan *et al* 2004) and because the microbial population of the rumen has not been acclimatised to the lactating cow diet, it may restrict rumen fermentation and therefore feed intake.

The mobilisation of fatty acids from adipose tissue to support the nutrient demands of lactation is a natural biological phenomenon that occurs in most lactating mammals orchestrated by the endocrine system. However, increasing concentrations of NEFAs in the blood of the dairy cow result in the accumulation of triglycerides in hepatocytes and the impairment of liver function. This fatty infiltration of the liver is particularly significant for dairy cows as approximately 85% of glucose for metabolism is derived from the liver, which also plays a central role in feed intake regulation, fertility and immunity. Propylene glycol prevents lipolysis, while choline facilitates the export of fatty acids from the liver as very-low-density-lipoproteins. Because of their different modes of action, both may act synergistically to form a very effective supplementation strategy (Grummer 2008). It is interesting that cow management (group changes, diet changes, cow comfort, etc.) has been implicated as a factor that may potentially be more important than nutrition in the development of fatty liver. One such management strategy that has proven useful in reducing the severity of NEB and triglyceride accumulation in the liver is shortening the dry period. While nutrition and management during the transition period are obviously relevant to the development of fatty liver, late lactation feeding and historical energy status are also important, as cows that are over conditioned at drying-off mobilise more adipose tissue pre-calving than thinner herd mates (Kim and Suh 2003). Recently, it has also been shown that butaphosphan and cyanocobalamin injected on the day of calving decreased the prevalence of ketosis in mature cows as well as the levels of BHB (Rollin *et al* 2010)

In the context of negative energy balance, the maintenance of an optimal body condition score (BCS) relative to lactation stage, milk yield, nutrition and health status, throughout the lactation cycle is perhaps the most important aspect of dairy cow management that facilitates a healthy transition from pregnancy to lactation. The system of body condition scoring dairy cattle proposed by Edmondson *et al* (1989), which is based on a five-point scale (1 = emaciated; 5 = over-fat), is used in this preventative approach for production diseases. The BCS targets recommended in the present approach are shown in Table 2.

Table 2. Target Body Condition Score for dairy cattle (Holstein/Friesian) at different points of the lactation cycle

Point of Cycle	BCS
Drying off	2.75
Calving	3.0
Breeding	> 2.5
150 DIM	2.75
200 DIM	2.75
250 DIM	2.75

As outlined above, records of BCS for all cows at key stages in the lactation cycle should be compared to the targets in Table 2. Scoring is best performed with a printed version of the appropriate scale, describing individual scores, at hand, with each individual being palpated and not relying solely on visual assessment. Apart from calculating the average condition score for relevant groups of cows at key stages in the lactation cycle, the proportion of each group that deviate markedly from the target should be noted.

The transition from gestation to lactation is often a perilous time in the lactation cycle of the dairy cow. The events occurring in this period are probably among the most significant factors that predispose dairy cows to ill health. Many of the most common disease conditions that arise in dairy cows occur either in the immediate periparturient period or early in the subsequent lactation. Most veterinarians are familiar with the list of the common clinical conditions of the transition cow such as dystocia, retained fetal membranes, fatty liver, ketosis, displaced abomasum and milk fever. However, frequently little attention is given to the consequences of a poor transition period. For example, it has been shown that dairy cows recovering from milk fever are eight times more likely to develop mastitis in the following lactation (Curtis *et al* 1983), are likely to have a reduced level of immune competence (Goff 2003), will have slower uterine involution (Borsberry and Dobson 1989) and delayed first ovulation after calving (Jonsson *et al* 1999). Furthermore, research with the UCD Herd Health Group, utilising social science methodologies has revealed a poor understanding by farmers of the significance of subclinical production diseases (Devitt *et al* unpublished data). Dairy cows suffering from subclinical ketosis are eight times more likely to develop left displaced abomasum (Le Blanc *et al* 2005), while subclinical hypocalcaemia has been associated with impaired gastrointestinal motility (Goff 2003). Ultimately, the consequences of failing to successfully manage the transition period of dairy cattle will result in reduced producer profitability and reduced dairy cow welfare. The cost of increasing replacement rate from 20% to 30% for a 100-cow dairy herd in Ireland ranges from €6,750 (Donnellan *et al* 2002) to €9,600 (Ryan and O'Grady 2004).

Transition cow health: body condition score (BCS)

Although the actual strength of the association is variable, lower calving BCS is associated with reduced production and reproduction, whereas calving BCS ≥3.5 is associated with a reduction in early lactation dry matter intake (DMI) and milk production and an increased risk of metabolic disorders (Roche *et al* 2009). The most significant problem experienced by the UCD Herd Health Group is that of over-conditioned cows at calving both in herds with a year-round calving pattern and spring-calving herds. Therefore, achieving optimal BCS at calving is one of the most important aspects of good transition cow management. However, this requires monitoring and recording BCS throughout the lactation cycle.

Transition cow health: energy balance

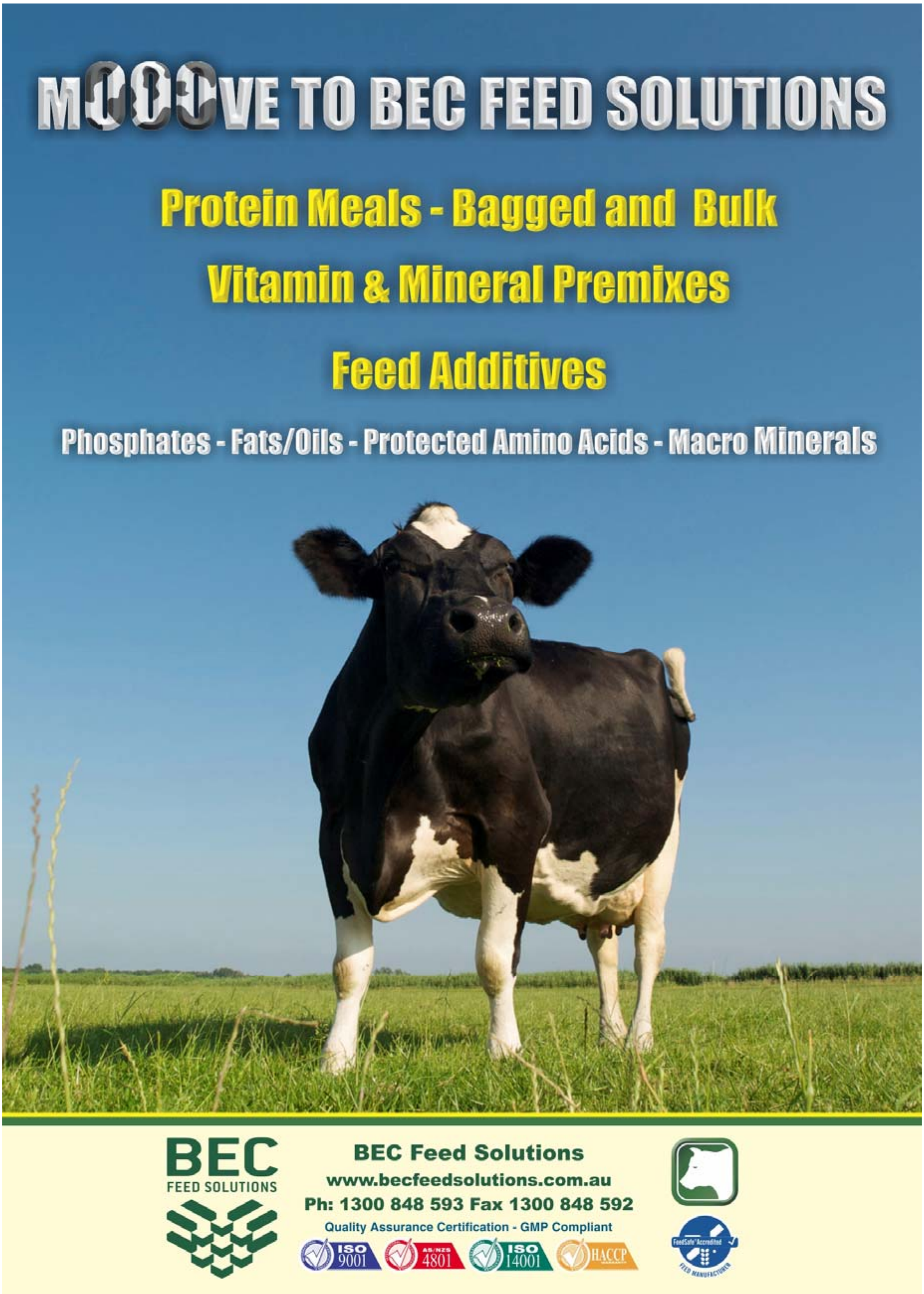
Negative energy balance before calving has been associated with the development of LDA (Le Blanc *et al* 2005). Similarly, dystocia, retained placenta, fatty liver and ketosis, reduced feed intake after calving and immunosuppression have all been related to negative energy balance before calving. In order to avoid this, all efforts to avoid a large reduction in feed intake immediately prior to calving should be made. This means avoiding unnecessary stress and the use of poor quality diets in the last 2 weeks pre-calving and not having cows calve before they are moved to the calving group. Furthermore, overfeeding energy pre-partum resulted in large changes in periparturient energy balance. Even in the absence of over-conditioning, a large change in DMI and energy balance pre-partum influenced post-partum DMI and BCS loss, especially for multiparous cows. Chopped wheat straw was effective at controlling energy intake pre-partum, although primiparous cows did not achieve predicted DMI. Even so, controlling or restricting energy intake in primiparous cows was not detrimental to lactational performance over the first 8 weeks of lactation (Janovick and Drackley 2010)

Energy balance in early-lactation

There are several management factors important in the prevention of NEB in early lactation. The failure to feed early-lactation cows to appetite is quite common. On many farms the feed trough will be empty for a period before the next day's feed is offered. Thus, there can be a huge rush for newly offered feed with all the associated aggressive behavior, such as bolting of feed etc., which can lead to digestive upsets and lameness. Ensuring adequate trough space for transition cows is also important and a trough space of 0.6m per cow has been recommended (Shaver *et al* 1993). Furthermore, factors such as limited water availability and quality, poor grouping strategy, excessive time standing after milking, and slippery floors at the feed trough, will all limit feed intake. Dietary factors such as grass availability, which has been a huge problem in Ireland this year, with extensive dry weather during the summer, and silage quality are also very important to ensure adequate feed intake. In general, once sward height is less than 7cm, the voluntary feed intake of dairy cattle is reduced (Gibb *et al* 1997). Early-lactation dairy cows should not be used to graze pastures to a very low sward height (a practice often used to ensure adequate grass quality later in the grazing season, when many dairy cows tend to get too fat anyway). If such a severe grazing is desired, then it should be done with other animals not on the brink of an energy balance crisis (horses or sheep are ideal for close grazing, or other cattle) or, alternatively, pastures can be topped. Many Irish farmers now want to feed very little supplementary feed at pasture. This is possible where grassland management is excellent and where high levels of milk yield are not expected and preferably where cows are past 100 days in milk. Feeding very low levels of concentrate supplements at pasture will often result in cows being 'limit-fed' (not to appetite) in early-lactation. Significantly, Horan *et al* (2005) reported that cows fed lower levels of concentrate supplements at pasture lost greater amounts of BCS in early-lactation. In other cases, the extra supplements are not necessary. It is probably best to give advice on the supplementation level necessary, based on the monitoring of energy balance status in the herd. Table 3 indicates several criteria that can be used for monitoring energy balance in dairy herds. When it is considered that cows with higher feed energy intakes in the first 100 days of the lactation have been shown to be more fertile (Mayne *et al* 2002), then all efforts to increase feed intake in this period should be made. It is also important to realise that healthy cows are likely to have a higher feed intake. This is because several cytokines, which are released as a component of the immune response to inflammatory conditions such as mastitis and endometritis, may reduce feed intake (Ingvartsen and Andersen 2000).

Table 3. Useful monitoring criteria for negative energy balance in dairy herds (taken from Mulligan *et al* 2006)

Criterion	Target
Percentage of energy requirements supplied eight weeks after calving	≈95%
BCS at drying off	2.75
BCS at calving	3.0
% of cows with > 0.5 units BCS loss in early-lactation	<25%
BCS at breeding	>2.5
% of early-lactation cows with milk / milk protein > 1.5	<10%
% of early-lactation cows with nadir milk protein < 3.05%	<15%
% of early-lactation cows with nadir milk lactose < 4.5%	<15%
Weekly decline in milk yield (%) post peak	≤2.5%
Trough space for transition cows	0.6m
Percentage refusals accepted in transition cow trough	≥3%
Post-grazing sward height for early-lactation cows	7cm
% cows 2 – 14 days pre-calving with blood BHB > 0.6mmol/	≤10%
% cows 2 – 14 days pre-calving with blood NEFA > 0.4mmol/l	≤10%
% early lactating cows with blood BHB > 1.4mmol/l	≤10%
% early lactating cows with blood NEFA > 0.7mmol/l	≤10%



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Monitoring energy balance

It is important to be capable of monitoring energy balance in early lactation. There are several criteria which when used collectively can be useful in indicating energy balance at herd level, albeit with a degree of accuracy that is acceptable for field diagnosis only. Criteria such as BCS and BCS loss, milk protein percentage, milk fat:protein ratio and milk lactose percentage, weekly decline in milk yield after peak yield, trough space and percentage feed refused, as well as blood metabolites, may all be used. Dietary analysis may also be used to estimate energy balance, together with a prediction of feed intake. However, predicting feed intake is often problematic, particularly in the first few weeks after calving. Therefore, the type of monitoring activity outlined in Table 3 should always support a calculated energy balance. The diet may look appropriate on paper but, in reality, the estimated intake is not realised and as a result dairy cows have a much different energy balance than predicted.

Hypocalcaemia

Milk fever and subclinical hypocalcaemia (total blood calcium ≤2.0 mmol/l) are the most important macromineral disorders that affect transition dairy cows. On average, 5-10% of dairy cows succumb to clinical milk fever, with the literature suggesting that the incidence rate in individual herds reaches as high as 34% (Houe *et al* 2001). In Ireland, the Dairy Herd Health Group at UCD has recently encountered several cases where the incidence rate of clinical milk fever in individual dairy herds was 50% or more. Interestingly, Roche (2003) has reported an incidence rate of subclinical hypocalcaemia for grazing New Zealand dairy cows of 33%, where clinical milk fever incidence was only 5%. Unfortunately, there is no definitive data on the prevalence of subclinical hypocalcaemia in Irish dairy herds. However, if it is as prevalent here as it is in other countries, then control strategies must not focus solely on the five or so clinical cases in every 100-cow dairy herd. It has been recognised for some time that milk fever and subclinical hypocalcaemia reduce the ability of the transition cow to effect smooth and skeletal muscle contraction. More recently it has been reported that both milk fever and subclinical hypocalcaemia exacerbate the level of immunosuppression experienced by periparturient dairy cattle (Kimura *et al* 2006).

Clinical consequences of hypocalcaemia

Several published studies indicate an increased likelihood of dystocia in milk fever cows in comparison to normal cows. In some cases the increased odds of dystocia were reported as six times that of normal cows with other reports indicating an increased likelihood of around 2.5 to 3 times that of normal cows (Curtis *et al* 1983; Erb *et al*., 1985; Correa *et al*., 1993). Apart from dystocia, it has been reported that cows suffering from uterine prolapse have a lower serum calcium (Ca) concentration than normal cows (Risco *et al* 1984). Furthermore, in the latter publication, 19% of the cows suffering from uterine prolapse were classed as having severe hypocalcaemia (serum Ca <4mg/dl) while a further 28% of the affected cows were classed as having moderate hypocalcaemia (serum Ca 4.1 to 6.0mg/dl). Following milk fever, cows are three times more likely to experience retained placenta than normal cows (Houe *et al* 2001) and Whiteford and Sheldon (2005) observed a significantly higher incidence rate of endometritis in United Kingdom (UK) cows that suffered clinical hypocalcaemia in comparison to normocalcaemic cows. Whiteford and Sheldon (2005) reported that cows with clinical hypocalcaemia had a greater diameter of the gravid uterine horn and non-gravid uterine horn between 15 and 45 days post-partum (indicative of slower uterine involution) and a significantly reduced likelihood of having a corpus luteum (indicative of ovulation since parturition) than normal cows. Furthermore, Kamgarpour *et al*

(1999) reported that subclinical hypocalcaemic cows have fewer ovulatory sized follicles at days 15, 30 and 45 post-partum and smaller follicles at first ovulation than normal cows. Other workers (Borsberry and Dobson 1989) reported an increased number of services per conception (1.7 versus 1.2), an increased calving to first service interval (68 versus 61 days) and an increased calving to conception interval (88 versus 76 days) for milk fever cows, in five UK dairy herds with an incidence rate of clinical milk fever of 7.5%. Therefore, trying to improve fertility without first having a good idea of transition cow health status, management and nutrition will bring limited improvements only.

Curtis *et al* (1983) reported that cows that had suffered clinical milk fever were eight times more likely to develop mastitis than normal cows. It has been hypothesised that the reasons for this phenomenon are (a) a reduction in smooth muscle function at the teat sphincter and hence an easy route for infection after milking and (b) an exacerbated suppression of immunity in milk fever cows when compared with normal cows (Goff 2003). Furthermore, hypocalcaemia is associated with reduced intracellular Ca stores in peripheral blood mononuclear cells and that this exacerbates periparturient immunosuppression (Kimura *et al* 2006). Goff (2003) has indicated that low plasma Ca concentration around calving will result in reduced motility and strength of abomasal contractions and hence abomasal atony and distension of the abomasum. Therefore, hypocalcaemia has been implicated as a predisposing factor for many other transition cow disorders.

The prevention of milk fever and subclinical hypocalcaemia

Body condition score (BCS) management

Achieving the correct BCS at calving and drying-off is critical for the prevention of milk fever (Roche and Berry 2006). Dairy cows that are over-conditioned at calving are up to four times more likely to develop milk fever (Ostergaard *et al* 2003). It is unclear why this is the case, but several hypotheses have been suggested to explain this effect. Firstly, it has been suggested that dairy cows with higher BCS at calving have a higher Ca output in milk, making them more prone to milk fever. Secondly, it is widely appreciated that over-conditioned dairy cattle have a reduced feed intake relative to thinner cows, in the last week or 10 days pre-calving. This may reduce their intake of Ca and magnesium (Mg) to levels, which predispose them to the development of hypocalcaemia. Finally, it has been shown, in human patients suffering from non-alcoholic fatty liver disease, that serum concentrations of 25-OH-vitamin-D3 are lower than healthy controls. Thus one wonders if over-conditioned dairy cows are capable of producing sufficient amounts of the active form of vitamin-D3 to prevent hypocalcaemia.

Magnesium (Mg) supplementation

Ensuring adequate Mg supplementation is vital for the prevention of milk fever. Magnesium plays a very important role in Ca metabolism, for example, it is a key intermediate in the re-absorption of Ca from bone by parathyroid hormone. Increasing Mg supplementation was found to have the greatest influence amongst dietary strategies for the prevention of milk fever (Lean *et al* 2006). Therefore, dietary Mg concentration for pregnant dairy cattle should be in the region of 0.4% of dry matter (DM) (Goff 2004; Lean *et al* 2006). In order to feed Mg at 0.4% of DM for diets based on Irish grass and grass silage, approximately 20g of Mg needs to be supplemented pre-calving. This is based on the average Mg concentration of Irish grass of 0.2% and the average Mg concentration of Irish grass silage of 0.18% (Rogers and Murphy 2000). Some of the mineral premixes currently sold in Ireland for pre-calving cows supply only 10-12g of Mg when fed at the recommended feeding rate. This will result in a Mg intake of around 0.3% of diet DM, which is not ideal, as Lean *et al* (2006) reported that increasing Mg supplementation from 0.3 to 0.4% of the diet DM reduced milk fever incidence by 62%. To identify herds where the Mg feeding strategy is not optimal, blood Mg concentration may be determined in cows that are expected to calve in the next 24–48 hours (Whitaker 1997). The ideal range has been reported as 0.8 to 1.3 mmol/l (Whitaker 1997).

Dietary cation anion balance (DCAB) and potassium

The concept of dietary cation (sodium (Na) and potassium (K)) anion (chlorine (Cl) and sulphur (S)) balance {(Na + K) – (Cl + S)} has focused attention on the level of potassium that is contained in the feed of pre-calving dairy cattle. It is now widely accepted that the homeostatic mechanisms that result in milk fever prevention, work more efficiently when DCAB is negative. The most common strategy employed to achieve this negative DCAB is the addition of anionic salts to the diet of pre-calving cattle (Goff, 2004). Goff (2004) has stated that it is very difficult to control hypocalcaemia if total ration K is >1.8%. Given that the average K values reported for Irish grass and grass silage are 2.9 and 2.3%, respectively (Rogers and Murphy 2000), it will be difficult to achieve negative DCAB for many dairy farms. Some people in Ireland do use DCAB strategies to prevent milk fever in dairy cows. It is important if using this strategy to use grass silage or grass where no potassium fertiliser or slurry has been recently applied. On the other hand, some Irish silages can be as low as 1% K, so it is probably best to have the forage tested for potassium if using this strategy. One of our foremost mineral premix manufacturers currently recommend testing urine pH in dry cows before implementing the DCAB strategy for milk fever prevention. For those using the addition of anionic salts to try and prevent milk fever and hypocalcaemia, it is important that (a) the DCAB for dry cows is between –100 and –200 meq/kg DM (Goff and Horst 1997), (b) that urine pH for cows fed using the DCAB strategy is 6.0 to 6.8 and (c) that dietary Ca concentration is 1.2% of the diet (Ca sulphate and not Ca carbonate should be used) (Oetzel *et al* 1988). The monitoring of urine pH for eight or more close-up cows fed using this DCAB strategy is extremely useful to determine if optimal dietary acidification has been achieved (Oetzel 2004). It is also important to state that even if you are not using a strict DCAB strategy for milk fever prevention, reducing dietary K is advantageous for milk fever prevention in all circumstances (Lean *et al* 2006). This is likely related to the reported reduction in milk fever incidence by reducing DCAB even if DCAB does not actually get negative (Lean *et al* 2006) and also because K prevents Mg absorption from the gastrointestinal tract.

Calcium restriction and milk fever prevention

One of the classical strategies often proposed for milk fever prevention is the restriction of Ca intake pre-calving. This has the effect of making sure that parathyroid hormone and the active form of vitamin-D3 are in higher concentrations in circulation on the day of parturition when Ca export in colostrum increases suddenly. This strategy does work, and recent data where Ca binders were used to block Ca uptake from the gut have shown a reduced milk fever incidence on several farms in New Zealand (Wilson 2001). However, in practical situations it is necessary to achieve a Ca intake of 30g per day or less for this strategy to work. Irish grass and grass silage contain on average 6.5 and 6.9g of Ca per kg of DM, respectively. For a 600kg dry cow consuming 1.8% of liveweight as dry matter, this equates to a Ca intake of 70 to 75g per day. Therefore, Ca restriction is not a practical alternative for milk fever prevention on Irish farms using grass or grass silage as a large component of the dry-cow diet.

Table 4. Useful monitoring criteria for the management of hypocalcaemia in dairy herds (Mulligan *et al* 2006)

Criterion	Target
BCS at 250 DIM	2.75
BCS at drying off	2.75
BCS at calving	3.0
Intake of Ca (g/day)	≤30
Diet P%	≤0.3% of DM
Diet Mg%	0.3–0.4% of DM
Diet K%	<1.8% of DM
DCAB	−100 to −200 mequiv/kg DM
Blood Ca concentration, 12–24 h post-calving	>2.0 mmol/l
Blood Mg concentration, 24–48 h pre-calving	0.8–1.3 mmol/l
Blood P (inorganic P) concentration, 12–24 h post-calving	1.4–2.5 mmol/l
Incidence of retained placenta in multiparous Cows	<10%
Incidence of LDA in multiparous cows	≤3%
Incidence of dystocia in multiparous cows	<10%
Incidence of clinical milk fever	<5%
Urine pH (if DCAB strategy used)	6.2–6.8 (Holstein cows)

Sub-acute ruminal acidosis (SARA)

SARA has been reported to be prevalent in 19% of early lactation and 26% of mid-lactation dairy cows in the USA. Furthermore, recent Australian and Irish data indicate that between 10% and 15% of dairy cows grazing perennial ryegrass-based pastures have the condition

(Bramley *et al* 2005; O'Grady *et al* 2008). SARA has been implicated in the aetiology of laminitis (Oetzel 2000; Enemark *et al* 2002), reduced and erratic feed intake, low BCS in lactating cows (Oetzel 2000), low milk fat syndrome, caudal vena caval syndrome, abomasal displacement/ulceration (Olson 1991), rumenitis (Enemark 2008), immunosuppression (Kleen *et al* 2003) and inflammation (Plaizier *et al* 2008). Early lactation cows and cows at peak DM intake are most at risk from SARA; the early lactation cows are at higher risk due to reduced absorptive capacity of the rumen, poorly adapted rumen microflora and the rapid introduction to high-energy dense diets (Dirksen *et al* 1985), while cows at peak dry matter (DM) intake are at increased risk due to the greater amount of acids produced in the rumen (Oetzel 2005). Enemark (2008) describes a strong physiological association between SARA and immunosuppression. The metabolic acidosis that results from SARA may result in reduced glucose-dependent insulin secretion, increased cortisol secretion, reduced phagocytic activity and migratory speed of neutrophils (Enemark 2008). There is also evidence that cows become more prone to acidosis over time and that the severity of each subsequent bout of acidosis increases, especially for cows fed diets low in physically effective fiber and at high acidosis risk (Dohme *et al* 2008). Therefore, a bout of acidosis that occurs due to improper feed delivery or poor diet formulation can have long-term consequences on cow health and productivity. In the field, the diagnosis of SARA remains problematical due to a combination of factors, including questions over the validity of rumen pH measurements. However, it is likely that diagnosis of SARA at herd-level will continue to be based on a thorough herd investigation that takes cognisance of the inherent diagnostic difficulties, together with the fact that many of the associated clinical signs occur much later than the SARA episode itself.

Components of Practical Approach

The clinical picture may vary greatly between farms with no one sign confirming the presence of SARA, meaning a closer assessment of the problem is needed. Oetzel (2003) recommended the sampling of 12 cows at risk, with a positive herd diagnosis if 3 or more have a rumen pH of less than 5.5. Indications of SARA at herd level include:

- Higher incidences of lameness (laminitis mainly), displaced abomasum, BCS loss, caudal vena cava syndrome, erratic feed intake or milk yield.
- Less than 80% of resting cows are ruminating.
- Fecal consistency for lactating cows is extremely loose (score < 3).
- Ten percent of the mid-lactation cows with milk fat concentrations of ≤ 2.5% or if 10% of the mid-lactation cows have a milk fat concentration less than the milk protein concentration by 0.4%.
- Dietary levels of effective fiber are not adequate.
- High levels of total concentrate or cereals are being fed.
- Feed trough space and management are not ideal.

Trace element and antioxidant status

Although trace element status is thought to be of less importance than other nutritional risk factors for periparturient health problems and reproductive performance, trace element deficiency may be linked to conditions such as retained fetal membranes (Gupta *et al* 2005), abortion (Mee, 2004) and weak calf syndrome (Logan *et al* 1990; Van Wuijckhuise *et al* 2003).

Components of Practical Approach

Key monitoring criteria for trace element status have been suggested based on dietary concentrations or daily supplies as well as blood concentrations of trace elements and or metabolites. Although care has been taken to ensure only values derived in the same way are used to inform these criteria, it is important to use these suggested values carefully as reference ranges can vary widely between laboratories both nationally and internationally. Initial suspicions of trace element deficiency are often reliant on the occurrence of classical deficiency signs on the farm being investigated or in that locality.

- Assessment of dietary trace element supply should be made based on what trace elements have been added to the diet and compared to suggested targets.

- Investigators should consider local trace element deficiencies or excesses (e.g. high molybdenum areas).

- Interactions with other mineral sources like concentrates should always be considered.

- Blood samples may be taken from ‘marker animals’, that are fed the homegrown forage or pasture only (e.g. maiden heifers), for assessment of farm-specific trace element status.

- Blood samples may be taken from eligible groups within the herd (e.g. early lactation cows or close-up dry cows) for assessment of trace element status.

- For trace element problems of the dairy cow and calf that occur close to parturition, trace element status in dry cows, not lactating cows should be assessed.

- The use of liver analysis from fallen animals or liver biopsy may prove useful for the detection of some trace element deficiencies (e.g. subclinical copper deficiency).

- Assessing the response to supplementation for specific trace elements or mixes in the eligible group of cows is often invaluable. It is important that only a proportion of the eligible group is treated to truly diagnose deficiencies.

Conclusions

Production diseases of the dairy cow continue to cause economic loss to the dairy industry and animal welfare concerns. The challenges facing us in the rapidly changing international agricultural industry of the 21st century are to prevent disease, enhance animal welfare and farmer profitability while taking cognisance of food safety issues, the consumer and the environment. The former agricultural policy of the European Union that was primarily concerned with increasing production has been replaced by a European rural development policy that focuses on agri-competitiveness, animal welfare, food quality and safety and environmental sustainability.

These challenges have clear implications for research in bovine health management. Notwithstanding the need for continued strategic research, notably in the area of the rumen microbiome, disease resistance and the environment, there will be an increasing need to develop and refine disease management systems and particularly their 'data mining' interface with central databases containing milk production and fertility data, for example. Whether or not an individual farmer implements optimal disease management strategy following herd health advice represents the 'intention-behavior deficit' (Sniehotta *et al* 2005) as it applies to animal health. Therefore, there is also a need to engage with the social scientists and methodologies such as action research, as well as behavioral economics, which will facilitate evaluation of the economic benefits of consumer perceptions of novel preventive approaches as well as conventional cost-benefit analyses.

Disease prevention, in its broadest sense is no longer the sole preserve of veterinarians and addressing this challenge will require the adoption of an interdisciplinary partnership approach involving the farmer, the veterinarian and the farmer's advisors, nutritional and animal breeding consultants. The recent creation in Ireland, of *Animal Health Ireland* is a national example of a dairy industry-service provider partnership that has these principles at its core (www.animalhealthireland.ie). With the emphasis given in this article to the implementation of integrated production disease management systems linked to sustainability and optimal animal health and welfare, it is important to note that, as previously indicated, much of the knowledge required already exists. A sustained commitment of the resources necessary to support the application and systematic transfer and uptake of the large accumulated reservoir of existing knowledge would make an immediate and essential contribution. There is an increasing need to place significant emphasis on dissemination of knowledge, training, motivation and the encouragement of fundamental attitudinal changes to disease prevention within the industry. Achieving sustainable competitiveness will involve a shift from farming subsidies to farming knowledge, by developing innovative knowledge-based farm production and animal health and welfare systems that will provide real marketing advantages. Education, including continuing professional development, is key to meeting the challenge of enhancing the innovation capacity of farmers and those professionals including veterinarians engaged in rural business and services. This paper has provided an over-view of the major health issues relating to the transition cow and presented a simple on-herd approach based on the experience of the Herd Health Group at University College Dublin.

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FROM RESEARCH INTO PRACTICE: IS THE COWS' HEALTH WORSENING?

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In New South Wales (NSW) over the last 10 years herd size has increased by 60% and the average cow is producing 1400 litres more milk. This reflects a trend across the Australian industry. Increasing herd size and higher production requires better management of all facets of the dairy operation including herd health management. As an industry both farmers and the veterinary profession have risen to the challenge, but has this approach been successful?

What data do we have on disease levels?

Unfortunately we do not have a comprehensive system of disease monitoring in Australia, so it is hard to know what is going on at a national level. We do know that there are some diseases on the increase, over the past few years we have seen an increase in mastitis caused by *Mycoplasma bovis*, which can prove a huge challenge for affected herds; *Strep. agalactiae* mastitis seems to be making a comeback and there has been a sharp increase in sick and dying cows in NSW due to Theileria. Anecdotally other diseases such as bloat, milk fever and hypomagnesaemia have decreased due to better understanding and management tools. As an attempt to make some assumptions at a big picture level, I compared national herd data from 1998/9 and 2008/9.

Heifers are more prone to certain diseases, such as lameness, mastitis, and reproductive diseases following dystocia, i.e. metritis. Across Australia, 2 year olds made up 16% of the national herd, in 2008/09 it was 17%. In 1998/99 1st calf heifers produced 83% of the production of a mature cow, in 2008/9 it was 85%. This means we are growing our heifers a little better and the average herd is meeting InCalf milk production targets for heifers. Well grown heifers adapt better to the milking herd and are less likely to suffer from dystocia. These figures indicate that there has been little change over the past 10 years and as the proportion of heifers in a herd has not changed, consequently there has been no noticeable influence on the disease level in a herd.

The impact of milk pricing schemes and drought has resulted in a decrease in the percent of the national herd calving in July to September from 54% to 47%, with most of the corresponding increase occurring in March to May. In most regions, Autumn is drier and milder than Winter, which should result in decreased disease incidence.

What are the impacts of larger herds?

As discussed above herd sizes are getting larger. The increased stocking density observed in larger herds should increase the risk for infectious disease, but evidence to support this contention is sparse (Lean, Westwood *et al*. 2008). Several herds that our practice is involved with have encountered serious herd health issues through purchase of cows from multiple sources in order to increase herd size. A common problem encountered is due to the contagious mastitis pathogens: *Mycoplasma bovis* and *Strep*. *agalactiae*. The risk of introduction of pestivirus into some of these herds has also been a cause for concern. These herds have also encountered increased incidence of calf scours, salmonellosis and hairy heel warts (an infectious cause of lameness). It is difficult to know whether this is due to the challenges of managing a rapidly expanding herd, poor biosecurity or the result of intensification and large herd sizes.

Increased stocking density and short rotation lengths favour nematode parasites. Since 2004 there have been an increasing number of reports of cases of resistance to the macrocyclic lactone anthelmintics in *Cooperia* spp*.* and *Haemonchus placei.* In Australia, initial reports of resistance were in beef cattle in SW Victoria (Rendell 2008), then earlier this year the failure of macrocyclic lactone treatments to control subtropical Cooperia spp. and suspected failure to control H. placei was reported in calves on two dairy farms in the subtropical, summer rainfall region of eastern Australia (Lyndal-Murphy, Rogers *et al*. 2010).

Periparturient disease

Improved transition management of calving cows has been one of the most significant preventative measures that has changed over the last 15-20 years. This has been driven by good extension, development of new products and the requirements of increased milk production. The feeding of some form of lead-up or springer pellet is now commonplace. Whilst there is likely to be some room for improvement on many farms, transition management is not noted as a significant problem for many pasture based dairy farms that we deal with and consequently very few herds monitor energy balance in their cows using blood samples. Simple monitoring tools for farmers include recording (or observation of) the incidence of milk fever, condition scoring of cows pre and post calving, and for herds that herd record, the ability to look at the post calving milk fat: protein ratio. Unfortunately we have no ongoing records of this data to determine how herd health is changing.

A little data has been published on acidosis: When rumen samples were taken from 8 fresh cows (<100days in milk) 2-4 hours after milking across 100 herds in NSW and Victoria there were at least 3/8 cows with acidosis in 12% of the herds and at least 3/8 cows with suboptimal rumen parameters in another 36% of herds (Bramley, Lean *et al*. 2008). However this was a single sampling in each herd and does not give a good picture of the seasonal variation or longer term change. Similarly there is little information on the levels of ketosis in pasture based Australian dairy herds. Certainly cows demonstrating overt clinical signs of ketosis are not common, but the incidence of subclinical ketosis is unknown and the effects of subclinical ketosis on reproduction and milk production are not as obvious.

Mastitis

Poor transition management results in reduced milk production, poor reproductive performance and an increased susceptibility to periparturient disease, notably left displaced abomasums and mastitis. Increased incidence of mastitis is also associated with increased herd size. Mastitis provides a challenge to most dairy farmers, especially with decreasing penalty bands, and is an area where we have good monitoring at a farm, regional and national level. Clinical mastitis is more prevalent around calving and a case of mastitis will often result in an elevated cell count for some months or even the rest of the lactation.

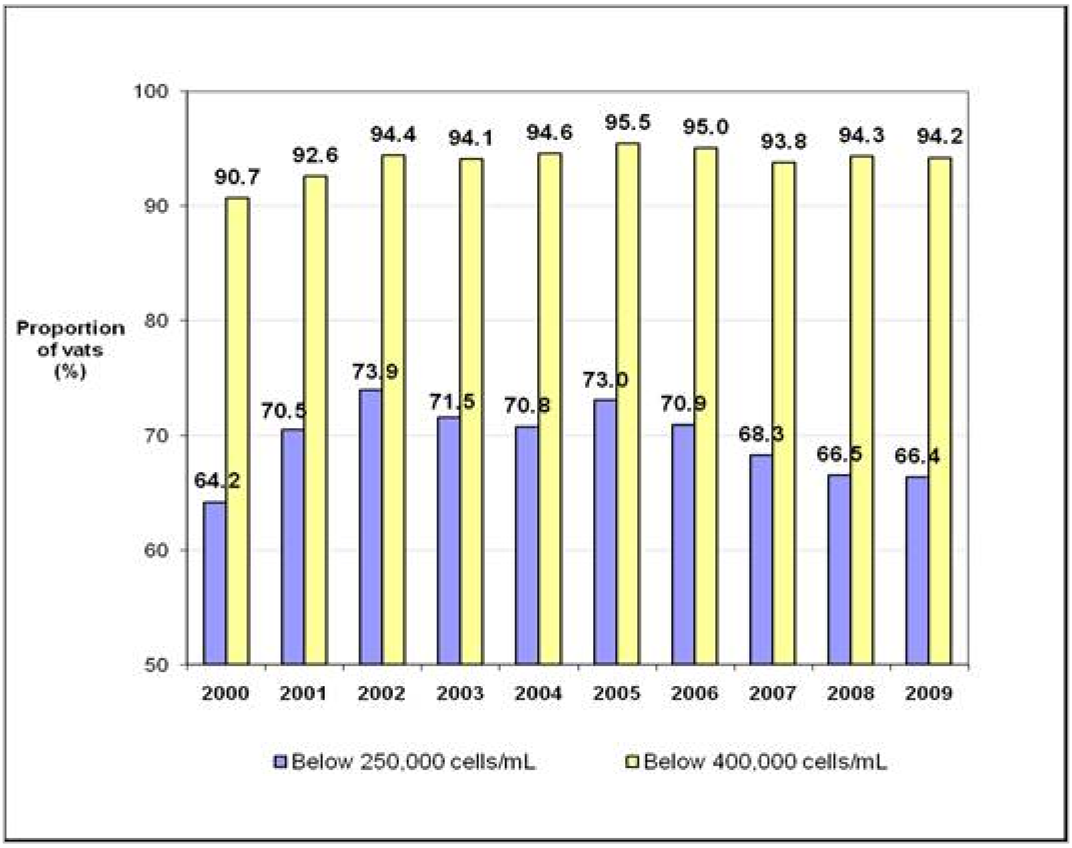

Figure 3: National Bulk Milk Cell Count data 2000-2009. Source: Countown Downunder

Despite the massive improvement in the availability and standard of knowledge made by Countdown Downunder (CDDU), there are still many herds that struggle with both mastitis around calving and keeping their Bulk Milk Cell Count consistently in the premium band. National BMCC figures from Countdown Downunder show that the proportion of vats less than 250,000 cells per ml has increased from 64.2% in 2000 to 73.9% in 2002, but have subsequently declined back to 66.4% in 2009 (Brightling 2010; Figure 3). The initial rapid increase corresponds to the roll out of the CDDU program, but this was halted by the challenges of the 2003 drought and more recently CDDU has had significantly reduced funding and activity. Similarly the proportion of vats less than 400,000 cells per ml increased from 90.7% in 200 to 95.5% in 2005, but have has declined slightly to 94.2 in 2009.

Maintaining and improving cell count are a big challenge for farmers trying to increase herd size. Commonly I encounter farmers that do not want to cull cows, resulting in a higher proportion of chronic cell count cows in the herd and a steady increase in their BMCC. Farmers wishing to expand more rapidly by purchasing cows face a larger problem, as purchasing cows and even heifers may result in the introduction of *Mycoplasma* or *Strep agalactiae*.

Mastitis solutions

CDDU has provided many solutions to these challenges, but the biggest challenge of controlling mastitis is that it requires persistence, and levels of mastitis in the herd can often directly reflect the focus of the staff at any given time. Effective mastitis control requires repeated staff training and ongoing revision of policies and preventive practice. Since the last revision of the CDDU publications new research has provided some solutions, particularly in the areas of mastitis at calving and biosecurity.

Heifers

In many herds, heifers have more mastitis at calving than the lactating cows. There have been several large studies on reducing clinical mastitis in heifers, mainly originating in New Zealand. If you have more than 5% of your heifers calving with mastitis you should discuss the cost benefits of the following management strategies with your veterinarian.

1. Use of Teatseal™ (2.6g bismuth subnitrate, Pfizer Animal Health). (Parker, Compton *et al*. 2008) showed that the use of Teatseal™ infused into heifers 5-6 weeks prior to calving reduced the new bacterial infections by 66% and reduced the incidence of clinical mastitis from which any pathogen was isolated by 74%. The overall incidence of clinical mastitis was not reduced, but it was suggested that as Teatseal™can remain in the udder for days or weeks post calving, farmers were interpreting fragments of Teatseal™ as clots in the milk. If you use Teatseal™ ensure milking staff are aware that other signs of clinical mastitis such as heat and swelling and overtly abnormal milk should be used to diagnose clinical mastitis.

2. Bring the heifers in to be milked as soon as possible after calving. This has been a recommendation for a while and there many good reasons to do this. It was reinforced by a study published in 2008 which demonstrated that bringing heifers into be milked at 10 hours vs 20 hours reduced the incidence of clinical mastitis from 15% to 8%, reduced the risk of severe udder oedema on Day 1 of lactation (but not at Day 4) and resulted fewer open teats at Day 4. (Compton and McDougall 2008)

3. Ensure good udder hygiene. Poor udder hygiene is associated with increased intramammary infections in heifers. One study in New Zealand brought heifers into the parlour 3 times a week and their udders were sprayed with a commercial iodine preparation (Lopez-Benavides, Williamson *et al*. 2009). This resulted in a decrease in *Strep uberis* mastitis (3.6% vs 7.4%) but the overall level of clinical mastitis was the same. The number of bacteria cultured from the teat at calving was similar to the number at the beginning of the trial, but the number of bacteria in the control group tripled. It was suggested that walking the heifers 3 times a week on the track increased the teat end contamination in cows that were not sprayed.

Prevention of clinical mastitis at calving in multiparous cows.

Dry cow therapy has been the key preventive strategy used for minimising mastitis at calving for many years. Choice of antibiotics should be based on previous incidence of clinical mastitis and knowledge of the common pathogens causing disease on your farm.

Studies have shown that a high proportion of new infections occur at the beginning of the dry period as well as in early lactation. Teatseal™ can be used alone in low cell count cows to prevent new infections, however where farmers are experiencing a problem with clinical mastitis at calving (>5% of calving cows in the first month of calving) a recent study has also shown significant decrease in clinical mastitis when using combination therapy of Teatseal™ and antibiotic Dry Cow treatment (Runciman, Anderson *et al*. 2010). Over 2000 cows in six seasonal calving herds were treated with antibiotic Dry Cow therapy, (Cloxacillin 600mg, Orbenin Enduro™, Pfizer Animal Health) either alone or in combination with Teatseal™. Treatment with Teatseal™ and antibiotic resulted in a 60% decrease in the number of cows with clinical mastitis in the first 28 days after calving: 12.7% vs 5.4%. Combination therapy also resulted in a significantly reduced cell count at the first herd recording and it was calculated that this would have resulted in a 100,000 cells/ml decrease in the BMCC. This combination offers significant benefits for the control of mastitis at calving. Obviously a combination therapy is more expensive and so the cost benefit needs to be explored on each farm.

With clinical mastitis at calving also remember these key points from the CDDU recommendations: Change the calving paddocks regularly; always calve onto a clean dry area; consider training the heifers in the milking area before calving; treat udder oedema and ensure all quarters of all cows are milked out thoroughly.

Diagnosis of mastitis

The other area where there has been some exciting development with more to come is in the diagnosis of mastitis. At the University of Sydney, Mycoplasma mastitis is a significant area of research and we are routinely culture all clinical samples for Mycoplasma. Milk culture is the most cost effective test for mastitis pathogens at an individual cow level, but is harder to interpret when used for herd monitoring, as infected milk is diluted by normal milk.

New molecular diagnostic techniques are being developed which allow us to look for the DNA of a bacteria rather than culturing it. This is an excellent tool for herd and group monitoring. Currently the only commercially available test is for *Strep agalactiae*. Samples do not need to be refrigerated and the test is highly sensitive. It can and should be used to test herds for *Strep agalactiae* prior to purchase. It is also a very useful tool during an eradicating program to detect *Strep agalactiae* in groups and should increase the success rate in these difficult programs. Our research group at the University of Sydney are currently developing similar tests to diagnose Mycoplasma mastitis, funded by the Geoffrey Gardiner Dairy Foundation. Similar tests for other mastitis pathogens are expected to become available within the next year.

Conclusions

In summary, although data is lacking in some areas there is little evidence that the cow's health is worsening, but it is clear that new challenges are emerging and we need to revisit old problems in a new light. Areas of particular focus for research include monitoring for parasite resistance, the challenges of managing disease risk when buying in cattle and the constant battle to maintain milk quality. Farmers may be reassured that researchers are aware of all these challenges and are focussed on providing practical and cost effective solutions to the dairy industry.

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GROWING A HEALTHY DAIRY BUSINESS

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We are like many other young farming families – juggling a busy working schedule and with four boys under 11 – and all the school and sporting commitments that come with children.

I came home at the age of 15 in 1985 – dad was unwell at this stage and I was needed home. We were milking 45 cows and had 45 horses – dad was into thoroughbreds on 180 ha.

Well that soon changed (see table below)– we were milking in an eight unit walk through – at that stage. By 1992, we were milking 120 cows – we wanted to convert the dairy to a ten swing over so we welded the walkthrough bales together and dragged them on to the yard. That's where we milked for four months as we converted the old shed into the 10 swing over in between milkings.

Year	No of cows	Milking platform area (ha)	Milk production	
1985	45	159	**Litres**	**Milk solids (kg)**
2004	490	159	3.6 M	253,000
2010	820	240	6.0 M	426,000

In 1999, we were at 300 cows and had doubled up the shed by then to 10 double up. In 2002, I went on a study tour with the milk company to Mount Gambier and saw what could be done with water using pivots. We saw some of the best irrigated pastures I had ever seen, and came home wanting to do the same at home. I was able to get 850 megalitres of water license and we set the plans in place to develop the 100 ha on the 180 ha property that we were milking on.

The spring of 2002 was a very hard time for us, dad had been fighting cancer for twelve months and we lost him at the end of September just before silage time. It was not until after Christmas that things were becoming easier.

Dad was very much part of the planning for the pivot to the point that he divined the site of the bore and said if you are going to do it, it must go there. The hole was drilled and it gave us more than we needed, so it was developed and it was doing 120 litres a second, once again dad had come through for us.

The pivot was in place by November 2003 and by then we were milking 350 cows. At this stage we were looking where to from here – we could see that a new dairy would make things a lot easier but with the milk price at 28 cents/litre, this would take some doing. The bank at this stage said we needed to grow the cash flow to go ahead and then look at a new dairy in the future.

So the decision was to keep growing to the point that it would allow us to make the move. At this time the neighbour's farm came up as well, just when we really were not ready for it. It was a farm that we had been looking at for a long time and it linked up two other properties that we already were running so we had to make it happen.

Cutting milking hours by half

In 2004, we peaked at 490 cows giving 38 litres and taking 16 – 17 hours to milk a day. This was with one fulltime person and 2 casual people and me running around like an idiot. Prices were still 28 cents/litre and it was either go and get a job at the mines or take the challenge head on. I had the family backing but Denise was adamant that, if we were going to do this we had to do it for the right reasons and we had to get some balance in our lives in the future. We had three boys at this stage and having no time off and doing the hours that I was doing, I was really wondering would this next step be really worth it– and give us the changes in the way we were living.

In the end, it came down to the fact that dairying is what we really love doing and have a passion for.

It was not going to be easy, but I did not want to look back in ten years and say I wish we had done it. So the decision was made to invest in a new dairy. The planning started in January 2006 and our 50 stand rotary was ready to start milking in by the first week in November.

In the first milking, we cut two hours off milking and within a week we were doing two milkings in the time it used to take us to do one. We started having every second weekend off and the holidays were booked well ahead of time.

The land we had bought in early 2004 had a water licence on it as well, and typical of things we received a letter telling us that we had to develop the water by 2008 or lose it.

In the summer of 2009, it had a 55ha pivot working on it and the fencing and laneways were done. Here we are in 2010 this year – we will peak at 820 cows. We now have three to four weeks holidays a year – regular weekends off.

Looking back I do wonder how we every got through what we did. Along the way there have been a number of factors that have given us the confidence to grow, including

- My passion for seeking out research to pushing the boundaries
- Focusing my energy on what I can control
- Strong partnership with Department of Agriculture in on-farm research
- Ability to increase pasture harvest through grazing management and decision tools
- Ability to improve soil nutrition and nutrient efficiency
- Monitor, plan and evaluate
- Strong industry involvement - Western Dairy RDP

Well, where to from here?

We will now focus on consolidation for a while. We have invested in the necessary infrastructure that now allows us to work the system to reduce debt.

With the boys growing up fast, our lifestyle is important. We are actively involved in their sporting interests and their school community. For us, this is evidence that we have achieved our aim of growing a successful business that allows us to balance our family and business interests, which in turn may encourage the boys to consider agriculture as a healthy career!