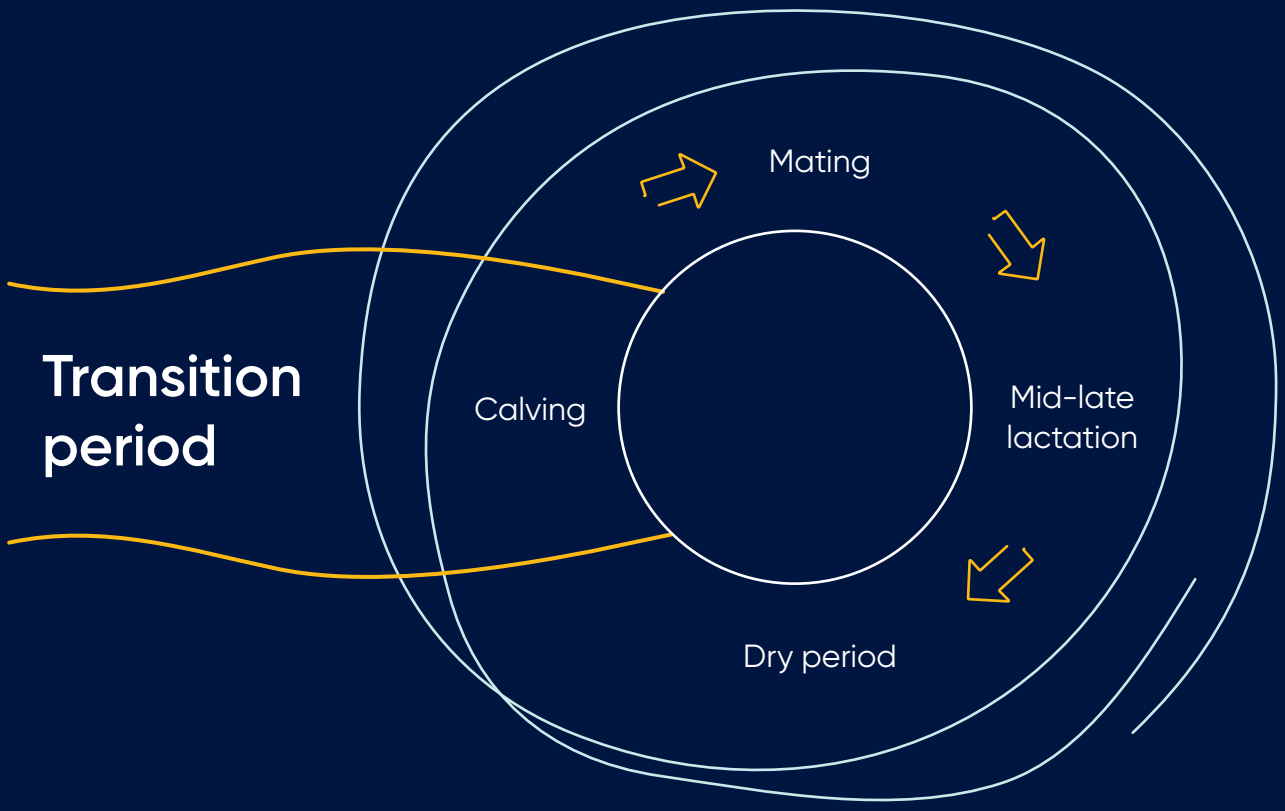
Dairy Australia

TRANSITION COW MANAGEMENT

A TECHNICAL REVIEW FOR NUTRITIONAL PROFESSIONALS, VETERINARIANS AND FARM ADVISERS

Second edition 2021 | Ian J. Lean and Peter DeGaris



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FOREWORD

Significant advances in dairy cow nutrition, health and production have been achieved on Australian farms over the last 20 years from better management of cows in the pre- and post-calving period. Many dairy farmers have also minimised their stress through incremental improvements to transition feeding programs over time and advisory support to improve cow health at calving time.

According to the 2019 Dairy Australia Feed and Animal Nutrition Survey of 500 dairy farmers, around 77% of farmers sometimes or always implement a transition feeding program before calving. Smaller farmers, those with year-round-calving patterns and those in more geographically dispersed regions were less likely to have implemented transition feeding programs. In response, the 'Transition Cow Management (TCM) Online' program was developed as the first fully online learning platform and was launched in May 2020. This delivery model enables farmers to connect into extension and industry experts from anywhere in Australia and work through the program from the convenience of their own home or workplace.

There have been considerable advances in the global scientific literature on transition cow management over the last 10 years. In response, Dairy Australia has commissioned the publication of a second edition of *Transition Cow Management: A technical review for nutritional professionals, veterinarians and farm advisers.*

This review is arranged in 12 chapters, commencing with an introduction and overview of transition cow management, and ending with chapters on practical applications of transition cow management, assessment of transition feeding strategies and the cost of disease during this period.

The authors, Adjunct Professor Ian Lean (Scibus) and Dr Peter DeGaris (Gippsland Veterinary Group) together have published more peer-reviewed papers on transition feeding than any other Australians. This publication is the most extensive review of transition cow management ever undertaken, drawing upon over 300 peer-reviewed scientific papers.

Transition Cow Management: A technical review remains the ultimate reference for nutritional professionals, veterinarians, and farm advisers on transition cow management in Australia and is the foundation for all other adviser and farmer information resources on transition cow management being developed by Dairy Australia.

I trust that you find this review a valuable technical resource.

David Nation
Managing Director
Dairy Australia

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CHAPTER 1

INTRODUCTION TO THE TRANSITION PERIOD

The periparturient, or transition period is defined as the four weeks before and after calving and is characterised by a greatly increased risk of disease (Shanks, 1981, Curtis et al., 1985, Stevenson and Lean, 1998, Dubuc and Denis-Robichaud, 2017). Despite advances in the management of the transition period and reduced incidence of some transition disorders, the period remains the time of highest risk for dairy cows.

The transition period is critically important to health, production, fertility, and profit.

The lactating cow performs at a level similar to an Olympic athlete. They both require two to three times more energy and protein than is required for maintenance to perform at their peak. The modern dairy cow must rapidly increase her nutrient intake from near maintenance in the early dry period to three times maintenance in early lactation. This is a substantial challenge.

Transition responses are dominated by a series of adaptations to the demands of lactation, which is a type of process termed 'homeorhetic' (Bauman and Currie, 1980).

The transition period is a time of change: Homeorhetic processes are the long-term adaptations to a change in state such as 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.

Homeostatic change is that which occurs minute to minute to keep animals functional and alive. An example is the relationship between blood glucose and insulin.

The diseases that occur around calving are often inter-related (Curtis et al., 1983, Curtis et al., 1985, Curtis, 1997a). They result from a failure to adapt to increased nutrient demand both in the long term (homeorhetic adaptation) and in the short term (homeostatic adaptation). Ultimately, the failures to adapt result in shortages of nutrients that are vital for existence. These disease conditions include:

- Hypocalcaemia and milk fever
- Hypomagnesaemia (grass tetany)
- Ketosis (acetonaemia) and fatty liver
- Udder oedema
- Abomasal displacement
- Mastitis
- Ruminal acidosis
- Retained foetal membranes (RFM; retained placenta) and metritis
- Poor fertility and poor milk production

The metabolic processes that influence health, production and fertility are intricately linked.

In the past, there has been a tendency to look at metabolic systems in isolation. However, it is now clear that 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 of 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 primarily on control of hypocalcaemia and milk fever to an integrated nutritional approach that aims to optimise:

- Rumen function and digestion
- Calcium and bone metabolism
- Energy metabolism
- Protein metabolism
- Immune 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 overwhelming evidence clearly confirming that the transition period represents a brief,

but critically important period in a cow's life where careful manipulation of diet can substantially improve subsequent health and productivity.

The focus of transition cow management has evolved from controlling hypocalcaemia and milk fever to an integrated nutritional program addressing multiple aspects of homeostasis and homeorhesis.

Aims of transition

The aims of the transition period can be summarised by cattle being free from:

- Macromineral deficiency (conditioned or otherwise)
- Lipid mobilisation disorders
- Excessive or prolonged immune suppression or dysfunction
- Ruminal disruption

These freedoms are described further in Table 1.1.

Table 1.1 The four freedoms of dairy cattle in the transition period

Condition	Detail
Macromineral deficiency	Mainly refers to calcium, magnesium and phosphorus. Hypocalcaemia and hypomagnesaemia can result from a conditioned deficiency* where excess potassium reduces the capacity of the cow to maintain stable blood concentrations of calcium and magnesium. Absolute deficiencies of calcium and magnesium are rare.
Lipid mobilisation disorders	Includes ketosis (acetonaemia), fatty liver and pregnancy toxaemia. These diseases are largely influenced by a failure to provide sufficient or effective energy sources around calving.
Immune dysfunction	Often associated with lack of energy or protein intake. Micronutrients are often involved including copper, selenium, zinc, vitamin E and vitamin D.
Ruminal disruption	Cows are very vulnerable to ruminal acidosis during the transition period resulting from lower feed intake and rapid introduction of grains and other highly fermentable feeds (e.g. turnips, swedes, and lush pastures) post-calving.

*A conditioned deficiency is the result of an excess of one or several minerals causing a deficiency in another mineral

Properly addressing these aims during the transition period will result in a successful calving, productive lactation, and good reproductive performance. The targets for cow health problems during calving and early lactation outlined in Table 1.2 should be achievable.

Table 1.2 Achievable targets for cow health problems expressed as percentage of cases of calving cows within 14 days of calving unless otherwise specified. Based on data sets from Morton, Curtis, Beckett, Moss and Stevenson.

Indicator	Target performance	Seek help if
Milk fever	1% (8 years of age or less) 2% (greater than 8 years of age)	Greater than 3%
Pregnancy toxaemia	No cases	One or more cases
Clinical ketosis	Less than 1%	Greater than 2%
Abomasal displacements (left or right)	Less than 1%	Greater than 2%
Clinical mastitis	Less than 5% in the first 14 days after calving	Greater than 5% in the first 14 days after calving
Lameness (Sprecher et al., 1997 scale 1-5)	Less than 2% (greater than Score 2)	Greater than 4% (greater than Score 2)
Hypomagnesaemia	No cases	One or more cases
Retained foetal membranes greater than 12 hrs after calving	Less than 3%	Greater than 6%
Endometritis – infected after 21 days	Less than 3%	Greater than 10%
Calving difficulty	Less than 2%	Greater than 3%
Lactic acidosis	Less than 1%	Greater than 1%

Influencing the future with transition cow management

There is strong evidence that nutritional strategies that influence the transition result in increased production that extends over much or all of lactation (Lean et al., 2014). These responses are outlined in Table 1.3 and are discussed in detail throughout this review.

Some nutritional interventions applied for approximately three weeks pre-calving produce positive production responses over an entire lactation.

Benefits of an integrated approach to transition nutrition

Establishing successful lactations is much more than delivering a live calf. It requires:

- A rumen environment successfully adapted to higher energy feeds
- Almost no milk fever cases in the herd
- Very low incidence of other cow health problems common in the first four weeks after calving
- Low culling and death rates in the first four weeks
- High herd fertility
- More productive lactations
- Less labour and stress from time spent on sick cows
- Enhanced animal welfare

This review provides evidence and guidelines to help achieve these benefits in Australian dairy herds.

Table 1.3 Potential interventions pre-calving that have a prolonged effect on milk production and reproduction in lactation

Intervention type	Physiological basis	Examples	References
Dietary cation anion difference (DCAD) interventions	Upregulation of metabolism through skeleton, decreased disease risk.	Randomised controlled and cohort studies showing increased milk production with DCAD interventions.	(Block, 1984) (DeGaris et al., 2008) (DeGroot et al., 2010) (Martinez et al., 2018a, b) (Rodney et al., 2018a)
Hormonal intervention	Increase in mammary parenchyma or sensitivity to other stimuli.	Recombinant somatotropin (rBST)*, increased short-term milk production.	(Gulay et al., 2004a,b)
Reduced nutrient demand pre-calving or increased energy or protein intake	Increased availability of glucose, fats, protein, macrominerals and micronutrients.	Increased lactational milk production of cows that give birth to heifers.	(Bell, 1995) (Hinde et al., 2014)
Controlling the negative effects of oxidative stress and inflammation	Pro-oxidative damage and inflammation can impair organ function e.g. hepatic lipidosis.	Increased milk production of cattle treated with salicylic acid (aspirin).	(Bertoni et al., 2004) (Farney et al., 2013) (Shwartz et al., 2009)

*Not registered for use in Australia at the time of publication.

CHAPTER 2

KEYS TO ACHIEVING SUCCESSFUL LACTATIONS

Establishing successful lactations aims to achieve the following outcomes:

- Successful rumen adaptation and freedom from ruminal disruption
- Maintaining adequate dry matter intake to reduce the risk of micromineral deficiency, marked immune suppression, ruminal disruption, and lipid mobilisation disorders
- Meeting the demands of the foetus and udder for calcium and other nutrients to reduce the risk of macromineral deficiency, lipid mobilisation and immune dysfunction
- Reducing the adverse effects of lipid mobilisation on liver function to reduce the risk of metabolic disorders and immune dysfunction

An integrated approach to transition cow management is needed if these challenges are to be dealt with effectively.

Successful rumen adaptation

Cows are vulnerable to disorders of rumen function when they move from diets lower in energy density to those of higher energy density. These disorders, collectively referred to as ruminal acidosis, represent a continuum that ranges from mild to fatal and are described in more detail in Table 2.1. Whilst there have been improvements in management to provide more energy dense rations in the transition period, dry cow rations continue to have a lower energy density than lactating cow rations, even in pasture-dominant feeding systems. In many cases, ruminal acidosis is relatively mild; however, a failure to manage the risk of ruminal acidosis can result in herd outbreaks with serious effects on health and production.

Table 2.1 Ruminal acidosis and lactic acidosis

Condition	Common clinical signs	Control measures
Ruminal acidosis is the accumulation of total volatile fatty acids in the rumen, especially propionate. The rumen pH range is typically 5.5 to 6.0	Some cattle off feed, some evidence of lameness, reduced fibre digestion, mild milk fat depression, often good to excellent production, scouring can be present.	Ensure evenness of access to pasture and other forages. Chop length of silage or hays should be more than 2.5cm. Check that very soluble sources of carbohydrates (e.g. sugars) and feeds high in lactic acid (e.g. wheys, corn silages and especially corn earlage) are not in excess.
Lactic acidosis is the accumulation of lactate, a strong acid. The rumen pH is typically less than 5.5.	Acutely sick cattle with low rumen pH, off feed, low milk fat, high prevalence (more than 10% of cows) with lameness greater than Score 2. Cattle die with liver or lung abscess, often see large amounts of unconsumed grain in bails, many cows scouring. Scour contains large amounts of grain and bubbles, many cows not eating.	Increase the effective fibre in the diet. This may involve reducing the amount of concentrate, slowing the pasture rotation, and feeding palatable fibre in the form of silage or hay. Consider using rumen buffers or modifiers. Ensure even access to forage so that all cows get fibre. Introduce grain and concentrates before calving.

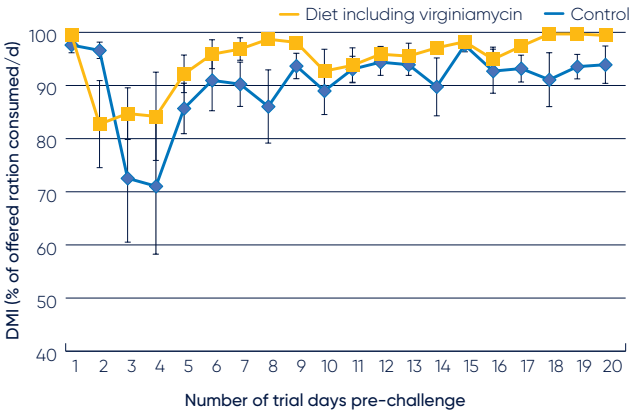
It is important to adapt cows to feeds of higher energy density before calving. Part of the adaptive process in the rumen involves the elongation (hypertrophy) of ruminal papillae and an increase in absorptive surface area of the papillae (Dirksen et al., 1985). It has been suggested that a lower absorptive area of ruminal epithelium may reduce the rate of absorption of volatile fatty acids and lactic acid from the rumen (Goff and Horst, 1997). Figures 2.1 and 2.2 show the development of rumen papillae before and after adaptation to concentrates. The need to adapt cows to higher energy density lactating diets may be more important in pasture-based systems than total mixed ration (TMR) systems as TMR systems tend to utilise higher levels of starch in transition rations resulting in sufficient ruminal adaption to lactating rations (Penner et al., 2011). In both systems, there is also a need to allow rumen microbial populations to form a stable ecosystem based on greater activity of starch utilising (amylolytic) bacteria.

Changes to rumen microbial populations are quite rapid (7 to 10 days). Full development of ruminal papillae takes longer (3 to 6 weeks).

Dry matter intake (DMI) is lower during ruminal acidosis as a rumen pH of less than 6.0 does not favour fibre digestion and a cyclic pattern of eating can be observed in which cattle increase and decrease DMI in association with acidosis. This is illustrated in Figure 2.3 (modified from Golder et al. (2014a)) whereby fluctuations in mean percentage of dry matter consumed (plus or minus standard error of the mean) can be observed in the pre-challenge period of a starch and sugar challenge study. All animals were fed a 62:38 forage to concentrate TMR at 2.5% of bodyweight in the 20-day pre-challenge period shown. The blue line represents the dry matter intake of heifers fed the control diet and the orange line represents a similar diet to that fed to the controls with ruminal acidosis risk decreased by including virginiamycin.

Figure 2.1 Ruminal papillae before adaptation

Figure 2.3 Cyclic eating associated with ruminal acidosis



The blue line represents the dry matter intake of heifers fed the control diet and the orange line represents a similar diet to that fed to the controls with ruminal acidosis risk decreased by including virginiamycin. Modified from Golder et al. (2014a).

A large Australian study found that an estimated 10% of dairy cows less than 100 days in milk had ruminal acidosis, as defined by assessment of ruminal volatile fatty acids (VFA), ammonia, lactic acid, and pH (Bramley et al., 2008). In addition, two studies in Wisconsin found that 20% and 23% of cows, respectively, had subacute ruminal acidosis as defined by rumen pH less than 5.5 (Oetzel et al., 1999, Oetzel, 2004). A study in Ireland found 11% of cows had subacute ruminal acidosis (O'Grady et al., 2008). Therefore, it is likely that many cows will experience some level of acidosis during lactation and some may be affected multiple times. It can be estimated that if the prevalence of acidosis is 10% (Bramley et al., 2008) and the duration of a case is two days, based on data by Golder et al. (2014a) and associated assumptions made by this review's authors, then there would be an incidence of approximately 500

Figure 2.2 Ruminal papillae, showing hypertrophy, after adaptation

cases over the first 100 days of lactation per 100 cows. Understanding and controlling acidosis is therefore critical to ensuring animal well-being and production.

Ruminal acidosis can range from minimal clinical signs to more serious signs such as lameness, diarrhoea (often with grain and/or gas bubbles in the faeces), low milk fat percentage and poor production. Potential sequalae include rumenitis, liver abscess, pulmonary infections, abomasal displacement, epistaxis, and death. Ruminal acidosis arises after the ingestion of moderate to large amounts of rapidly fermentable carbohydrates to which the animal is not accustomed.

One survey found that an estimated 10% of Australian cows less than 100 days in milk had ruminal acidosis at the time of sampling. Cows are particularly vulnerable to ruminal acidosis during the transition period.

Bramley et al. (2013) found that herds with a high prevalence of ruminal acidosis had variable individual cow milk production, a high prevalence (greater than 40%) of lameness, high prevalence of milk fat to milk protein ratio of less than 1.02 and diets that were high in non-fibre carbohydrates (NFC; greater than 40%), but low in neutral detergent fibre (NDF; less than 31%) (Bramley et al., 2013)

It is important to note that a low-fat test (i.e. less than 3.4% fat) in Holsteins does not necessarily mean that the herd or a particular cow is acidotic, but herds and cows with ruminal acidosis will very probably have a low milk fat test.

Dry matter intake

Maintaining feed intake is one of the most important goals of the transition period.

Periparturient disease conditions are associated with decreased DMI. Feed intake in the dry period and transition period is a critical determinant of subsequent health and productivity. Decreased DMI may be evident sometime before calving and the onset of disease.

Feed intake and nutrient density of the diet determine the availability of nutrients to the cow, the rapidly developing udder and foetus. Grant and Albright (1996) reviewed the feeding behaviour and management factors during the transition period for dairy cattle and found that feed intake decreased by up to 30% during the week before calving. Factors that influenced feed intake include social dominance, digestibility of the diet, access to feed and the palatability of the feed (Grant and Albright 1996).

An Australian study that measured daily feed intakes of dry cows fed on poor quality hay and a total mixed ration (TMR) found that intakes of the hay diet declined over the three weeks before calving while intakes of TMR remaining relatively constant until just before calving. The total DMI over the transition period was also higher for the TMR than the hay-based diet (Stockdale 2007).

Cows are relatively insensitive to insulin around the time of calving and have relatively low concentrations of insulin at this time, helping maintain a constant blood glucose level despite declining feed intake in the last week or so before calving. This is because utilisation of glucose by tissues decreases, while utilisation of energy sources derived from lipids by muscle increases, sparing glucose. This signals an increase in the rate of mobilisation of body fat stores to support lactation.

This has implications for health and fertility as excessive mobilisation of tissue increases the risk of diseases such as ketosis, uterine infections, and fatty liver. It has been suggested that control of feed intake is mediated in part through oxidation of propionate in the liver, resulting in greater satiety (Allen et al. 2009). Consequently, fats and less fermentable carbohydrate sources may be important to use in early lactation.

Cows and sheep in higher body condition scores have lower dry matter intakes after parturition (Gainsworthy and Topps 1982; Gowan et al. 1980) and lower dry matter intake has been noted immediately after calving (Lean et al. 1994) and before calving (Lean et al. unpublished) for cows with clinical ketosis. Heavily conditioned cattle can have markedly lower dry matter intakes, and this is noted especially in cattle with a body condition score greater than 6 out of 8 (3.5 on the one to five scale). More obese animals are also at greater risk of milk fever (Stockdale 2007).

However, providing access to feed for more than eight hours per day and maintaining adequate availability and nutrient density of feed, controlling dominance behaviour by grouping and providing adequate feed access and controlling body condition to an ideal of approximately 3.5 on the five-point scale (Edmondson et al. 1989) or 5.5 on the eight point scale will reduce the risk of inadequate nutrient intake. In particular, the use of more digestible forages with a lower slowly digestible fibre content will allow greater DMI.

The effect of greater dry matter intake was demonstrated by the force feeding through a ruminal fistula of periparturient cows (Bertics et al. 1992). Cows that received more feed had less hepatic lipid accumulation and higher milk production after calving. The higher milk production resulted from greater post-calving feed intake and a highly significant positive correlation between pre- and post-calving feed intake was identified (Bertics et al. 1992).

Demand for calcium

Changes in calcium metabolism induced by lactation are more significant than parturition (calving) *per se* to the pathogenesis of hypocalcaemia and, more specifically, milk fever. The loss of blood calcium to milk may exceed 50 to 80 grams per day; whereas before calving, the daily requirement for calcium is only approximately 30 grams per day (15 grams per day lost in faeces and urine and 15 grams per day required for foetal growth). The increased demand for calcium at the onset of lactation may only be satisfied by increased absorption from the rumen or intestines and increased mobilisation from tissue, especially bone, as circulating blood calcium reserves are limited. This results in most cows having some degree of hypocalcaemia at calving.

Total blood calcium is maintained within a narrow range (2.0 to 2.5 mmol/L). Cows can only afford to lose approximately 50% of circulating blood calcium reserves before a hypocalcaemic crisis is precipitated. The amount of calcium available for mobilisation from bone reserves is limited, therefore, increased absorption of calcium from the gut is critical to maintaining blood calcium.

The skeleton contains around 98% of total body calcium and calcium pools are under strict homeostatic control. There is around 3 grams of calcium in the plasma pool and only 8–9 grams of calcium in compartments outside the bone of a 600kg cow. At parturition, there is a sudden increase in the cow's calcium requirements for colostrum 2.0 to 3.5 grams of calcium per litre, or an increase in total requirement from 15 to 25 grams per day (Rodney et al., 2018a). This is nearly 10 times the amount circulating in plasma at any time. In milk, there is 1.22–1.45 grams of calcium per litre, so meeting these needs requires at least a 2 to 4-fold increase in calcium availability. This increase comes mainly from an increased rate of dietary calcium absorption and to a much lesser degree, calcium mobilised from bone storage.

The onset of lactation increases the cow's daily calcium requirement by 2 to 4-fold. Increased calcium uptake from the gastrointestinal tract is critical to meeting these needs; bone mobilisation is much less important.

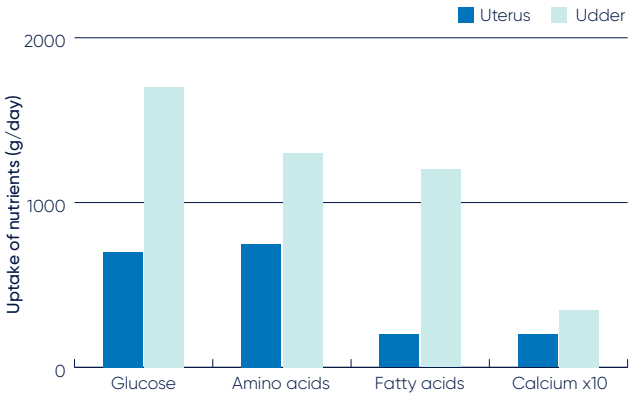
Demands of the foetus and udder for nutrients

Bell (1995) reviewed studies in which the nutrient demands of the foetus in late gestation were examined. These studies show that the foetal requirements for energy, while modest, are demanding in that the requirement for glucose is four times greater than that for acetate. The glucose must be primarily supplied by gluconeogenesis in the liver. This demand highlights problems with the low energy density of dry cow diets recommended by National Research Council (NRC; 2001). The foetus has an *a priori* demand for glucose over the dam (Stephenson et al., 1997). This means that the cow may need to mobilise body tissues to support the foetus.

The foetus also has significant requirements for amino acids, which are used for tissue deposition and for oxidation. This requirement for amino acids appears to be three times greater than the net requirement for growth (Bell, 1995) because of significant oxidation of amino acids in the foetus.

Figure 2.4 derived from Bell (1995), shows that the demand for nutrients to support lactation increases markedly at the onset of lactation. It is not unusual for cattle to produce a kilogram of fat, a kilogram of protein and more than a kilogram of lactose (sugar) within a few days of calving. This represents an extra-ordinary feat of metabolic control.

Figure 2.4 Uptake of nutrients by the foetus and mammary gland (modified from Bell 1995)



Demands of the foetus for nutrients are substantial in late gestation. Demand for nutrients is even greater in early lactation.

Lipid mobilisation and impact on liver function

As previously noted, there is an extraordinary effort needed to meet the increased nutritional demands of the foetus in late gestation and the udder in early lactation. Cattle are adapted to manage periods of feed deficit by mobilising body tissues to support the needs for maintenance, lactation, or the foetus. This process, however, requires adaptations to allow for the efficient use of these nutrients. A failure to adapt can result in conditions such as pregnancy toxaemia (Lean, 2011a) and ketosis (Lean, 2011b).

Many cows do adapt to these challenges successfully and an elevation in ketone concentrations does not necessarily reflect a problem. The table in Appendix F provides information on concentrations of ketones that may indicate increased risks of other disorders. However, numerous studies show that cows with higher blood ketones do not uniformly have poorer performance (Lean et al. 1994; Westwood et al., 2000; DeGaris et al. 2010). Lean et al. (1994) and Horst et al. (2019) suggest that inflammatory processes are critical to the development of clinical ketosis. These views are strongly supported in a comprehensive review of the role of inflammation in the transition period (Bradford and Swartz, 2020).

Overton (2001) examined the effects of fat (lipid) mobilisation on liver function. Increased tissue mobilisation increases the flux of free fatty acids to the liver for oxidation and increases the need to export some of these back to peripheral tissues as ketones. The liver may not be able to re-export sufficient levels of these fatty acids and accumulates fat in hepatocytes. This accumulation implies that both rates of production of glucose and urea may be impaired (Strang et al., 1998). Additionally, Strang et al. (1998) reported that hepatic ureagenesis was reduced by 40% with exposure of liver cells to free fatty acids that resulted in increased triglyceride accumulation similar to that of cows after calving. Zhu et al. (2000) found that when cows were fed a 21% crude protein diet after calving, ammonia concentrations in blood doubled during the first two days after calving. For the pasture-based dairy production systems, these changes may have significant implications given the higher propensity to feed cows less well in the transition period and the very high pasture protein concentrations in late winter and early spring. Feed additives that assist in the control of ketosis and other lipid mobilisation disorders are outlined in Table 2.2. However, it is important to note that diets and feeding strategies that meet the guidelines for transition diet formulation described in this review will reduce the risk of lipid mobilisation disorders.

Clinical ketosis and fatty liver are serious health conditions that often reflect the combined effects of inflammation and tissue mobilisation.

Table 2.2 Feed additives with evidence of preventive effects on ketosis/fatty liver syndrome

Additive	Monensin	Propylene Glycol	Chromium	Choline
Inclusion rate	240 to 400 milligrams per day	200 to 300 millilitres twice a day	20 grams per cow per day of 0.04% or 2 grams per cow per day of 0.4%	Source dependent – often ~ 15 grams per cow per day
Mode of action	Inhibits gram positive bacteria in the rumen	Supply of propionate precursor	Reduced insulin resistance	Increased export of non-esterified fatty acids (NEFA) from liver
Benefit	Increases propionate in the rumen leading to increased glucose, reduced NEFA and beta hydroxybutyrate (BHB) in blood	Increased milk yield in early lactation n and reduced duration of illness	Reduced NEFA, increased dry matter intake (DMI), increased milk yield in early lactation	Reduced liver fat content, reduced clinical ketosis, improved milk yield in early lactation
Feeding period	From -21 to 305 days in milk (DIM)	From diagnosis of ketosis to resolution	-21 to 30 DIM, depending on feeding management	-21 to 21 DIM

CHAPTER 3

PATHOPHYSIOLOGY AND CONTROL OF HYPOCALCAEMIA (MILK FEVER)

Table 3.1 Definition of hypocalcaemia, milk fever and subclinical hypocalcaemia

Term	Definition
Hypocalcaemia	Decline in blood calcium levels at calving (parturition), associated with increased demands for milk production, which may be normal, subclinical, or clinical.
Milk fever	Clinical hypocalcaemia. Also called periparturient, post parturient or parturient paresis.
Subclinical hypocalcaemia	Hypocalcaemia that has not progressed to clinical disease (milk fever). May be defined by depth of hypocalcaemia, duration of hypocalcaemia or a combination.

The terms used in this chapter are defined in Table 3.1. Milk fever (also called periparturient, post parturient or parturient paresis) is a clinical manifestation of hypocalcaemia, a condition that affects most cows after calving. Hypocalcaemia has been arbitrarily defined as a blood concentration less than 2.0 mmol/L. The table in Appendix F provides details on concentrations of blood calcium that have been used to define hypocalcaemia. Despite this, strict definitions of hypocalcaemia based on calcium concentrations measured near calving can be problematic, as calcium concentrations are very dynamic in this period.

For every case of milk fever there may be eight or more cases of subclinical hypocalcaemia.

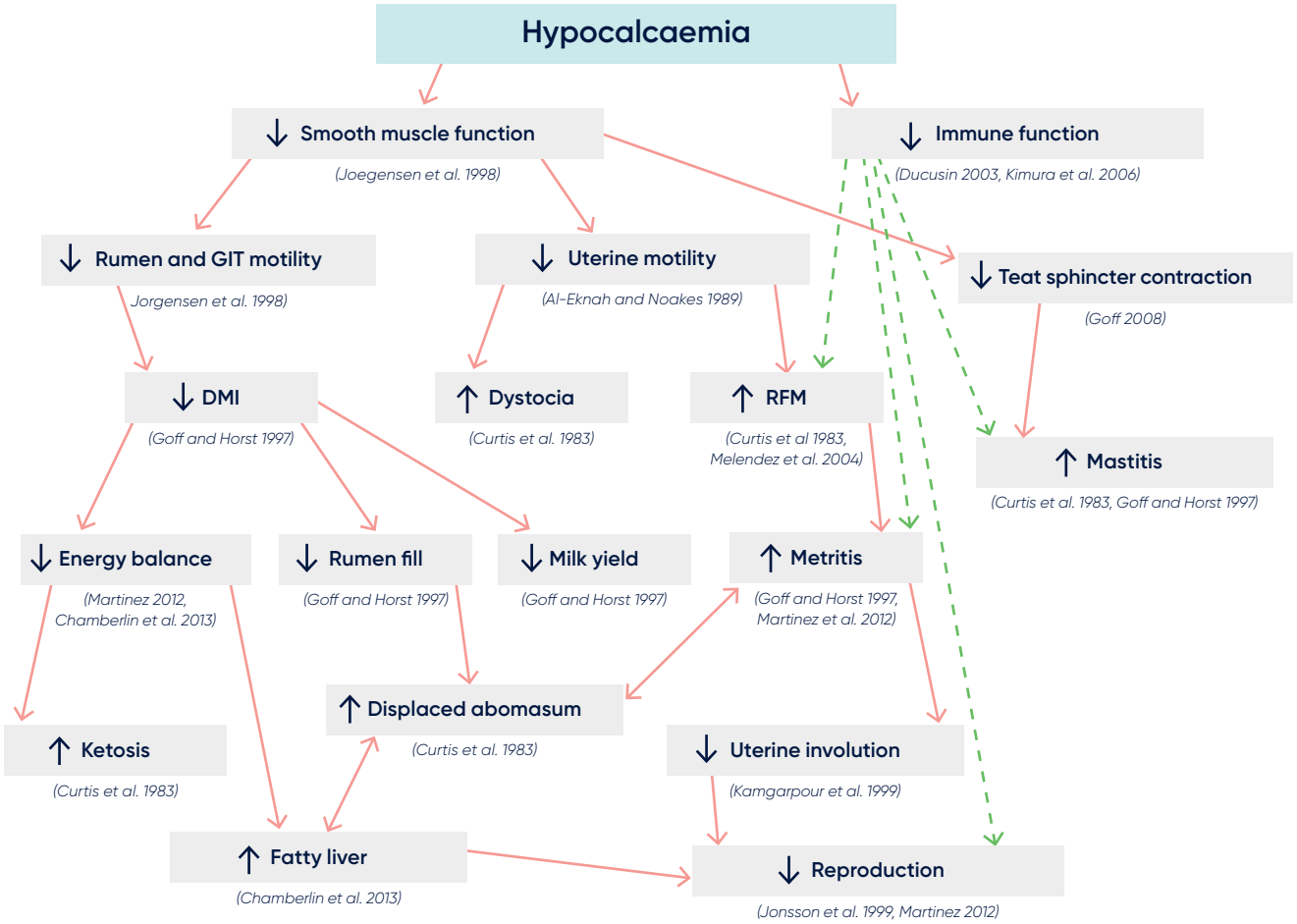
Milk fever risk can be predicated from dietary levels of calcium, magnesium, phosphorus and dietary cation anion difference (DCAD), age and breed of cattle, duration of exposure to the pre-calving transition diet and other factors including social interactions, environmental stress, and fluctuations in dry matter intake (DMI) (DeGaris et al. 2008; Lean et al., 2019; Santos et al., 2019). Ignoring any of these areas could lead to poor results.

Hypocalcaemia – a gateway disorder

Why is calcium important? Calcium is critical to bone, blood clotting, heart function, smooth and skeletal muscle function, but also as a signalling agent in the body. Changes in calcium in blood or tissues can have a profound effect on tissue function.

Hypocalcaemia is often referred to as a 'gateway' disease with many potential flow-on effects that increase the risk of other diseases, including mastitis, ketosis, retained foetal membranes (RFM), displaced abomasum and uterine prolapse. Many of these effects have now been quantified. Figure 3.1 illustrates the flow on effects of hypocalcaemia on the risk of other diseases and the studies to support this.

Figure 3.1 Flow on effects of hypocalcaemia on the risk of other diseases

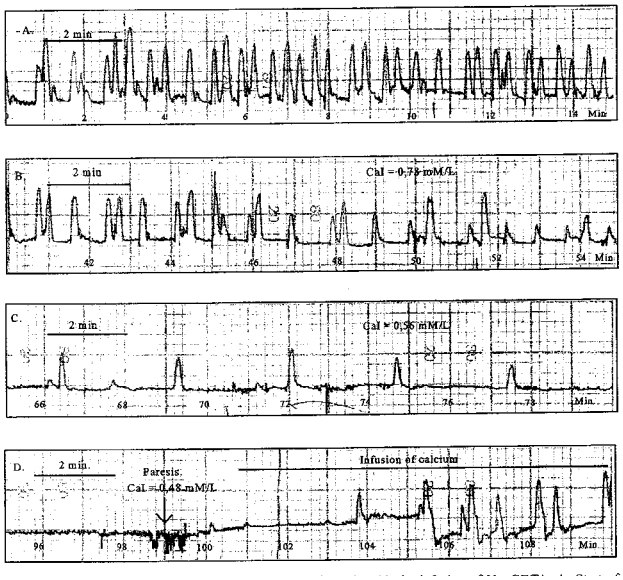


Hypocalcaemia and milk fever are risk factors for reproductive disorders and are an indirect risk factor for increased culling.

Hypocalcaemia is a risk factor for reproductive disorders (Caixeta et al., 2017), as is milk fever (Borsberry and Dobson, 1989), and is an indirect risk factor for increased culling. These effects are primarily mediated through reduced smooth muscle contractility and a direct negative effect of hypocalcaemia on the function of the immune system (Wilkens et al., 2020).

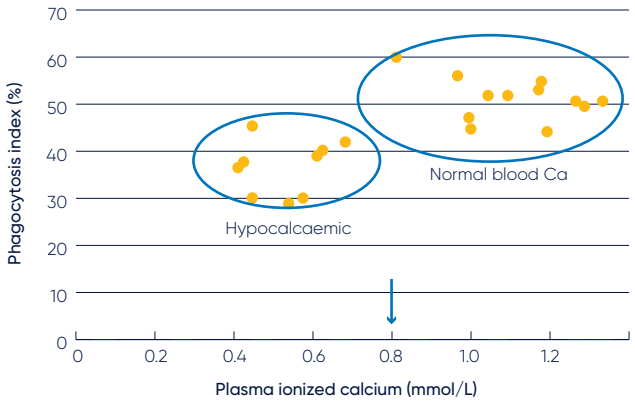
The negative effects of hypocalcaemia on smooth muscle contractility were demonstrated by Jørgensen et al. (1998) when they artificially induced progressively severe hypocalcaemia in cows via the intravenous infusion of EDTA (a potent calcium binder) while monitoring rumen contractility. Figure 3.2 shows the significant reduction of rumen contractility with even mild subclinical hypocalcaemia (0.78 mmol/L ionised calcium). Similarly, reduced uterine contractility associated with hypocalcaemia after calving can be associated with an increased risk of RFM (Melendez et al., 2004, Lean et al., 2019, Santos et al., 2019). Lean et al. (2019) found a marked reduction in the incidence of RFM with use of low dietary cation anion difference (DCAD) feeding strategies during the transition period. In addition, calcidiol feeding before calving appears to enhance this effect (Martinez et al., 2018a). This is described in more detail in Chapter 4.

Figure 3.2 Hypocalcaemia (ionized Ca) and reduction of rumen contractility with increasingly severe hypocalcaemia (extracted from Jorgenson et al., 1998)



The depression of the immune system around calving is well recognised (Goff and Horst 1997) and is more severe in cows with milk fever (Curtis et al. 1983). Calcium is essential for the activation of neutrophils. Figure 3.3 shows the high percentage of neutrophils phagocytosing fluorescent particles in cows with normal blood calcium versus cows with low blood calcium. The effects of reduced immune function have flow-on effects for the risk of mastitis, metritis and reproductive functions (Ducusin et al., 2003).

Figure 3.3 Reduced percentage of neutrophils phagocytosing fluorescent particles in cows with normal blood calcium versus low blood calcium (Adapted from Ducuscin et al., 2003)



Age and breed

The higher susceptibility to hypocalcaemia of the Channel Island breeds compared to Holsteins is well established (Harris, 1981). Jerseys are roughly twice as susceptible to milk fever as Holsteins (Harris, 1981, Lean et al., 2006). Older cows are also at greater risk of hypocalcaemia. This increased risk is associated with a decreased capacity to mobilise calcium from bone (van Mosel et al. 1993) and possibly a decreased number of 1,25 dihydroxycholecalciferol ($1,25(OH)_2D_3$) receptors in the small intestine (Horst et al., 1990). DeGaris et al. (2008) found that the risk of milk fever increased by 9% per lactation in the subpopulation of studies used for a meta-analysis that reported age (Lean et al., 2006).

Jerseys have about twice the risk of hypocalcaemia compared to Holsteins. The risk of milk fever also increases with age, by approximately 9% per lactation.

Calcium

Calcium is so essential to the function of the body that concentrations in blood must be kept within a tight range to maintain life. Consequently, the body has a finely tuned system of homeostasis to maintain concentrations in this range.

Physiological controls over calcium homeostasis include the hormone calcitonin, secretion of which is stimulated in response to elevated blood calcium concentrations. Parathyroid hormone (PTH) is released from the parathyroid glands in response to lowered blood calcium. When the amount of calcium coming into the digestive tract decreases, PTH is released, stimulating the production of active vitamin D_3 and the absorption of more calcium from the gut. Parathyroid hormone plays a critical role in vitamin D metabolism and is the main short-term regulator of calcium homeostasis. Although calcitonin does cause the concentration of calcium in blood to fall, the effect is small in comparison to the potential effect of PTH. Vitamin D has an important function in maintaining calcium homeostasis, in part through steroid hormone-like roles in the body. Appendix E describes the complex interplay between the various pathways influencing calcium concentrations and discusses the roles of vitamin D, bone hormones and serotonin in influencing calcium metabolism.

Dietary calcium intake before calving

Early studies (Boda and Cole, 1954, Goings et al., 1974) found that feeding diets low in calcium before calving reduced the risk of milk fever. However, Goff (2000) concluded that calcium concentration in pre-calving diets had little influence on the incidence of milk fever when fed at levels above the daily requirements of the cow (approximately 25 to 30 grams per day). Quantitative reviews tend to suggest that a low dietary calcium percentage (Oetzel 1991; Lean et al., 2006) or intake (Santos et al., 2019) in the pre-calving diet is effective at reducing the risk of hypocalcaemia. One approach to controlling calcium availability has been to use calcium binding agents (Thilsing Hansen et al., 2002; Kerwin et al., 2019) and this has been reviewed in Chapter 10.

Oetzel (2000) recommended a daily intake of calcium in the pre-calving diet of 150 grams per day and a calcium concentration of between 1.1 and 1.5% of dry matter (DM), in conjunction with a dietary DCAD of approximately –150 mEq/kg of DM. However, this level of dietary calcium is not supported by the meta-analyses of Oetzel (1991), Enevoldsen (1993) and Lean et al., (2006) which found the highest risk of milk fever occurred with dietary calcium concentration in the range of 1.1 to 1.5%. Lean et al. (2019) did not find an effect of differences in pre-calving calcium intake on hypocalcaemia or milk fever risk, however, Santos et al. (2019), using a larger database, found a tendency ($P = 0.06$) for increased pre-calving dietary calcium intake to increase the risk of milk fever. Both these data sets from 2019 are smaller than those from Lean et al. (2006).

On balance, a strategy of feeding sufficient calcium (0.5 to 0.7% of diet DM) seems prudent to allow calcium balance to be maintained when calciuria, stimulated by feeding a negative DCAD diet, occurs before calving. Rodney et al. (2018a) fed approximately 63 grams per day of calcium (0.55% of diet DM as calcium) to cows that maintained an estimated positive calcium balance of more than 10 grams per day when fed a diet with DCAD less than –120 mEq/kg of DM, indicating adequate calcium intakes. Certainly, given the important role of vitamin D metabolism, using high concentrations and amounts of calcium which will depress vitamin D responses seems imprudent.

DeGaris et al. (2010) developed a model showing the interactions between calcium and length of exposure to the transition diet and milk fever. It suggests that short term exposures to high calcium concentrations in the diet (greater than approximately 0.9%) result in high rates of milk fever. Therefore, high calcium concentrations in the pre-calving period are not recommended.

A strategy of feeding low levels (0.5 to 0.7% of diet DM) of calcium before calving is supported by the current literature. Calcium influences hypocalcaemia independent of DCAD.

Magnesium

Magnesium is an important element and is critical to enzymatic function in every major metabolic pathway. Approximately 70% of body magnesium is present in bone and almost all the remaining magnesium is found in soft tissue. It serves with calcium to preserve membrane stability; hence it is important to cardiac muscle function, skeletal muscle function and nervous tissue function.

Magnesium plays a very important role in calcium homeostasis. There are sound physiological bases for a protective role of magnesium in the pathogenesis of hypocalcaemia. Magnesium is critical in the release of PTH and in the synthesis of the hormone calcitriol. In hypomagnesaemic states, kidney and bone are less responsive to PTH (Sampson et al., 1983, Goff, 2000). In contrast, Wang and Beede (1992) found that non-pregnant, non-lactating cows fed a diet high in magnesium had lower renal calcium excretion than those fed a diet low in magnesium. Contreras et al., (1982) and van de Braak et al., (1987) both demonstrated poor calcium mobilisation in hypomagnesaemic cattle.

Increased magnesium intake plays a protective role in hypocalcaemia independent of DCAD.

Phosphorus

There is evidence that a pre-calving diet high in phosphorus can have a negative impact on calcium homeostasis (Julien et al., 1977, Kichura et al., 1982, Barton et al., 1987, Peterson et al., 2005). Phosphorus also may play an important role in milk fever, with increasing dietary phosphorus concentrations (Lean et al., 2006) and increased intake (Lean et al., 2019) increasing milk fever risk. Phosphorus concentrations are regulated directly by calcitriol and indirectly by the PTH/calcium negative feedback loop (Goff, 1999), albeit with less homeostatic control than calcium.

Increased dietary phosphorus increases the risk of milk fever independent of DCAD.

Dietary Cation Anion Difference

The Dietary Cation Anion Difference (DCAD) theory of milk fever control began with studies by Norwegian workers who 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 acidogenic salts, decreased the incidence of milk fever (Ender et al., 1962, Dishington, 1975, Dishington and Bjornstad, 1982). Block (1984) found a significant decrease in the incidence of milk fever for cattle fed diets that differed only in their quantities of chlorine, sulphur, and sodium. Further studies (Oetzel et al., 1988, Gaynor et al., 1989, Leclerc and Block, 1989, Goff et al., 1991, Beede et al., 1992, 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).

Subsequent meta-analyses of the available literature demonstrate that reducing DCAD is a powerful means of reducing risk of milk fever (Oetzel 1991; Charbonneau et al., 2006; Lean et al., 2006; Lean et al., 2019; Santos et al., 2019) and hypocalcaemia (Lean et al., 2019; Santos et al., 2019). The linear relationship between Dietary Cation Anion Difference (DCAD) and milk fever risk (Lean et al., 2005) predicts that any reduction in the DCAD percentage of the diet will decrease the risk of milk fever and is shown in Figure 3.4. This linear relationship should not be confused with the curvilinear relationship between DCAD and urine pH which is described later.

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

Reducing DCAD reduces the risk of milk fever.

Recent meta-analyses by Lean et al. (2019) and Santos et al. (2019) found that reducing DCAD reduced risk of hypocalcaemia, irrespective of whether the treatment DCAD achieved was an overall negative DCAD diet.

Figure 3.4 Relationship between DCAD and milk fever risk (Lean et al., 2006)

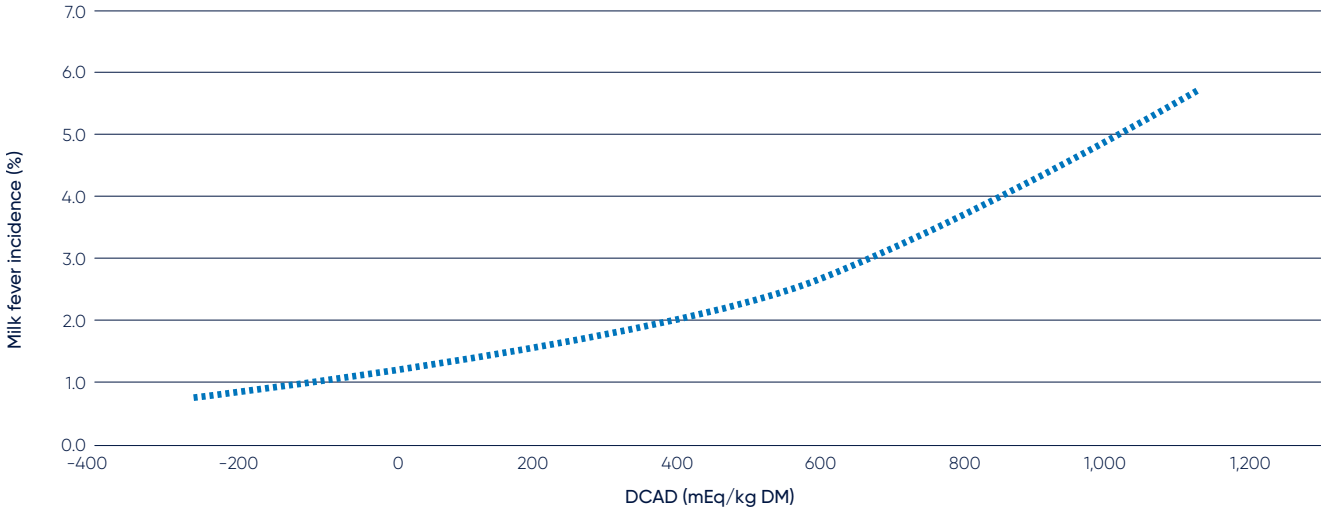
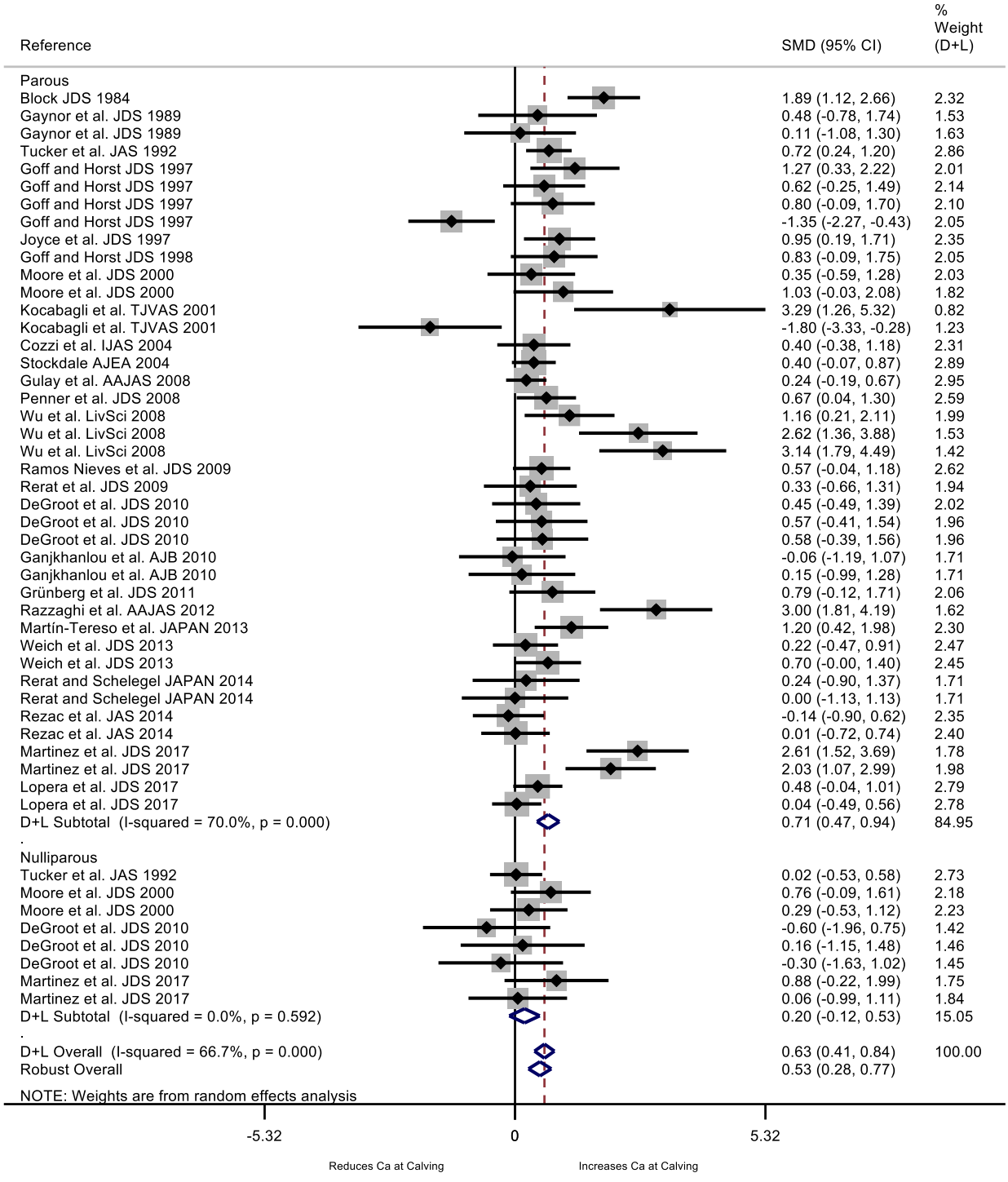


Figure 3.5 Forest plot of the effect of a lowered DCAD intake on calcium in plasma at calving in parous and nulliparous dairy cattle (Lean et al., 2019; Santos et al., 2019).



Each square around the point effect represents the mean effect size for that study and reflects the relative weighting of the study to the overall effect size estimate. The larger the box, the greater the study contribution to the overall estimate. The weight that each study contributed are in the right-hand column. The overall pooled effects size or SMD and 95% CI pooled using the DerSimonian and Laird (D + L; DerSimonian and Laird, 1986) and Robust meta-analytical models methods for random effects models are indicated by the respective diamonds at the bottom. The heterogeneity measure, I^2 is a measure of variation beyond chance among treatments included in the meta-analysis. Calcium in plasma was substantially heterogeneous as indicated by the I^2 of 66.7%, indicating variability in the positive response. A further explanation on interpretation of forest plots can be found in Appendix A.

DCAD Equations

Many formulae have been proposed for calculating the DCAD of diets. The variations of the DCAD formula are generally broken into short equations that contain only ionic sodium (Na^+), potassium (K^+), chlorine (Cl^-) and sulphur ($S2^-$) and longer equations that contain also calcium (Ca^{2+}), magnesium (Mg^{2+}) and phosphorus, as phosphate (P), in varying combinations and with differing coefficients.

The review and meta-analysis of Lean et al. (2006) developed two statistically significant and biologically plausible equations for predicting the risk of milk fever based on pre-calving dietary constituents. The authors preferred the equation whereby the risk of milk fever could be predicated from the dietary levels of calcium, magnesium, phosphorus and 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)].

Another meta-analysis examining DCAD only (Charbonneau et al. 2006) determined the most appropriate form of the DCAD equation was $(Na^+ + K^+) – (Cl^- + 0.6\ S^{2-})$ on the basis that this equation could be used to predict both risk of milk fever and urine pH. However, the equation $(Na^+ + K^+) – (Cl^- + S^{2-})$ was equivalent in predicting milk fever risk (Charbonneau et al., 2006). Consequently, based on the Simplified Strong Ion Model, described below, and the meta-analyses of Lean et al. (2005) and Charbonneau et al. (2006), we conclude that the equation DCAD = $(Na^+ + K^+) – (Cl^- + S^{2-})$ should be used to predict the effect of a diet on the risk of milk fever.

The most widely adopted equation that best predicts hypocalcaemia, milk fever, milk production and health is DCAD = $(Na^+ + K^+) – (Cl^- + S^{2-})$. The units used to describe DCAD are milliequivalents per kg of dry matter (mEq/kg DM). This is what is reported by Australian feed laboratories. The cations are sodium (Na^+) and potassium (K+) and the anions are chlorine (Cl^-) and sulphur (S^{2-})

Physiology of DCAD theory and milk fever control

The underlying physiology of the DCAD theory of milk fever control has its basis in the Strong Ion Model of acid base balance (Singer and Hastings 1948), modified by Stewart, (1981) and simplified by Constable, (1997). The basic tenets of the Simplified Strong Ion Model are that plasma pH is determined by four independent factors; the partial pressure of calcium dioxide (CO_2 p_{CO2}); solubility of CO_2 in plasma (So) which is temperature dependent; the net strong ion charge or strong ion difference ($[SID^+]$) and the total plasma concentration of non-volatile weak buffers, principally albumin, globulin and phosphate ($[A_{TOT}]$). The major strong ions consist of cations (Na^+, K^+, Mg^{2+}, Ca^{2+} and NH^{4+}) and anions (Cl^- and $S0_4^{2-}$).

The Simplified Strong Ion Model (Constable, 1999) to predict plasma pH is:

$$pH = pK_1' + \log \frac{[SID^+] - K_a[A_{TOT}]/(K_a + 10^{-pH})}{So * p_{CO_2}}$$

pK_1' is the ion product of water, K_a is the effective equilibrium disassociation constant for plasma non-volatile weak acids, $[SID^+]$ is the strong ion difference, $[A_{TOT}]$ is the plasma non-volatile weak acid concentration, So is the solubility of CO_2 in plasma and p_{CO2} is the partial pressure of CO_2 in plasma.

The Simplified Strong Ion Model predicts that plasma pH can be lowered by:

- Increasing the temperature thereby increasing solubility of CO_2 in plasma (So)
- Increasing p_{CO_2} (respiratory acidosis)
- Decreasing $[A_{TOT}]$
- Decreasing $[SID^+]$

Functionally, the way DCAD theory is used to prevent milk fever is to reduce the $[SID^+]$, consequently lowering plasma pH, resulting in strong ion metabolic acidosis.

Acidogenic salts were formerly called anionic salts. However, they are more appropriately termed acidogenic salts as the salts themselves are not anionic, but act in the body to cause a metabolic acidosis.

This is achieved by feeding the strongly acidogenic salts calcium chloride ($CaCl_2$), calcium sulphate ($CaSO_4$), magnesium chloride ($MgCl_2$), magnesium sulphate ($MgSO_4$), ammonium chloride (NH_4Cl) and ammonium sulphate ($(NH_4)_2SO_4$) or acids of the anions hydrogen chloride (HCl) and hydrogen sulphate (H_2SO_4). The strong cations calcium (Ca^{2+}), magnesium (Mg^{2+}) and ammonium (NH^{4+}) are absorbed to a lesser extent from the gastrointestinal tract than the strong anions chloride (Cl^-) and sulphate (SO_4^{2-}). This results in a relative excess of absorbed anions compared to absorbed cations lowering the $[SID^+]$ and subsequently lower plasma pH. The comparative aspects of sources of acidogenic salts in the diet are described in Table 3.2.

Table 3.2 Comparative aspects of sources of anions in the diet

Sources	Comments	References
Mineral sulphates e.g. calcium sulphate, magnesium sulphate, ammonium sulphate	Sulphate salts are more palatable than chloride. Ammonium salts provide non-protein nitrogen (NPN). The NPN can be beneficial on low protein diets.	Oetzel et al., (1991)
Mineral chlorides e.g. calcium chloride, magnesium chloride, ammonium chloride	Lower DCAD than sulphates. Ammonium salts provide non-protein nitrogen (NPN). This NPN can be beneficial on low protein diets.	No specific reference
Hydrochloric acid	Hydrochloric acid is an effective agent to decrease DCAD. Molasses-based supplements are used to mask taste and encourage intake.	Goff and Horst (1998)
Mineral salts are embedded inside an organic matrix with the addition of agents to increase palatability	A source of chloride and sulfur. Provides nitrogen in the forms of protein and non-protein nitrogen.	Leno et al., (2017)
Hydrochloric acid in a protein meal	Hydrochloric acid is an effective agent to decrease DCAD. A protein meal is a safer means to deliver and provides nutritional benefit.	Goff and Horst (1998)
Stabilised hydrochloric acid and sulphuric acids in a protein meal	Hydrochloric acid is an effective agent to decrease DCAD. Sulphur is also effective in lowering DCAD. A protein meal is a safer means to deliver and provides nutritional benefit via mainly amino acids and peptides to increase metabolisable protein.	De Groot et al., (2010) Lean et al (2005)

Salt (NaCl) and potassium chloride (KCl) have a net effect of zero on DCAD, because Na^+ and K^+ are absorbed with near 100% efficiency in the intestine.

Several means by which risk of milk fever may be influenced by feeding greater concentrations of acidogenic salts have been identified.

1 Diets high in acidogenic salts cause metabolic acidosis in goats (Fredeen et al., 1988a, Fredeen et al., 1988b) and cattle (Gaynor et al., 1989, Santos et al., 2019). These observations are consistent with the Simplified Strong Ion Model.

2 Diets high in acidogenic salts stimulate calciuria (Lomba et al., 1978, Gaynor et al., 1989, Oetzel et al., 1991, Phillipo et al., 1994). Rodney et al. (2018a) found that both calcidiol and a negative DCAD increased calcium excretion with approximately 14 grams per day greater excretion for cows fed calcidiol and a negative DCAD versus cows fed cholecalciferol and a positive DCAD. Zimpel et al. (2018) found that cows fed a negative DCAD diet produced 5 to 10 grams of calcium in urine, a figure similar to that found for several diets described by Rodney et al. (2018a). Ramberg et al. (1996) calculated that loss of calcium in urine of cows was in the order of 3 grams per cow per day. The control cows on a positive DCAD diet in the studies cited above had similar losses of calcium to Ramberg et al., (1996). Calciuria can be induced by acute acidosis in several species.

3 Elevated hydroxyproline concentrations have been observed in cows fed acidogenic salts (Block, 1984; Gaynor et al., 1989) and other bone markers are increased in some, but not all studies (Liesegang et al., 2007), probably indicating bone mobilisation.

4 Plasma ionised calcium concentrations increase with feeding of acidogenic salts (Oetzel et al., 1991, Phillipo et al., 1994, Rodney et al., 2018a).

5 Diets high in acidogenic salts stimulated higher plasma levels of calcitriol (active vitamin D) before calving in some (Gaynor et al., 1989, Phillipo et al., 1994), but not all studies (Rodney et al., 2018a).

6 There is increased sensitivity of tissues to PTH. Goff et al. (2014) demonstrated in an elegant study that cows on a negative DCAD diet had much higher calcium and calcitriol concentrations than cows challenged with PTH injections fed on a positive DCAD diet.

7 Wilkens et al. (2020) suggest that there may be changes to calcium absorption induced by negative DCAD diets, but studies are conflicting.

8 Conversion of osteocalcin from the carboxylated (cOC) to undercarboxylated (uOC) form is favoured by acidic conditions in the lacunae of bone and depends on vitamin K. This may not be reflected in changes in calcium metabolism, but changes in energy metabolism.

9 It appears that the feeding of acidogenic salts acts to increase mobilisation of calcium from bone, allows loss of urinary calcium and increases absorption of dietary calcium, possibly mediated through increases in plasma calcitriol concentrations. The acidotic state allows a higher concentration of ionised calcium (the metabolically active form of calcium). Acidotic cows are in a state where both bone mobilisation and dietary absorption of calcium are more active.

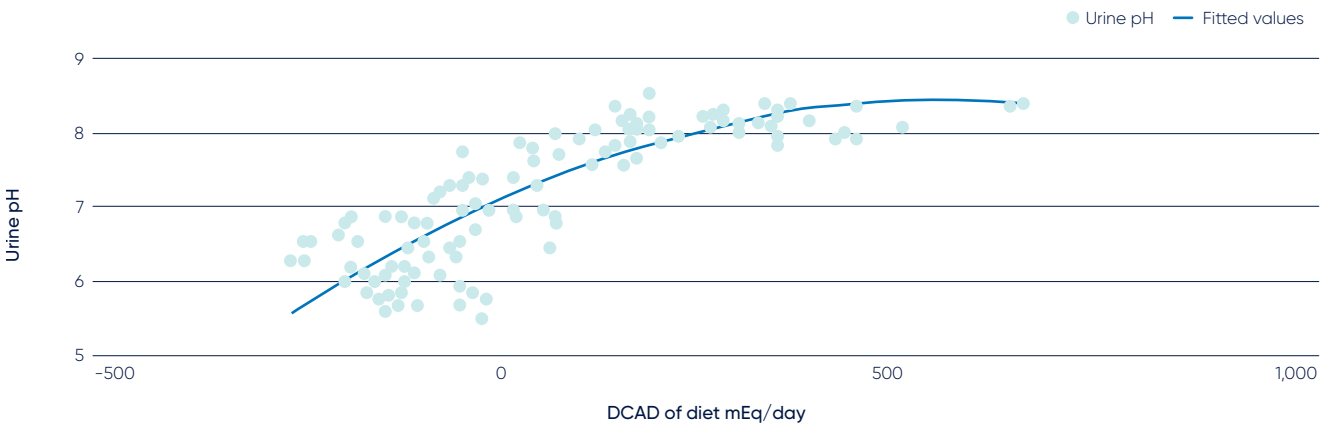
Feeding acidogenic feeds/salts lowers cows' blood pH, resulting in strong ion metabolic acidosis. This triggers more active bone mobilisation and absorption of dietary calcium from the gastrointestinal tract and a higher concentration of ionised calcium (the metabolically active form of calcium).

Monitoring urine pH

The degree of metabolic acidification can be monitored by evaluating the pH of urine. DCAD has little impact on urine pH until it reaches approximately 200 mEq/kg DM as shown in Figure 3.6. The curvilinear relationship between urinary pH and DCAD reflects renal buffering systems that maintain an alkaline urinary pH until overwhelmed. Jardon (1995), based on personal experience and communication with other researchers, suggested that a urinary pH of 6.0 –7.0 was optimal for Holstein cattle and a pH of 5.5–6.5 was optimal for Jersey cattle to indicate that the dietary DCAD was sufficiently lowered. Charbonneau et al. (2006) concluded that a urinary pH of 7.0, regardless of breed, may be more appropriate for transition cattle. While risk of hypocalcaemia is reduced by reducing DCAD (Lean et al., 2019), the pH of urine does not decline until the DCAD is less than approximately 200 mEq/kg of DM (DeGaris et al. 2010). Consequently, urine pH is a useful tool for determining whether the DCAD of the diet is negative, but not necessarily to determine the risk of hypocalcaemia, as this is influenced by other many factors as detailed in this review.

Urine pH is a useful tool for determining whether the DCAD of the diet is negative, but not necessarily to predict the risk of hypocalcaemia, as this is influenced by other many factors.

Figure 3.6 Curvilinear relationship (R^2 0.72) between DCAD (milliequivalents of intake per day) and urine pH (data from Santos and Lean)



CHAPTER 4

MINERAL NUTRITION FOR PREVENTING HYPOCALCAEMIA (MILK FEVER)

The historic focus of milk fever prevention was based around regulating calcium intake. Gradually, understandings have emerged that calcium intake alone does not determine milk fever risk. In this chapter, the role of macromineral nutrition is addressed, in particular, the important roles of calcium, magnesium, phosphorus, and dietary cation anion difference (DCAD) as determined by the evaluation of potassium, sodium, chloride and sulphur concentrations.

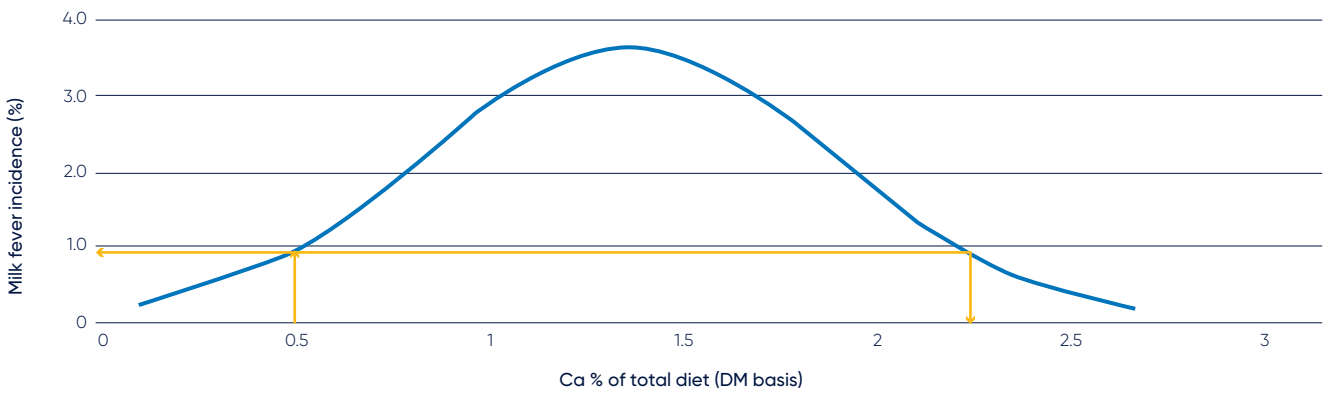
Calcium

The quadratic effect of calcium present in 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 and is illustrated in Figure 4.1.

The effect of low calcium diets on calcium homeostasis is well established, however, the process by which very high dietary calcium concentrations pre-calving may reduce milk fever risk is unclear. A protective effect of high dietary calcium was first proposed in the 1930s (Gould, 1933, Mattick and Little, 1933), but has been substantially refuted (Boda and Cole, 1954, Boda, 1956, Goings et al., 1974, Wiggers et al., 1975). The quadratic effect of dietary calcium concentration on milk fever risk is consistent with a biological model that has increased release of PTH and, consequently, calcitriol (active vitamin D) with a low calcium intake (Goings et al., 1974; Green et al., 1981) reducing risk of hypocalcaemia. At high calcium intakes, it is probable that paracellular uptake of calcium across the gastrointestinal tract (Hoenderop et al., 2005, Hyde and Fraser, 2014) reduces the risk of clinical hypocalcaemia. However, intermediate concentrations of calcium in dry matter of prepartum diets may increase risk.

Figure 4.1 Effect of calcium on milk fever risk

(DeGaris 2010)



An effect of low DCAD diets is to increase calcium excretion in urine (van Mosel et al., 1993, Vagnoni and Oetzel, 1998, Rodney et al., 2018a) and may lower readily available bone calcium, hence bone calcium reserves available for mobilisation after calving. This hypercalciuric effect may be greater with increased duration of exposure to a low DCAD diet pre-calving. Longer exposure to a pre-calving transition diet low in calcium would, therefore, increase the incidence of milk fever as predicted by models developed by Lean et al. (2006). This effect is supported by field observations. It is probable that a low calcium diet (less than 0.4% of DM) and prolonged exposure to a low DCAD diet may increase the risk of milk fever.

Unfortunately, neither of the recent meta-analyses examining calcium intake pre-calving and risk of hypocalcaemia (Lean et al., 2019; Santos et al., 2019) substantially clarified the optimal calcium intake pre-calving. However, there was a linear increase in risk of milk fever in multiparous cows (P = 0.06) with increased calcium intake (Santos et al., 2019) and this effect was significant in cows fed a negative DCAD diet (P = 0.03). This supports our present recommendations to use low calcium approaches (if not using low DCAD diets) or moderate calcium intake (0.5 to 0.7% calcium) (if using negative DCAD diets).

Lower dietary calcium concentrations in the transition diet pre-calving are lower risk for milk fever than higher concentrations.

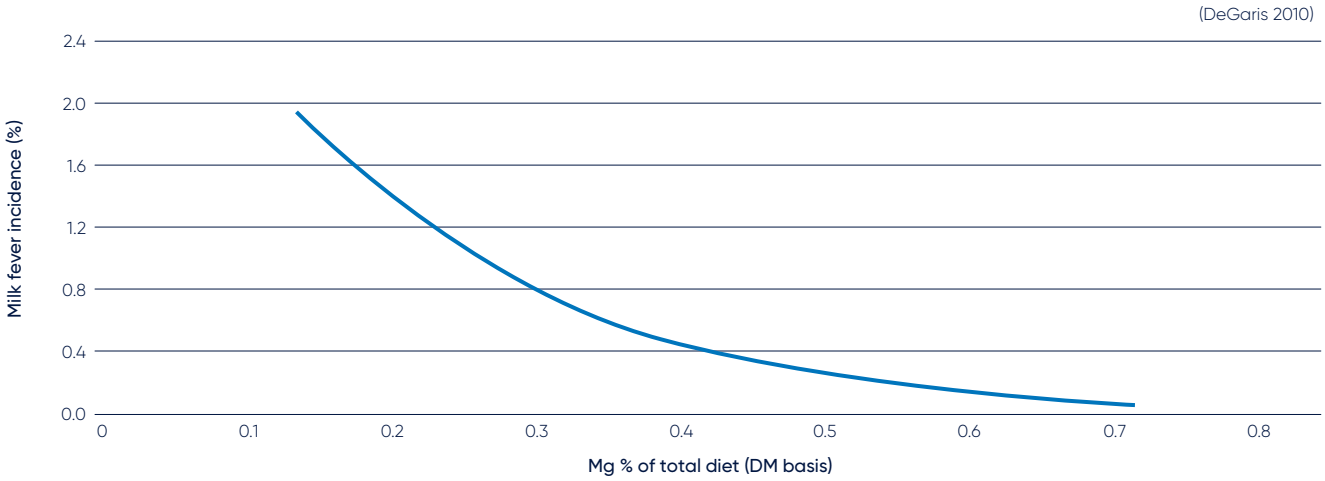
At present we recommend controlling calcium concentrations in the diet to 0.5 to 0.7% DM (or 60 to 80 grams of calcium intake per day) before calving when using a negative DCAD diet.

Magnesium

An increase in dietary magnesium percentage is associated with a lower risk of hypocalcaemia (Contreras et al., 1982, Sampson et al., 1983, Wang and Beede, 1992, Goff, 2000) and is predicted using the equation developed by Lean et al. (2006) and is illustrated in Figure 4.2. Interestingly, increased magnesium intake in grams per day before calving also increased milk fat production and reduced the risk of retained foetal membranes (RFM) (Lean et al., 2019). The equation developed by Lean et al., (2005) predicts that increasing magnesium concentration in the pre-calving diet substantially decreases the risk of milk fever. However, more recent meta-analyses did not detect an effect of increased magnesium intake (Lean et al., 2019 Santos et al., 2019) on milk fever. The authors recommend a magnesium concentration of at least 0.45% of DM before calving, based on the greater power of the early studies and the effect on RFMs in the latest studies. There is a lack of data to indicate the effects of feeding very high levels of magnesium.

An increase in dietary magnesium percentage has been associated with a lower risk of milk fever. Magnesium intake should exceed 0.45% of the diet dry matter.

Figure 4.2 Effect of magnesium on milk fever risk



Phosphorus

Whilst phosphorus has been considered to contribute to the anionic side of the DCAD equation, high phosphorus concentrations have been associated with increased risk of milk fever (Julien et al., 1977, Kichura et al., 1982, Barton et al., 1987, Lean et al., 2003, Lean et al., 2005, Peterson et al., 2005) and is illustrated in Figure 4.3. This is consistent with the Simplified Strong Ion Model of Constable (1997) that predicts increasing plasma phosphate will increase [A_{TOT}] and increase plasma pH.

Phosphorus concentrations should be controlled before calving to less than 0.4%.

Effects of DCAD and mineral nutrition on transition cows

The evidence for this section comes primarily from the four meta-analyses that reviewed the world literature. The two studies conducted in 2006 could only examine percentage inclusions of minerals in feed, not intake in grams per day of minerals, and were limited by use of some estimates of feed minerals based on literature values. The recent 2019 studies only used studies that contained data on feed intake, mineral analyses of feed, and evaluated responses to intake of minerals, but have fewer studies. Consequently, observations from all studies are useful.

Production

Lean et al. (2014a) reported that use of diets that are lower in DCAD pre-calving increased milk production in multiparous cows, but not in primiparous cows (first calving heifers). These results were supported by Lean et al. (2019) who found a 1.1kg /cow per day increase in milk yield and an increase in fat corrected milk in cows fed low DCAD transition diet. The mean difference in DCAD between treated and control studies was 263 mEq/kg with treated studies having a mean –51 mEq/kg DM. Santos et al. (2019) estimated a 1.7 kg/d difference in milk yield between cows fed on a diet differing in DCAD from +200 to –100 mEq/kg DM (Figure 4.4). Lean et al., 2019 found that milk fat percentage, milk fat yield, and milk protein percentages were not affected by treatment, although milk protein yield tended to increase in cows fed the lower DCAD diet (0.02 kg/d).

Milk production is increased by use of negative DCAD pre-calving diets. The increase extends well into lactation.

Reasons for the difference in milk response between heifers and older cows is not clear, but probably reflects the differences in calcium metabolism that result with age and parity. Interestingly, DeGaris et al. (2008) found that the most substantial milk response from exposure to a negative DCAD integrated diet was in the heifer group. This group will probably have a greater requirement than the older cows for energy and protein to support growth.

Figure 4.3 Effect of phosphorus on milk fever risk

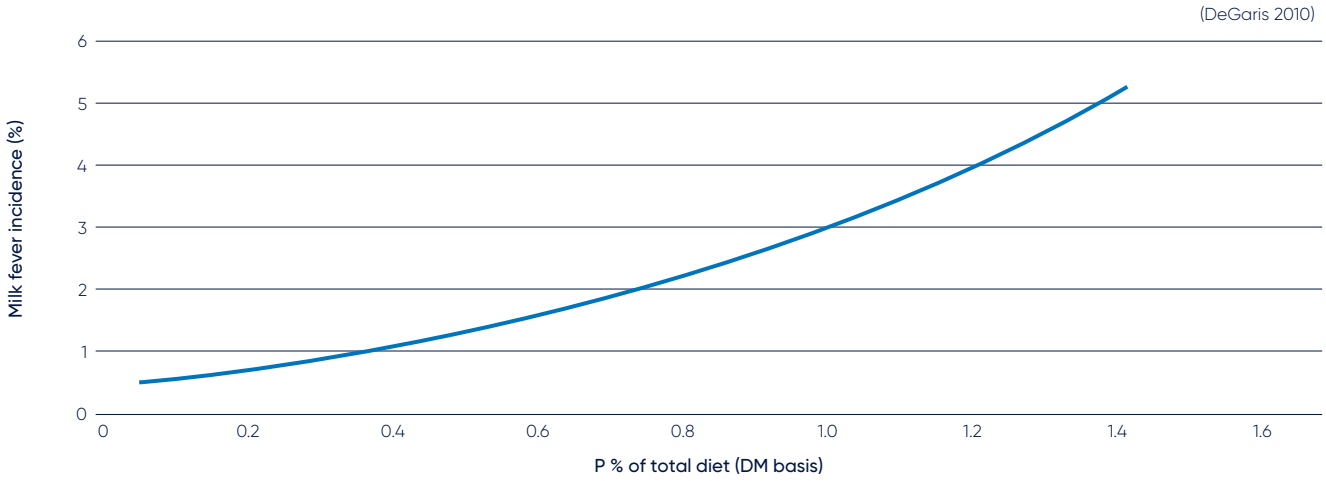
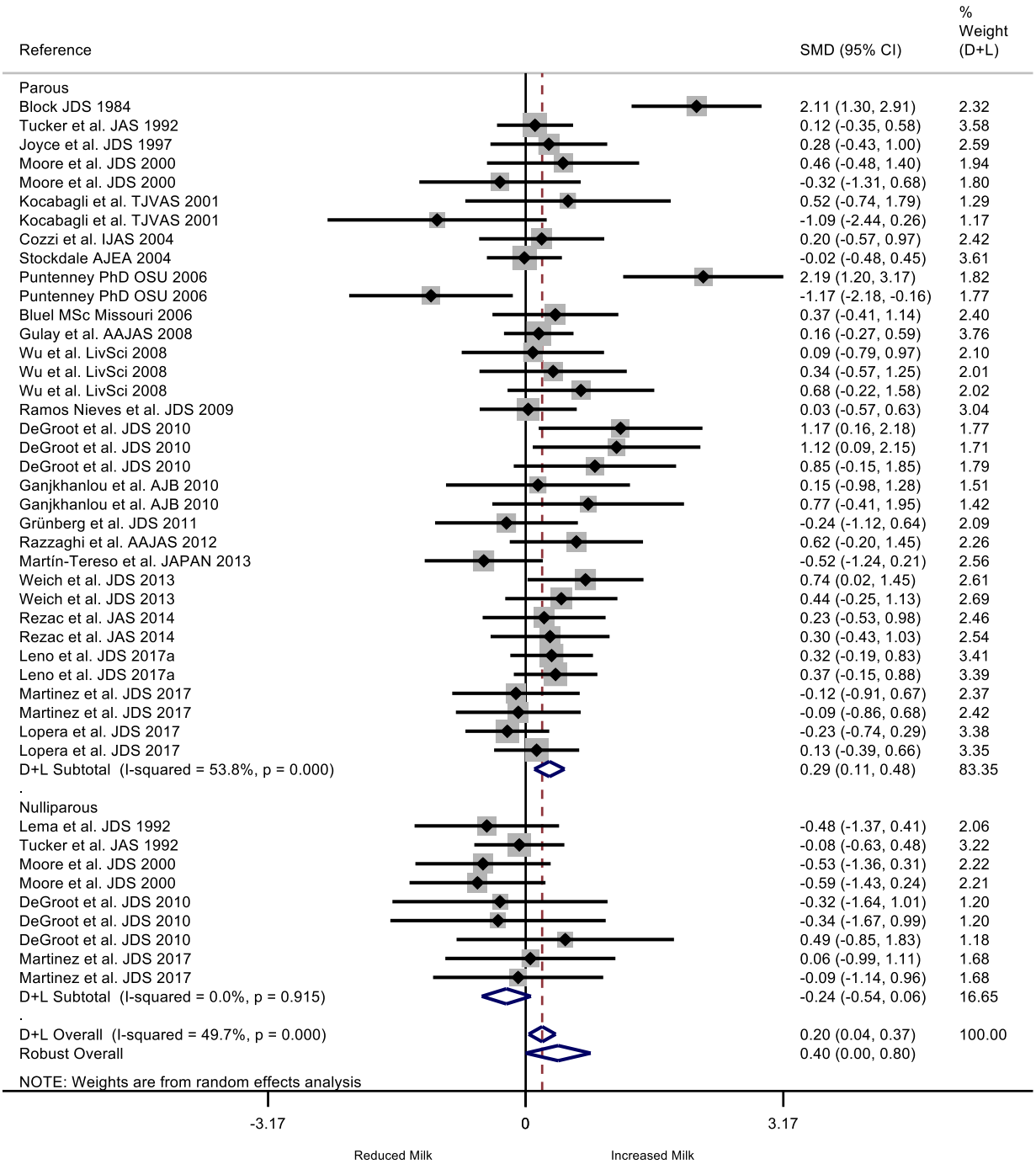


Figure 4.4 Forest plot of the effect of a lowered dietary cation to anion difference (DCAD) intake on milk yield in parous and nulliparous dairy cattle.



The overall pooled effects size or SMD and 95% CI pooled using the DerSimonian and Laird (D + L; DerSimonian and Laird, 1986) and Robust meta-analytical models methods for random effects models are indicated by the respective diamonds at the bottom. Milk yield was moderately heterogeneous as indicated by the I^2 of 49.7%.

Further, the differences in response between cows and heifers were observed for milk, but not DMI as both parity groups had approximately 0.3kg lower DMI before calving for DCAD fed groups (Lean et al., 2019) or with a negative DCAD (Santos et al., 2019). Zimpel et al. (2018) found that this effect reflects responses of cattle to a metabolic acidosis. Critically, both DCAD fed parity groups had increased postpartum DMI of 0.63 kg/d (Lean et al., 2019; Santos et al., 2019). These findings suggest a difference in partitioning of additional feed intake to body weight for heifers, rather than to milk and milk solids in cows.

Lower DCAD diets reduce DMI pre-calving by a small amount, but substantially increase DMI after calving.

Any decrease in DCAD will reduce milk fever risk even when 0 mEq/kg DM is not achieved.

Blood and urine measures

Urinary pH was decreased with DCAD treatment in both meta-analyses (Lean et al., 2019: Santos et al., 2019) supporting the earlier study of Charbonneau et al. (2006). Treatment increased blood calcium (0.13 mM/L; Figure 3.6) and phosphorus (0.13 mM/L) on the day of calving, and postpartum (0.06 mM/L) (Lean et al., 2019), however, there was no effect on blood magnesium. The only effect of treatment on blood metabolites [glucose, beta hydroxybutyrate (BHB) and non-esterified fatty acids (NEFA)] was a decrease in blood BHB in treated cows before calving (–0.04 mM/L; Lean et al. (2019)), however, Santos et al. (2019) identified a lower glucose concentration in treated cows before calving as well as lower BHB concentration after calving. Lean et al. (2014a) found strong associations between serum calcium and NEFA, BHB, glucose and cholesterol in 32 periparturient cows fed on a negative DCAD diet. Their findings support a positive effect of calcium on

Figure 4.5 Forest plot of the effect size or standardised mean difference (SMD; standardised using the z-statistic) and 95% confidence intervals (CI) of the effect of a lowered dietary cation to anion difference (DCAD) intake eq/d on risk of milk fever in parous and nulliparous dairy cattle. The risk of milk fever was consistent as indicated by the I^2 of 0%.

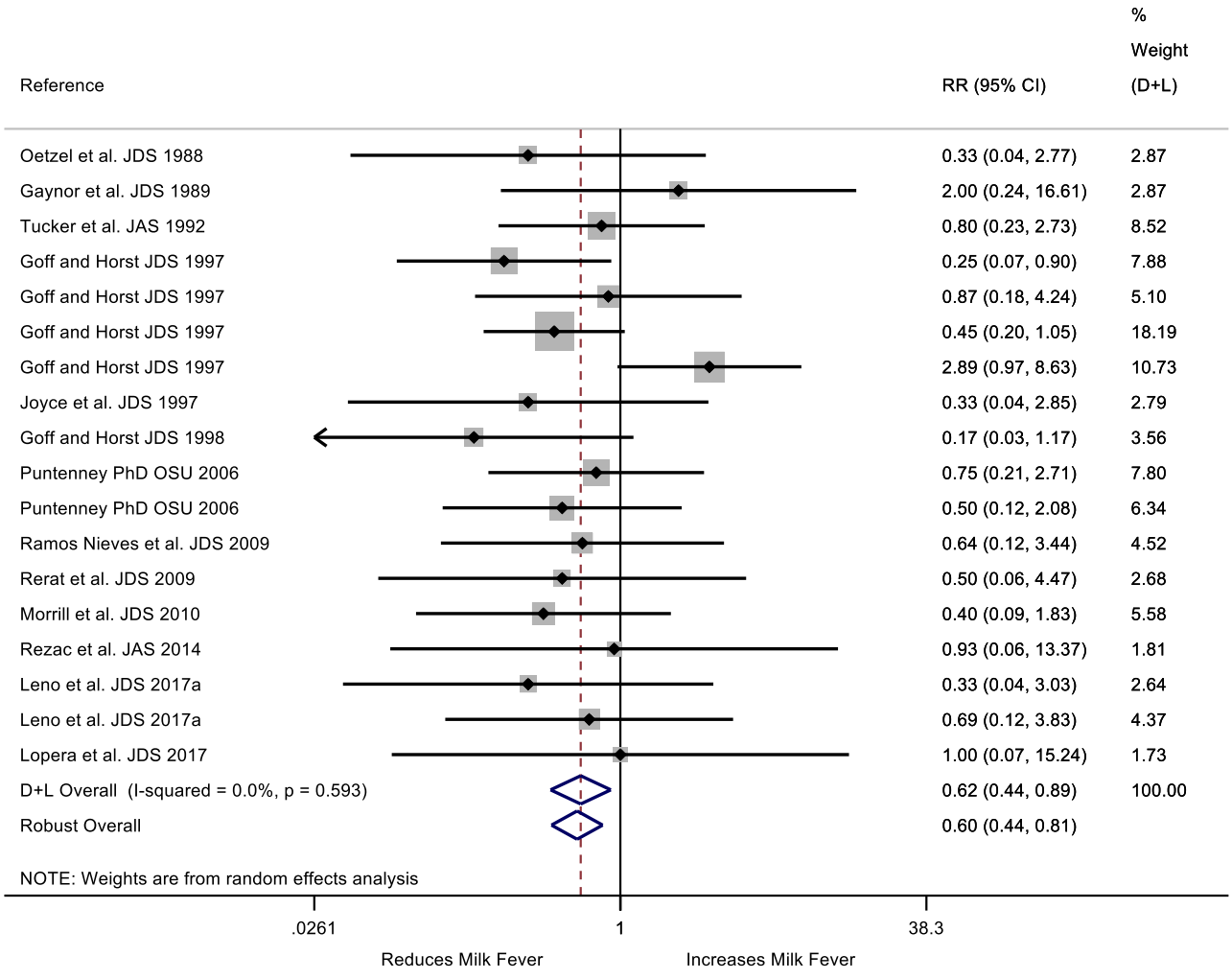
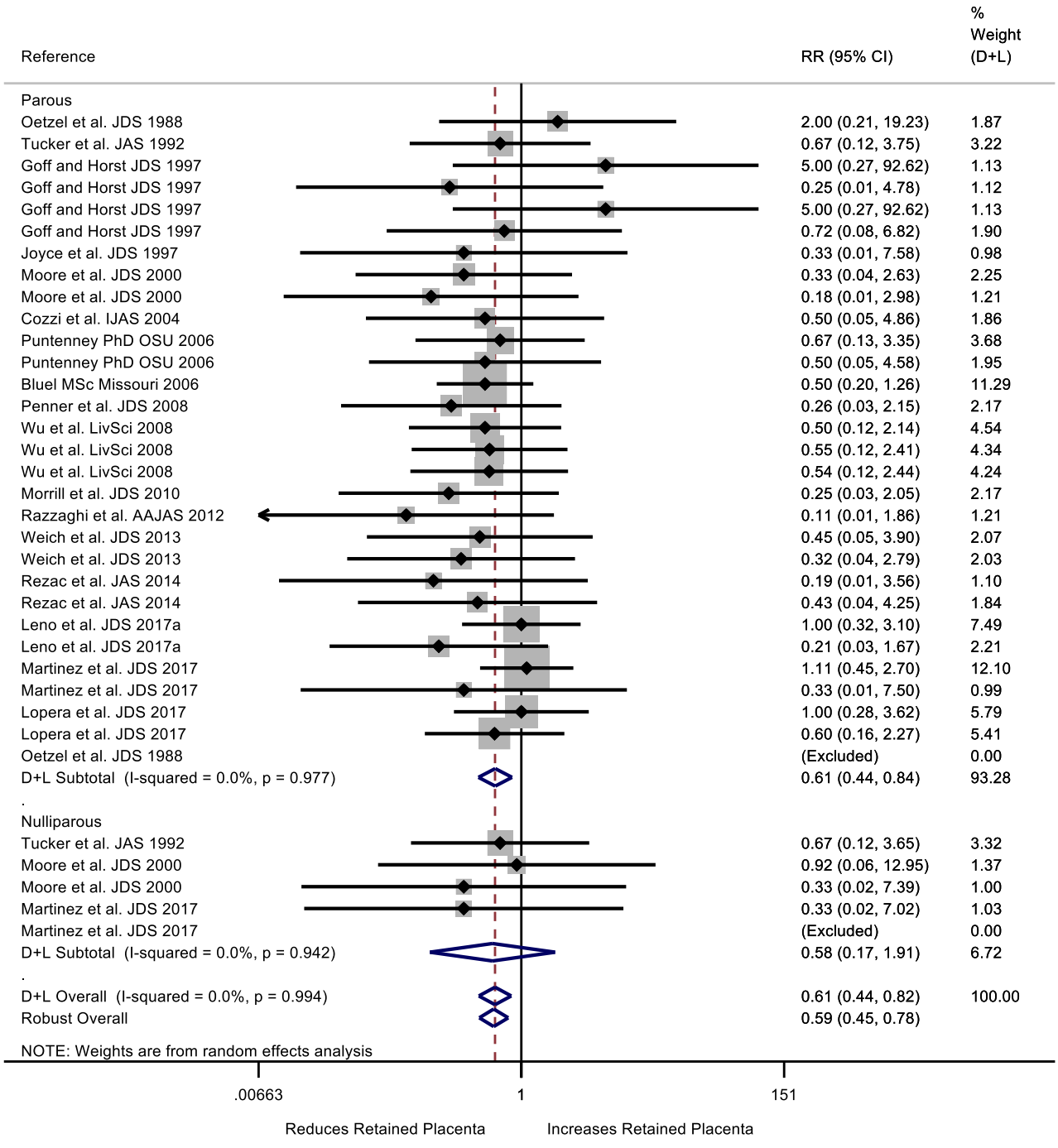


Figure 4.6 Forest plot of the effect of a lowered dietary cation to anion difference (DCAD) intake eq/d on risk of retained placenta in parous and nulliparous dairy cattle.



The overall pooled effects size or SMD and 95% CI pooled using the DerSimonian and Laird (D + L; DerSimonian and Laird, 1986) and Robust meta-analytical models methods for random effects models are indicated by the respective diamonds at the bottom. The risk of retained placenta was not heterogeneous as indicated by the I^2 of 0%.

energy metabolism with higher NEFA, glucose, and lower BHB concentrations subsequent to increased calcium concentrations. Rodney et al. (2018b) found strong links between the bone hormones, osteocalcin and undercarboxylated osteocalcin (uOC), with IGF-1, the powerful growth hormone.

Negative DCAD diets increase blood calcium concentration at and after calving.

Health

Reducing DCAD (Eq/d) in cows resulted in decreased risk of milk fever by 40% (Figure 4.5), RFM 40% (Figure 4.6), metritis 50%, and overall disease 39% (Lean et al., 2019), the findings consistent with Santos et al., (2019). This is shown in Figure 4.5. There was no effect on risk of abomasal displacements or mastitis. Increased magnesium intake between treatment groups reduced the risk of retained placenta. While the effects of a negative DCAD diet are important in controlling the risks of disease, other factors play a role and Table 4.1 provides information on other dietary factors that influence the risk of metritis and retained placenta.

A negative DCAD diet markedly lowers the risk of milk fever, RFM and metritis. It is now very clear that low DCAD approaches do much more than control hypocalcaemia.

Table 4.1 Approaches that will assist in reducing the risks of retained foetal membranes and metritis

	Additive				
	Acidogenic salts	**Vitamin E / Selenium (Se)**	**Monensin**	**Calcidiol**	**Chromium**
Inclusion rate	Aim for reduction of DCAD to -50 to -150 mEq/kg	Diet greater than 0.3 ppm Se. Vitamin E estimates vary greater than 600 IU.	240 to 400 mg per day	2 to 3 mg per day	20 grams per cow per day of 0.04% or 2 grams per cow per day of 0.4%
Mode of action	See Chapter 4 text	RFM and metritis are associated with low Se and vitamin E	Inhibits Gram-positive bacteria in the rumen	Stimulates calcitriol production, positive action on Calcium metabolism	Reduced insulin resistance
Benefit	Improved calcium status. May assist in placental loss and immune function	Se and vitamin E are important in controlling inflammation	Increases propionate in the rumen leading to increased glucose, reduced non-esterified fatty acids (NEFA) and beta hydroxybutyrate (BHB) in blood	Stimulates calcitriol production and better calcium status may assist in placental loss and immune function	Reduced NEFA, increased DMI, increased milk yield in early lactation
Feeding period	-21 to 0 days in milk	-21 to 305 days in milk for Se -21 to 0 days in milk for vitamin E	From -21 to 305 days in milk Do not feed to far off dry cows	-21 to 0 days in milk	-21 to 30 days in milk, depending on feeding management

CHAPTER 5

FEEDING THE TRANSITION COW TO ACHIEVE SUCCESS

This chapter is designed to establish a series of steps towards achieving a successful transition feeding and management strategy.

Understanding the causal web of effects of genetic merit, body tissue reserves and diet on reproductive outcomes, is central to understanding how to feed and manage cows through the period.

There are two major pools of total nutrients available to the cow:

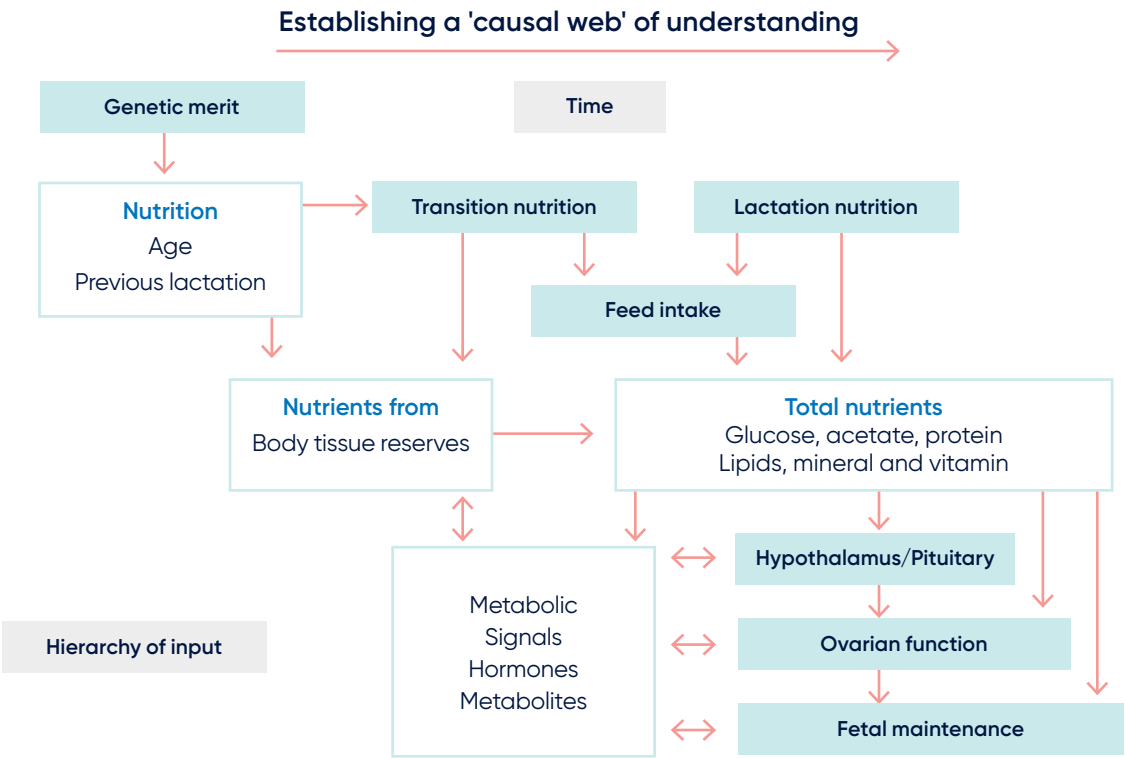
1 Those that result from previous nutrition as nutrients available from body tissues and
2 Those coming from the current diet.

The way that the cow allocates these to maintenance or work, for example exercise, growing a foetus, putting on weight or milk production, influences health, production, and reproduction.

Body tissue reserves and body condition score

A critical part of management is to establish the nutrient reserves in tissues that will be available to support the foetus, calving and early lactation, when feed intake can be suppressed. Body condition is the visual appearance of the cow, primarily determined by the amount and distribution of fat, her muscles, and bones. Body condition and cow nutrition affect farm performance and profitability and have a major impact on reproduction.

Figure 5.1 A causal web of understanding of the effects of genetic merit, body tissue reserves and diet on reproductive function



Body condition score is better understood if the effects of the mobilisable components (fats, protein, glycogen, minerals and vitamins) are considered.

Cows and sheep that have higher body condition score (BCS) before parturition have lower dry matter intakes (DMI) after parturition (Cowan et al., 1980, Garnsworthy and Topps, 1982) and lower DMI has been noted immediately after calving (Lean et al., 1994) and before calving (Lean et al., unpublished) for cows with clinical ketosis. These observations are consistent with recent understandings of the links between hormonal interactions between bone and lipid (see Appendix B).

Importantly, a BCS in the range of 4.5 to 5.5 out of 8 (3.25 to 3.5 out of 5 on the 5-point scale) at calving is optimal for reproductive success. Cows that are in a lower BCS than 4.5 out of 8 (3.25 on the 5-point scale) at calving have markedly lower in calf rates and those above 5.5 out of 8 or 3.5 on the 5-point scale also have lower in calf rates (Morton, 2004) compared to those in the optimal range.

Westwood et al. (2002) identified factors that influenced the display of oestrus. Higher body weight of cattle before calving and post-calving appetite were significant factors that increased oestrus display. Measures of metabolites in blood that reflected a better energy balance, including cholesterol concentrations and the ratio of glucose to beta hydroxybutyrate (BHB), were also associated with greater display of oestrus at ovulation.

There is also a challenge in controlling risks of metabolic disease, particularly lipid mobilisation disorders, should cows become over-conditioned. (BCS greater than 6 out of 8 or 3.75 on the 5-point scale). Over-conditioning of cows is often more a function of management (e.g. extended lactation) and lactation diets than management in the dry and transition periods.

In summary, improved body condition score up to approximately 6 out of 8 (3.75 on the 5-point scale) is associated with better fertility.

A body condition score of 4.5 to 5.5 out of 8 at calving is optimal for reproductive success.

Keys to achieving dry matter intake in transition and early lactation

Access to feed

A failure to supply enough feed pre-calving is a commonly observed failing in herds. For 600 to 650kg cows, the authors target 12.5 to 16kg dry matter intake, with adequate protein and energy levels before calving.

Wherever possible, transition cows should never be denied access to feed and maintaining adequate availability and nutrient density is important. The effects of feed restriction was explored in pasture-based studies in New Zealand (Roche, 2007). While the loss in milk fat production of 8.4% from feed restriction (0.9% of body weight compared to 2.3% body weight) before calving was less than restriction after calving resulting in 21% drop in fat production, it is clear that any restriction of intake should be avoided based on the adverse effects on production and BCS.

Transition cows should never be without access to feed and water.

Dominance behaviour

Controlling dominance behaviour by appropriately grouping cows and heifers and by providing adequate feed access help control BCS to an ideal of approximately 4.5 to 5.5 out of 8 or 3.25 to 3.5 on the 5-point scale (Edmondson et al., 1989). Without addressing the problems of dominant cows, the dominant cows can gain excessive body weight and less dominant cows may have inadequate nutrient intake and lose weight and BCS.

Ensure cows have at least 75cm per cow linear trough space when feeding concentrates to control dominance behaviour.

Achieving adequate target body weights of heifers will also help to reduce dominance by older cows. Use of separate parity groups can also do this. Extensive research undertaken in Australia has shown that heifers that reach target weights perform much better in several other key areas and recommended measures of heifer performance are outlined in Table 5.1.

Research has shown that the desirable body weight of heifers at first calving is 85% of mature liveweight.

Table 5.1 Recommended measures of replacement heifer rearing performance

Key measure	Measurement	Target	Seek help if
Age at first calving		21 to 24 months	Greater than 27 months
Heifer fertility	% calved by 3 weeks	70%	Less than 60%
	% calved by 6 weeks	90%	Less than 85%
First lactation heifer fertility	6-week in-calf rate	60%	Less than 50%
	21-week not in-calf rate	6%	Greater than 10%
	100-day in-calf rate*	53%	Less than 45%
	200-day not in-calf rate*	12%	Greater than 18%
Production	Relative to mature cows	Greater than 85%	Less than 80%
Longevity	% second calvers to first calvers	Greater than 85%	Less than 80%
	% of cows 4-8 years old	Greater than 50%	Less than 40%

*100-day in-calf and 200-day not in-calf measures apply to year-round calving herds.

Long term herd reproductive performance is heavily influenced by heifer reproductive performance.

Check heifer production. If you are not achieving at least 85% of adult cow milk production, there is a problem. Often this is a failure to achieve adequate body weight before calving.

Diet formulation

The use of more digestible forages with lower slowly digestible fibre content will allow for greater DMI. Grummer (1995) used corn to increase the starch and non-fibre carbohydrates in a pre-calving diet. The energy density increase from 9.2 MJ of ME/kg DM to 11.2 MJ of ME/kg DM was associated with a significant 2.4 L/cow per day increase in milk production after calving, lower concentrations of ketones and a lower liver triglyceride to glycogen ratio. This finding indicates that the adaptation of cattle to diets of higher energy content before calving may have production benefits after calving.

Other studies show that estimated energy balance after calving improves with increased energy density of the pre-calving ration (Hayirli et al., 2002; Westwood et al., 2002) and were associated with trends toward increased milk production, lowered milk fat percentage, and significant increases in protein percentage and yield (Minor et al., 1998).

Effects of an increased energy density of the pre-calving diet, especially starches, sugars, and soluble fibre, may reflect increased development and adaptation of rumen papillae (Dirksen et al.,1985), which takes between three and six weeks. Therefore, the benefit of increasing exposure to a prepartum diet high in fermentable carbohydrate is likely to be curvilinear. For example, Penner et al. (2007) found no additional benefit and possibly increased risk of acidosis when diets were increased to greater than 40% non-fibre carbohydrates before calving.

High quality cereal forages that are low in calcium and DCAD and are highly digestible can be a good base for pre-calving diets. They should be tested for quality and mineral content before use through wet chemistry analysis.

The requirements for energy are outlined, both in terms of total energy and carbohydrate fractions in Table 5.2. There is likely to be little benefit in exceeding these.

Table 5.2 Targets for far off dry cow, transition, and fresh cow (first 40 days) diets

Dry matter content	Far off dry cows	Transition (low DCAD)	Transition (low calcium)	Fresh cows
Neutral detergent fibre % (NDF)	Greater than 36	Greater than 36	Greater than 36	Greater than 32
Physically effective NDF %	30	25 to 30	25 to 30	Greater than 19
Crude protein (CP) %	Greater than 12	14 to 16	14 to 16	16 to 19
Degradability of CP	80%	65 to 70%	65 to 70 %	65 to 70%
Estimated metabolisable energy MJ ME	10 (9)*	11	11	11.5 to 12
Metabolisable energy intake per day (MJ)±	90 to 100	100 to 120	100 to 120	160 to 190
Starch %	Up to 18%	18 to 22	18 to 22	Greater than 20%
Sugar %	Up to 4%	4 to 6	4 to 6	8%
Ether extract %	3%	4 to 5%	4 to 5%	4 to 5%
Non-Fibre Carbohydrate	Less than 28%	Less than 36%	Less than 36%	Less than 40%
Calcium %	0.4%	0.5 to 0.7%	Less than 0.2% available Ca	0.8 to 1%
Phosphorous %	0.25%	0.25 to 0.4%	0.25%	0.4%
Magnesium %	0.3%	At least 0.45 %	At least 0.45 %	0.3%
DCAD mEq/kg	N/A	Less than 0	?	Greater than 250

*Energy content that is desirable will vary with body condition
± For a 500kg cow

Protein reserves and body condition

Mobilised tissue protein is an important source of amino acids for mammary metabolism and gluconeogenesis in the first one to two weeks of lactation (Bell, 1995). A reduction in skeletal muscle fibre diameter of 25% was observed immediately after calving (Reid et al., 1980), and declines in muscle protein to DNA ratio in ewes during early lactation were reported (Smith et al., 1981). These findings support the concept that skeletal muscle is an important source of amino acids in early lactation.

Estimates of body protein reserves mobilised by cows at calving are 25 to 27% of total body protein or approximately 10 to 17kg in total (Paquay et al., 1972, Belyea et al., 1978, Botts et al., 1979). Belyea et al. (1978) noted that there was a significant variation in the abilities of cows to mobilise protein. Bell et al. (1995) estimated a metabolisable protein (MP) deficit over 23 days after calving would be nearly 7kg, without accounting for gluconeogenic costs, and 12.5kg with gluconeogenic costs included. These values seem consistent with previous studies. If 10kg of protein were lost as muscle, this would equate to a loss of around 60kg of muscle mass.

The proteins and, ultimately, amino acids mobilised are used for mammary milk protein synthesis and for gluconeogenesis in the liver to support lactation. It appears that rates of mobilisation of fat and protein are similar (Baldwin et al., 1987, Oldham and Emmans, 1988), but there has been little recent work on the amounts of labile fat and protein in body tissue despite this being an important area of physiology. Given the amounts of body weight lost after calving, especially in cows of high body condition, we can be confident that the lipid reserves of these cows exceed the protein reserves.

VandeHaar and St-Pierre (2006) highlighted the partitioning of energy to body weight observed by Oba and Allen (2000) when lower neutral detergent fibre (NDF) diets were fed after calving. It can be hypothesised that cattle exposed to such diets and achieving higher BCS will have greater start-up milk, but the internal flux of nutrients provided from tissue mobilisation has a higher ratio, and almost certainly greater amounts of lipid compared to protein.

It is very likely that the amount of labile body tissue protein is an important determinant of health. Diets which do not meet metabolisable protein (MP) needs of cattle and exceed energy needs in a previous lactation may place cows at greater risk of lipid disorders if they deposit excess fat.

Protein intake before calving

It has been suggested that by increasing pre-partum protein body tissue reserves, the transition cow will be better able to utilise these reserves after calving to support lactation and minimise metabolic disorders (van Saun, 1991, Grummer, 1995). This effect is possibly mediated through increased labile protein reserves. Not all studies supplementing protein in pre-partum diets have observed effects on health or reproduction. Differences in dietary treatments, exposure time, protein source and amino acid balance, management factors, in addition to many other interactions may have influenced this outcome.

Data on the effects of pre-partum protein on subsequent reproduction and health are scant. Over-conditioned (BCS greater than 6 out of 8 or 3.75 on the 5-point scale) mature Holstein cows fed additional protein pre-partum from animal protein bypass sources had decreased ketosis prevalence and less health disorders (Van Saun, 1993). These supplemented cows also had improved reproductive performance, similar to effects seen in primiparous cows supplemented with additional bypass protein (Van Saun et al., 1993). Better health was also observed in cows fed additional bypass protein or supplementation with rumen protected methionine and lysine supplements pre-partum through early lactation (Xu et al., 1998).

Rodney et al. (2016) examined the effect of estimated MP balance before calving on production and reproduction. Milk protein and casein yields were greater with increased MP balance. Models developed by Rodney et al. (2016) suggest that cows which can adjust to anabolic stimuli (such as extra protein), increase yield of protein, maintain a higher milk protein percentage in addition to having better reproductive performance. A lower milk protein percentage is an indicator of risk for poor reproductive performance (Morton et al., 2016, Rodney et al., 2016). Increasing time exposure to a pre-partum transition diet with a positive MP balance improved reproductive performance and health in a grazing study (DeGaris et al., 2010).

Low milk protein percentage in early lactation can be a warning that reproductive performance will be reduced.

Husnain and Santos (2019) examined the effects of pre-calving crude protein (CP) intake, or estimated energy intake (NRC, 2001), on milk and milk constituent production in a meta-analysis using 27 experiments and 127 treatment means. The findings were that nulliparous cows benefit more from increased MP before calving than multiparous cows and that higher producing (greater than 36kg per day) cows also benefit from increased MP before calving. Yields of milk fat and protein were optimised for nulliparous cows at 14% crude protein (CP). Similarly, production for nulliparous cows linearly increased up to 1100 grams of MP per day.

Consequently, pre-partum diets with positive MP and energy balances are attributes that may increase subsequent milk production by providing adequate substrate for foetal and mammary development. McNeil et al. (1994) fed ewes in late gestation diets to meet estimated energy requirements and variable CP content (8, 12 and 15% CP). Ewes fed the low CP diet had foetuses nearly 20 percent less in weight compared to ewes fed the higher CP diet. Foetal weights were not different between the 12 and 15% CP diets, yet the ewes receiving the 12% CP diet lost maternal skeletal protein similar to the 8% CP diet ewes. These data suggest some capacity exists for the placenta to sustain amino acid delivery to the foetus, but it is not unlimited in the face of more severe or sustained dietary protein insufficiency. Mammary development was greater in ewes on the higher CP diets. Similarly, in cows, increased BCS at calving, reflecting improved body tissue reserves, increased subsequent milk production (Gainsworthy and Topps, 1982, Boisclair et al., 1986).

Despite many anecdotal observations of increased calf birth weight and dystocia with increasing pre-partum protein supplementation, controlled studies do not support a cause and effect response (Rice, 1994). No differences in calf birth weights were seen when dairy heifers were fed protein in excess of pre-partum National Research Council (NRC) recommendations (Van Saun et al., 1993). Feeding additional protein (12% compared to 14% CP) during the dry period did not increase calf birth weight (44.5 compared to 42.2kg, respectively) in mature Holstein cows (Van Saun, 1993). However, heavier birth weights (47.1kg) were observed in another group of mature Holstein cows with prolonged dry periods (greater than 75 days) fed a low protein (9% CP) diet initially followed by a high protein (15% CP) diet during the last four weeks of gestation (Van Saun, 1993). Sheep studies suggest that mid-gestation nutrition has greater potential to alter foetal birth weight (Bell, 2004).

Few studies have found pre-partum dietary effects on colostrum quality. Greater colostrum immunoglobulin concentration was observed in cows fed moderate (12% CP) or higher (14% CP) protein diets that contained animal-product bypass protein sources compared to cows consuming a pre-partum diet without supplemental bypass sources (Van Saun, 1993). These colostrum immunoglobulin concentration differences were the opposite of immunoglobulin concentrations measured in maternal serum over the last four weeks prior to calving. These observations might suggest an amino acid role in the transfer of immunoglobulins from maternal sera to colostrum.

Robust physiological data suggest a need for diets that contain good levels of MP. Given the variability of diet delivery and estimates of dietary MP, it is recommended to formulate diets that meet or exceed MP requirements of 1300 g/d as estimated by NRC 2001, CPM Dairy – Version 3.09 or Cornell CNCPS 6.55. These diets usually require more than 14% CP and adequate starch and sugar as defined in Table 5.2.

Target a metabolisable protein (MP) intake of about 1200 to 1300 grams per day in the pre-calving calving transition diet (often this requires 14 to 16% CP).

The balance and ratios of specific absorbed amino acids are of importance to production (Rulquin and Verite, 1993, Sniffen et al., 2001). Methionine and lysine are often considered the first rate limiting amino acids across a range of diets for dairy cows (NRC, 2001). However, recent studies identified histidine as another potentially important amino acid (Lean et al., 2018). Methionine and choline metabolism are closely related and a significant percentage of methionine is used for choline synthesis (Emmanuel and Kennelley, 1984). Choline and methionine are interchangeable regarding their methyl donor functions. Methionine has an important role in the formation of very low density lipoproteins in cattle (Auboiron et al., 1995) which are necessary for the export of stored fat in the liver. Notwithstanding the potential importance of specific amino acids, data on the responses to these fed solely in transition are sparse.

Methionine and lysine are the first two rate limiting amino acids in dairy cows. Methionine, choline, and betaine act as methyl donors.

Fat nutrition before and after calving

Perhaps the most rapidly developing area of ruminant nutrition is that of fat nutrition. Recent understandings of the role of fats in metabolism open new avenues to improving metabolism, health, and reproduction in cattle. Studies have identified substantial potential for milk fats, including the conjugated linoleic acids (CLA), to improve human health (Parodi, 1999). Critically, there is an increased awareness of the potential for specific dietary fats to improve health production and fertility of cows. Vast differences (up to 15 standard deviations difference) in milk production and composition responses to different fats commonly used were observed by Rabiee et al. (2012).

The optimal requirement for 15 to 25% of energy being supplied as lipogenic precursors (or about 8% long chain fatty acids in the diet dry matter) for efficient milk production has been described (Kronfeld, 1976). The variation in responses observed by Rabiee et al. (2012) and (Onetti and Grummer, 2004) suggests that there is considerably more complexity to responses to fats in the diet than suggested by energetics alone.

There is an increased understanding of the mechanisms by which different specific fatty acids in milk are generated and new ways to monitor this have been developed (Barbano and Lynch, 2006) that will allow farmers and their advisers to hone nutritional strategies to either increase or decrease milk fat percentage.

There is a marked difference in the fats derived from temperate pasture and in oil seed meals (canola, cottonseed) to those in maize silage or products such as tallow or palm oils. In temperate pastures the dominant fatty acids are C18:3 (linolenic), with lesser amounts of C18:2 (linoleic), whereas maize silage contains more C18:2 and C18:1 (oleic) fats and in lower concentrations than in temperate pasture.

Linoleic (C18:2) and linolenic fatty acids (C18:3) are classified as essential fatty acids and must be supplied in the diet, because the double bonds between the Δ-9-carbon and terminal methyl group of the fatty acids cannot be produced by cattle. Roles for fatty acids include precursors for reproductive hormones such as prostaglandins, cell membrane structures as phospholipids, and in immune function. These findings suggest support for the numerous pivotal roles identified for lipids in reproductive metabolism (Staples et al., 1998, Thatcher et al., 2006).

Lean and Rabiee (2007) noted that there is a striking difference in lipid intake to milk yield ratio for North American cows compared to Australasian cows. It can be estimated that lipid intake for North American cattle is about 15.5 g/L compared to 20-22 g/L of milk for the Australasian cows. Further, for essential fatty acids (C18:2 and C18:3) intake: duodenum ratios are 0.7 against 1.4 to 1.6 g/L, respectively or, approximately half.

Fats are not all the same. The fats in pasture can have substantial positive (e.g. reproduction) and negative effects (e.g. milk fat depression).

Ensuring that the fat content of the diet is sufficient, particularly in 18:3 (linolenic) fats is important for reproductive performance.

Fat intake pre-calving

Von Soosten et al. (2012) elegantly explored the effects of protected CLA, as compared to a stearic acid based fat supplement on tissue mobilisation in a serial slaughter study (slaughtered over time). Overall, a trend for a decreased body mass mobilisation suggested a protective effect of CLA supplementation on use of body reserves within 42 days in milk. Continuous CLA supplementation until 105 days in milk increased body protein gain. These effects suggested a more efficient utilisation of metabolisable energy in CLA-supplemented early lactation dairy cows. This effect of ruminally protected fats was not based solely on palm oil as identified independently in the meta-analysis of Rabiee et al. (2012).

While feeding fats during the pre-partum and immediate post-partum period has not traditionally been recommended (Santos et al., 2003) due to the potential to reduce DMI, particularly in heifers (Hayirli et al., 2002), there are now many studies where beneficial effects have been observed (Doepel et al., 2002, Selberg et al., 2002, Jones et al., 2008, De Veth et al., 2009). These outcomes included a reduction in liver triglyceride accumulation (Selberg et al., 2002) and levels of non-esterified fatty acids (NEFA) (Doepel et al., 2002) in the immediate postpartum period and improved pregnancy rates (Frajblat, 2000).

Fats before and after calving

Rodney et al. (2015) conducted a meta-analysis to examine the effects of fats on fertility of cows. The results were striking, there was a significant 27% increased probability of pregnancy to mating with fat feeding and a significant reduction in the interval from calving to pregnancy. This is shown in Figure 5.2.

Evaluation of the source of fats did not identify treatment differences, however, numbers of studies were limited for any category. de Veth et al. (2009) demonstrated marked improvements in fertility of cattle fed a ruminally protected CLA when compared with cows not receiving the fat (median time to conception was decreased by 34 days to 117 compared with 151 days in milk). That study could not be included in the meta-analysis by Rodney et al. (2015) because it lacked data on the diets used. Thatcher et al. (2006) also found positive effects of supplementation with ruminally protected CLA and palm fatty acids on reproduction and health.

Kay et al. (2004) found that around 90% of *cis-9, trans-11* CLA in milk is derived by endogenous synthesis of fats within fresh pasture. Studies in Ireland (Hutchinson et al., 2011) found positive trends to a lower services per conception, but little overall effect of supplementation with protected CLA on fertility in cows on pasture. This finding is consistent with the suggestions of Lean and Rabiee (2007) that at least some of the difference in fertility of cows on pasture-based diets and those on TMR diets may reflect the CLA generated from pasture.

Inclusion of fat in the diet can increase serum cholesterol concentrations, (Grummer and Carroll, 1988, Chilliard, 1993) a factor associated with better fertility. Westwood et al. (2002) found that higher concentrations of plasma cholesterol were associated with a shorter interval from calving to conception, with greater probabilities of conception and successful pregnancy by day 150 of lactation, a finding consistent with those of Kappel et al. (1984) and Ruegg et al. (1992), who found associations between cholesterol concentrations and fertility measures. Similarly, Moss (2001) found that low blood cholesterol concentrations at mating were strongly associated with conception failure.

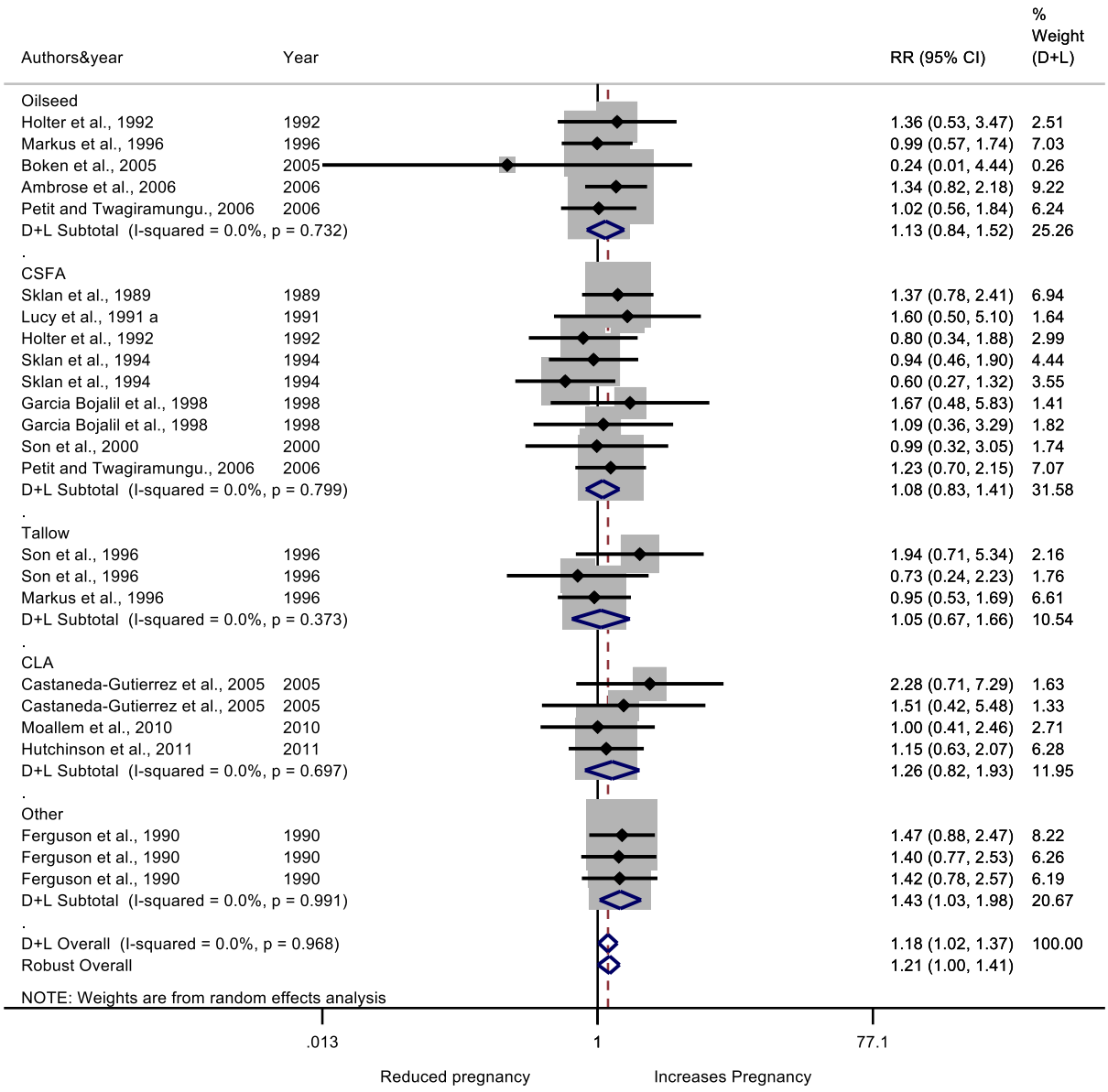
In summary, fat supplements can improve energy balance, reduce the risk of metabolic diseases such as ketosis and crucially, allow energy density to be maintained in diets without increased dependence on rapidly fermentable carbohydrates. Evidence is increasing of a very positive role for CLA, fed either as protected fats or derived from pasture, in retaining body tissue after calving and in improving fertility. Feeding fats in transition is an essential component of an integrated response to the control of tissue mobilisation. These fats can come from pasture, provided the diet is carefully balanced to reduce the risk of marked milk fat depression.

Controlling the rumen to prevent rumen acidosis

It is logical to consider the need to control the rumen in the context of optimising energy and protein nutrition. This section of the review is based primarily on post-calving nutrition; however, the principles are relevant to the pre-calving transition period.

Consistency of supply of feed is important as many studies have withheld feed as part of a protocol to create acidosis (Nagaraja and Titgemeyer, 2007). Providing adequate fibre and particle length (greater than 2.5cm long) (Zebeli et al., 2012) and greater than 30% NDF, based on Bramley et al. (2008) is appropriate for lactating dairy cattle. Diets formulated as partial mixed rations were safer, despite a higher non-fibre carbohydrate (NFC) content, than diets that were component-fed (Golder et al., 2014b).

Figure 5.2 Forest plot of the effect of a lowered dietary cation to anion difference (DCAD) intake on the proportion of cows pregnant with different fat treatments including oilseeds, calcium salts of fatty acids (CSFA), tallow, conjugated linoleic acids (CLA) and others (prilled fats).



The solid vertical line represents a mean difference of zero or no effect. Points to the left of the line represent a reduction in probability of pregnancy while points to the right of the line indicate an increase. Each square around the point effect represents the mean effect size for that study and reflects the relative weighting of the study to the overall effect size estimate. The larger the box, the greater the study contribution to the overall estimate. The weight that each study contributed are in the right-hand column. The upper and lower limit of the line connected to the square represents the upper and lower 95% CI for the effect size. The overall pooled effects size or SMD and 95% CI pooled using the DerSimonian and Laird (D + L; DerSimonian and Laird, 1986) and meta-analytical models (Knapp-Hartung; IntHout et al., 2014) methods for random effects models are indicated by the respective diamonds at the bottom. The heterogeneity measure, I^2 is a measure of variation beyond chance among treatments included in the meta-analysis. The risk of pregnancy was not heterogeneous as indicated by the I^2 of less than 20%.

Sugars in the diet should be controlled based on Nagaraja et al. (1981), Golder et al. (2012) and Golder et al. (2014a). We suggest the following guidelines for TMR based on Bramley et al. (2008) and Golder et al. (2014b) for a maximum total NFC of 40 to 42%, 22 to 24% of starch, 8% of sugar based on not exceeding approximately 0.35% of bodyweight for sugars intake. It is very likely that not all sugars will have the same effect on the rumen (Plaizier et al., 2018), and it is very evident that not all grains (Lean et al., 2013) or starches have the same effect on rumen function. Furthermore, the form of processing of the concentrate components in the diet will influence function.

Very lush young grass and finely chopped forage are risk factors for acidosis

Sugars and wheat are more likely to create acidosis than other energy sources. In descending order of risk:

- Sugars
- Wheat
- Triticale
- Barley
- Corn
- Sorghum

Pasture-based herds may often be fed on diets that contain lower NFC, but higher sugars than TMR herds. It is very possible that the ready availability of ammonia and peptides provided from the rapidly degradable protein present in grasses reduces the risk of acidosis. Observations that acidotic cattle have low rumen concentrations of ammonia (Bramley et al., 2008) and a reduction in the incidence and prevalence of acidosis with increased nitrogen in the diet (Golder et al., 2014b) support the observation that microbial protein is a significant sink for hydrogen in the rumen. When bacteria lack the nitrogen, peptides, or amino acids to reproduce, they produce more volatile fatty acids (VFA), which are waste products for bacteria. This 'spilling' of energy into VFA, rather than being productively used to grow, may be an important part of the pathogenesis of acidosis.

Reducing the risk of inflammation

It is well-understood that the period around calving is characterised by an altered and, generally, impaired immune function (Curtis and Lean, 1998, Bertoni et al., 2008, Bradford et al., 2015). This is evidenced by the increase in disease conditions that occur during this time. Some of the factors associated with immune suppression include abrupt changes in hormone concentrations, for example oestrogens and corticosteroids. Inflammation is an inherent part of the adaptation to lactation, in part, because increasing metabolic activity produces inflammation (Bradford et al., 2015). There is a significant increase in demand for glucose in inflammation (Kvidera et al., 2017; Bradford and Swartz 2020).

Factors that lead to excessive inflammation that ultimately impair health and productivity need to be controlled. Some of these disorders causing inflammation, including hypocalcaemia and milk fever, acidosis, and excessive lipid mobilisation, are discussed in this review. Hypocalcaemia results in reduced neutrophil function and increases risk of retained foetal membranes (RFM); acidosis produces inflammatory factors including lactic acid, histamine and lipopolysaccharide and damages cells in the gastrointestinal tract; and excessive lipid mobilisation increases the risk of formation of lipid peroxides that can propagate inflammation among other actions (Bradford and Swartz 2020).

Clinical situations in which inflammation is increased and free radicals may be generated include:

- Challenge from infectious agents
- Deficiency states of antioxidants, either single antioxidants or several antioxidants
- Calving:
  - Physical trauma during calving is likely in both unassisted and assisted birth
  - Contamination of the reproductive tract with bacteria
  - Depletion of antioxidants associated with the production of colostrum and milk
  - Increased metabolic demands associated with adaptation to lactation
- Depletion of antioxidants through losses in milk (particularly in high producing cows)
- Excessive intakes of pro-oxidants such as poly-unsaturated fatty acids (especially high in some grasses) or catalysts such as iron, copper, zinc, and selenium
- Oestrus activity*

** There is a considerable capacity for free radical generation and challenge during steroidogenesis and in the period of growth and atresia of ovarian structures (Riley and Behrman, 1991). Reproduction is not a sterile process, consequently, there is considerable potential for bacteria to create free radical challenge during conception and early embryonic development.*

Inflammation can be controlled by ensuring a good balance between exposure to pathogens and ensuring that cows mount effective innate and humoral immune responses. Uncontrolled inflammation is often mediated through propagating reactions that involve the generation of free radicals.

Free radicals are unstable atoms or molecules that contain a free electron. This makes them chemically reactive and capable of damaging cells and creating more free radicals that can cause even more damage.

Antioxidants are often mineral or vitamin containing enzymes or vitamins themselves that can control the effects of free radicals.

Free radicals are generated as a normal part of metabolism in cellular respiration, electron transport via cytochrome P450, enzymatic reactions and significantly in the killing systems used by macrophages, neutrophils, and other phagocytic leucocytes. This controlled release of free radicals is part of the immune response through the 'respiratory burst' of phagocytic leucocytes. Granulocytes, mononuclear macrophages, and lymphocytes use free radicals such as H_2O_2, myeloperoxides and superoxides in a respiratory burst as a means of destroying invading organisms and damaged tissue. The neutrophils and macrophages especially, engulf the bacteria before attempting to kill it with the free radicals that are burst onto the bacteria.

The oxidative agents released extracellularly or within phagosomes are a controlled response to defined activated pathways (Dean and Simpson, 1991). This process involves the production of high levels of superoxide, which can cause significant damage to biological molecules in an iron catalysed reaction where a hydroxyl radical ($OH^{\cdot}$). is an intermediate. This reaction is called the Fenton reaction and allows the formation of free radicals that are very destructive to tissues (Draper, 1990). Free radicals are unstable, react with the environment and create toxic lipids, reactive proteins and other free radicals and further damaging tissues, DNA and RNA (Mead et al., 1988). Damage from free radicals is more severe when systems that quench propagating reactions are impaired, often through deficiencies in the antioxidant vitamins and minerals.

However, excesses of trace elements can be just as damaging as deficiencies. Iron and copper are needed in protective enzymes such as transferrin, catalase (iron) and copper/zinc superoxide dismutase (copper) that bind these, however, excessive supplementation with copper or iron will saturate potential binding sites and raise the level of these metals in their free states. Free iron and copper may catalyse oxidative reactions, as evidenced in the spectacular sudden death syndromes associated with acute and chronic copper toxicity.

Serum concentrations of the fat soluble vitamins retinol (vitamin A) and α-tocopherol (vitamin E) decline around the time of calving (Goff and Stabel, 1990). This decline cannot be completely accounted for by losses through the mammary gland (Goff et al., 2002). Curtis (1997b) serially sampled Holstein cows from one month prior to calving until one month after calving and identified the likely transfer of many antioxidants to the calf, in utero and through colostrum. Curtis (1997b) demonstrated strong interactions among antioxidants.

At calving, cows with plasma α-tocopherol concentrations below 3.0 ug/ml were at 9.4 times greater risk of having mastitis within the first seven days of lactation compared to cows with higher concentrations (Weiss et al., 1997). LeBlanc et al (2004) did not find a protective effect of prepartum serum α-tocopherol concentration on mastitis, but for every 1 ug/ml increase, RFM incidence was reduced 21%. As serum retinol concentration increased 100 ng/ml during the last week of gestation, risk of clinical mastitis in early lactation was decreased 60% (LeBlanc et al., 2004). Serum vitamin concentrations can be augmented with appropriate dietary supplementation (Weiss et al., 1990, Weiss et al., 1992, Weiss et al., 1994, Chawla and Kaur, 2004). However, responses to additional vitamin E in dairy cattle have been extremely variable.

Although trace mineral nutrition of dairy cattle is of great importance and many trace minerals improve immune function (Gaylean et al., 1999), the capacity for interactions with other dietary inputs and variation in individual animal requirements means that despite extensive study, there are still many areas that require clarification. While the inflammatory pathways that influence health, productivity and reproduction are complex, the adviser need not understand all the pathways to be aware and enact preventive strategies. Ensuring that mineral and vitamin intakes meet or moderately exceed NRC requirements is essential. The source of such minerals may be important as responses have been noted in both production and reproduction to organic sources of minerals (Rabiee et al., 2010).

Controlling excessive inflammation: adequate levels of dietary vitamins, trace minerals and other antioxidants are critical during the transition period. Interactions are important and excessive supplementation of individual mediators may be harmful.

Table 5.3 Dietary sources, active forms, sites of action and type of action of antioxidants in cattle (Lean et al., 1998).

*Dietary input	Biologically active antioxidant	Site of action	Type of action
Selenium	Glutathione peroxidase (GSHPx)	IC/membrane	ROOH, H_2O_2
Copper	Cu/Zn superoxide dismutase	IC	O_2^-
	Caeruloplasmin	EC	Binds Cu/oxidises Fe, weak O_2^- scavenger
	EC superoxide dismutase	EC	O_2^-
Zinc	Cu/Zn superoxide dismutase	IC	O_2^-
	EC superoxide dismutase	EC	O_2^-
	Metallothionine	EC	Binds metal ions
Manganese	Mn superoxide dismutase	IC	O_2^-
Iron	Catalase	IC	H_2O_2
	Transferrin	EC	Binds Fe
	Lactoferrin	EC-milk/sweat	Binds Fe
Cobalt	Vitamin B_{12}		
Vitamin E	α-tocopherol	Membrane	Blocks peroxidation in lipids especially
Vitamin A	Retinol	EC	Maintains cell integrity
β-carotene	β-carotene Retinol	Membrane EC	Scavenges singlet O_2 cell integrity
Glucose	Ascorbate	EC	Vit E, GSSG reduction, radical scavenger
Sulphur amino acids	Glutathione (GSSG)	IC	Replenishes GSHPx
Protein	Albumin	EC	Binds Fe and Cu
	Haemopexin	EC	Binds Fe
	Haptopexin	EC	Binds Fe
	Histidine-rich glycoproteins	EC	Binds other metal ions
	Erythrocytes	EC	Transport radicals IC
	Mucins	EC	OH^- Scavenging

*Limiting dietary component.
EC – extracellular; IC – intracellular; ROOH – lipid peroxides; H_2O_2 – hydrogen peroxide, Fe – iron; OH^- – hydroxyl radicals, O_2^- – superoxides.

Feed additives that benefit the cow in the transition period

Buffers and neutralising agents

Caution: Do not feed sodium bicarbonate in the pre-calving transition diet as this will significantly increase the risk of milk fever due to its extremely high DCAD (+11740 mEq/kg).

Buffers have been well reviewed. They, by definition, reduce the decrease in pH without causing an increase in pH (Staples and Lough, 1989). Questions remain, however, regarding the function of sodium bicarbonate, potassium carbonate, potassium bicarbonate, sodium sesquicarbonate, and the skeletal remains of the seaweed *Lithothamnium calcareum* in controlling acidosis. In the case of sodium bicarbonate, there are questions whether the effects are mediated through buffering the accumulated acid or increases in dry matter and water intakes caused by sodium, facilitated through an increased ruminal fluid dilution rate and reduced starch digestion rate (Russell and Chow, 1993, Valentine et al., 2000). Recently, Penner (2019) outlined a series of observations that suggest stabilisation of rumen pH due to sodium bicarbonate supply results from increased absorption of volatile fatty acids. Similarly, potassium-based products including potassium carbonate sesquihydrate, may contribute to production increases through increased DCAD or potassium requirements rather than through buffering actions. There are positive interactions for sodium bicarbonate with magnesium oxide and combination of sodium bicarbonate and magnesium oxide had similar effects to virginiamycin in controlling cyclic eating behaviour in cattle during adaptation to a diet high in grain and containing fructose (Golder et al., 2014a). In summary, supply of ruminal buffers is an essential part of a balanced diet and more studies may be required to define the optimal approaches to these in conjunction with sodium and potassium supply.

Antibiotics

There is strong evidence that some antibiotics can control the risk of acidosis (Lean et al., 2014b). Currently, virginiamycin is the only antibiotic registered for the control of lactic acidosis in dairy cattle. Virginiamycin is effective in controlling ruminal acidosis and tylosin, in combination with monensin, is also effective (Lean et al., 2000). It appears that combinations of monensin and bambermycin are also effective in favourably modifying rumen function (Golder 2014a). Both the latter are non-human class therapeutic agents. However, it is important to note that there is considerable and increasing scrutiny over the use of in-feed antibiotics in dairy cattle, particularly virginiamycin and tylosin. It is critical that these products are used judiciously and only in circumstances where no other alternative exists.

In Australia, virginiamycin is rated by the Australian Strategic and Technical Advisory Group on Antimicrobial Resistance (ASTAG) as an antimicrobial of high Importance. These are essential antibacterials for the treatment or prevention of infections in humans where there are few or no treatment alternatives for infections. These have also been termed "last resort" or "last line" antibacterials and should only be used in exceptional circumstances.

Ionophores

Ionophores, particularly monensin and lasalocid, are widely used in beef and dairy production. There is a large body of literature on the use of monensin in transition cattle, with studies commencing before and after calving. There are fewer studies on lasalocid (Golder and Lean, 2016).

There is evidence of more sustained appetite (Lunn et al., 2005) and of increased production of propionate from lactate (which is a ruminal adaptation that sequesters hydrogen ions in safer ruminal pools) when monensin is fed in diets that may cause acidosis. Monensin appears to be very effective in controlling ruminal acidosis risk when fed with tylosin or virginiamycin. Nagaraja et al. (1981) investigated the use of lasalocid to control lactic acidosis induced using finely ground corn or glucose. Use of lasalocid equalled or exceeded the reduction in lactic acid production observed for monensin (Nagaraja et al., 1981). Both monensin and lasalocid prevented acute lactic acidosis in the study of Nagaraja et al. (1981); however, both products were included in the diet at concentrations of 1.30 ppm of diet above concentrations recommended. Nagaraja et al. (1982) found that 0.33, 0.65, and 1.30 ppm of lasalocid were effective in reducing lactic acid concentrations and increasing pH compared to control cattle with lactic acidosis induced using glucose fed at 12.5 g/kg BW. More studies would be useful to evaluate the effect of lasalocid on rumen acidosis.

Milk yield was consistently increased with monensin use with a raw weighted mean of 0.7 kg/cow per day, reflecting a 2.3% increase (Duffield et al., 2008). The milk yield increase was reflected in an increase in milk protein yield of 0.016 kg/hd per day. The effect of monensin on milk fat yield was highly variable and not significant, whereas the effect on milk fat percentage was to reduce fat percentage by 3.2%.

Seven studies (11 comparisons) were used to assess effect of lasalocid on dairy performance but there were relatively few cows in each study, and the evidence base is limited. Lasalocid decreased DMI in total mixed ration–fed cows by 0.89 kg/d but had no effect on milk yield, milk components, or component yields (Golder and Lean 2016). Given, the modest production responses from monensin, it is clear more large studies are needed to determine whether lasalocid has similar effects on production.

The results of the meta-analysis on the effects on disease of monensin in dairy cattle is described below in Table 5.4 (Duffield et al., 2008) using studies from New Zealand (Wilson et al., 1992), Australia (Beckett et al., 1998), Canada (Duffield et al., 1999), the EU (Heuer et al., 2001) and South America (Gallardo et al., 2005) among others. Most of the studies commenced feeding or treatment before calving. Many of the findings are very consistent with the known metabolic effects of monensin that include increased production of ruminal propionate resulting in reduced concentrations of ketones and NEFA. The 25% reduction in risk of ketosis is consistent with the increase in ruminal propionate production and the 25% reduction in risk of displaced abomasum is consistent with effects on gas production and increased rumen stability.

The 9% reduction in mastitis risk with monensin feeding was consistent across studies and significant. This finding is consistent with positive effects of monensin on neutrophil function *in vitro* (Stephenson et al., 1996) and with the depressive effect of BHB concentration on neutrophil function, which is alleviated by monensin use.

The markedly inconsistent effects of monensin on dystocia, retained foetal membranes (RFM) and metritis may have a common link, given that these disorders are highly related. For both dystocia and retained placenta a shorter period of treatment before calving greatly reduced the risk of an adverse outcome (Duffield et al., 2008). The cut point for this analysis was 21 days before calving. It is possible that substantial increases in propionate production in the far-off dry cow may not be optimal and some dry cow nutrition strategies are based on controlling starch intake in that period (Drackley and Janovick, 2007b). Monensin controlled release capsule (CRC) use reduced the risk of RFM and metritis, compared to studies using a top-dress or total mixed ration monensin delivery and responses stratified by CRC indicated that health outcomes were improved compared to controls (Duffield et al., 2008). The reasons for this are not apparent but could include confounding with pasture studies or other dietary differences among studies, differences in disease definition or underlying biological differences in response to the method of dosing.

If a rumen modifier is used in the lactation diet, the same rumen modifier should be used in the transition diet pre-calving.

Yeasts

There is increasing evidence that yeasts and yeast cultures may have a role in stabilising rumen function. Actions that have been identified with live yeasts include small increases in rumen pH, reductions in lactic acid, enhanced fibre digestion, alterations in immune function and small increases in VFA production. These actions are modest in magnitude, but may synergise with other strategies to control the risk of acidosis. Li et al. (2016) found that a *Saccharomyces cerevisiae* fermentation product stabilised rumen pH and Bach et al. (2018) demonstrated changes in immune markers in the epithelium and rumen to a live yeast. Weight gains and average daily gain improvements have been identified in beef receival cattle fed a hydrolysed yeast (Salinas-Chavira et al., 2018) and reductions in severe liver abscess incidence were also noted with an autolysed yeast (Ran et al., 2018). While these findings are encouraging, it is

Table 5.4 Meta-analysis outcome summary of the effects of monensin on health (Duffield et al., 2008)

Variable	Relative risk	Direction of effect	Heterogeneity (I^2)*	P-value
Displaced abomasum	0.75	-	0%	0.008
Ketosis	0.75	-	0%	0.001
Mastitis	0.91	-	0%	0.016
Milk fever	1.11	----	0%	0.309
Calving difficulty	1.39	↑-	71%	0.118
Retained foetal membranes	1.01	↑-	46%	0.890
Metritis	1.14	↑-	51%	0.243
Sold	0.97	---	0%	0.412
Lameness	1.00	----	0%	0.978
First service pregnancy	0.97	----	18%	0.283

* The heterogeneity measure, I^2 is a measure of variation beyond chance among treatments included in the meta-analysis. Studies with an I^2 of greater than 50% can be considered to be substantially heterogenous.

challenging to understand differences in the different yeast-based products and the best application of these in the field.

Probiotics

There is also some evidence that probiotics may provide benefits in terms of acidosis control; however, there are challenges in this area as candidate agents such as *Megasphera elsdenii* have not provided clear and consistent benefit in studies to date. It seems likely that more studies will investigate the roles of other agents in acidosis control in the future.

Choline

Choline is a micronutrient that has an essential role in one carbon metabolism. One carbon metabolism comprises a series of inter-linked metabolic pathways that provide methyl-groups (1 C units) vital for the synthesis of DNA polyamines, amino acids, creatine and phospholipids (Clare et al., 2019). Other important components that interact in these pathways include methionine, folate, cysteine, and glutamine. In peri-parturient cattle choline may reduce the accumulation on lipids in the liver (Cooke et al., 2007, Zom et al., 2011). This result probably reflects the important role of choline in formation of phosphatidylcholine which is essential to the export of lipids from the liver. There is also limited evidence that choline may mitigate declines in vitamin E status around the time of calving (Baldi and Pinotti, 2006).

There are three reviews that show increased milk production from supplementation with rumen-protected choline (Baldi and Pinotti, 2006, Sales et al., 2010, Arshad et al., 2020), however there are few, if any, pasture-based studies. Arshad et al. (2020) found that choline supplementation during transition increased pre- and post-calving DMI, milk yield, energy corrected milk, fat, and protein yield. Sales et al. (2010) found that marginal responses decreased with increased amounts of choline. For the Arshad et al. (2020) study, the mean intake was 12.8 g/head per day and almost all studies supplemented for at least the last 14 days of gestation and the first 15 days of lactation. Interestingly, Arshad et al. (2020) also found that there was a reduction in retained placenta from choline intake, a finding supporting a possible role for choline in the mitigation of inflammatory processes. Further, Arshad et al. (2020) found that supplementation with choline had small but significant effects on glucose concentrations in blood (increased), on beta hydroxybutyrate (BHB; decreased after calving only) and fatty acids (increased before calving, but decreased after calving).

Choline must be fed in a ruminally protected form as it is destroyed in the rumen unless protected (Sharma and Erdman, 1989).

Chromium

Chromium is an essential trace element required for carbohydrate, protein, and lipid metabolism. It has several oxidation states. The trivalent and hexavalent forms are the most stable.

Chromium enhances insulin signalling, increases the uptake of glucose and amino acids by muscle and increases RNA synthesis. While the results from studies examining the effects of chromium supplementation in dairy cattle have been inconsistent, dietary supplementation during times of stress may be of benefit as chromium excretion in urine is enhanced during stress. The effects on blood insulin and glucose have been variable with some studies showing beneficial effects (Subiyatno et al., 1996, Hayirli et al., 2001, Sumner et al., 2007, Kafilzadeh and Targhibi, 2012) and others showing no effect. Supplementation with chromium during the periparturient period has consistently reduced blood NEFA concentrations before and after calving (Bryan et al., 2004, Smith et al., 2005, Soltan, 2010, Yasui et al., 2014). Reduced concentrations of NEFAs indicate an improved energy balance. A meta-analysis examining the effects of organic chromium supplementation on DMI and milk production found supplementation significantly improved DMI (17.69 kg/d compared to 18.67 kg/d, $P < 0.001$), milk yield (34.25 kg/d compared to 35.80 kg/d, $P < 0.001$), milk fat yield (1.32 kg/d compared to 1.39 kg/d, $P < 0.001$) and milk protein yield (1.17 kg/d compared to 1.21 kg/d, $P < 0.001$) (Harris et al., 2019).

Chromium may provide metabolic and production benefits by helping increase insulin sensitivity of tissues.

Mineral composition and DCAD of feeds commonly used in transition diets

Mineral composition and DCAD of commonly used acidogenic feed ingredients, commonly used feed stuffs and conversion factors needed to calculate DCAD from % DM are detailed in Tables 5.5, 5.6 and 5.7, respectively.

Published mineral composition of feeds may vary widely depending on source, fertiliser history, seasonal conditions, and other factors. Published values should always be used as indicative only. Feed analysis via wet chemistry methods must be conducted on a representative sample of all feeds to be included in transition cow rations.

Table 5.5 Mineral composition and DCAD of minerals and acidogenic feeds commonly used in transition diets

Mineral or feed	Name	Ca %	Mg %	Cl %	S %	Na %	K %	DCAD (mEq/kg)
$MgSO_4.7H_2O$	Magnesium Sulphate	-	9.98	-	13.01	-	-	-8100
$MgCl.6H_2O$	Magnesium Chloride	-	11.96	34.87	-	-	-	-9830
$CaSO_4.2H_2O$	Gypsum	27.26	-		18.63	-	-	-10590
$CaCl_2.2H_20$	Calcium Chloride	23.28	-	48.22		-	-	-13800
$(NH_4)_2SO_4$	Ammonium Sulphate	-	-	-	24.26	-	-	-14950
NH4Cl	Ammonium Chloride	-	-	66.26	-	-	-	-18590
MgO	Magnesium Oxide	-	54.00	-	-	-	-	0
NaHCO2	Sodium Bicarbonate	-	-	-	-	27.00	-	+11740
NaCl	Salt	-	-	60.70	-	39.34	-	0
Limestone		33.0	2.06	0.03	0.04	0.06	0.12	+20
BioChlor*		0.09	2.07	9.08	3.6	1.49	1.22	-3847
SoyChlor 16:7*		4.04	2.65	10.29	0.35	0.15	0.70	-2870
Animate		1.38	4.89	13.96	5.44	0.25	0.90	-6922
X- Zelit (Zeolite A)		0.01	0.02	0.02	0.02	11.10	0.01	+4873

*Chemical composition expressed on a dry matter basis.

Table 5.6 Mineral composition and DCAD of feeds commonly used in transition diets

Feed*#	Ca %	Mg %	Cl %	S %	Na %	K %	Typical DCAD (mEq/kg DM)	Range for DCAD
Rye/clover pasture	0.63	0.23	0.85	0.28	0.53	3.4	+390	+10 to +750
Kikuyu pasture	0.34	0.37	0.45	0.10	0.44	1.96	+680	+10 to +750
Lucerne hay	1.53	0.31	0.61	0.30	0.14	2.57	+360	+10 to +750
Oat hay	0.35	0.16	0.91	0.14	0.42	1.87	+280	0 to +750
Pasture hay	0.47	0.18	0.66	0.17	0.02	2.00	+230	+10 to +750
Wheat hay	0.35	0.16	0.53	0.16	0.08	1.77	+240	0 to +750
Grass silage	0.57	0.22	0.76	0.20	0.05	2.78	+390	+10 to +750
Maize silage	0.31	0.22	0.32	0.12	0.01	1.22	+150	+ 5 to +300
Sorghum silage	0.49	0.28	0.60	0.12	0.02	1.72	+200	+10 to +750
Triticale silage	0.52	0.17	0.75	0.20	0.08	2.90	+440	+10 to +750
Wheat	0.05	0.16	0.09	0.17	0.02	0.41	-20	0 to +50
Barley	0.05	0.14	0.08	0.13	0.01	0.52	+40	0 to +50
Almond hulls	0.27	0.11	0.04	0.03	0.02	2.65	+660	
Molasses	1.00	0.42	0.75	0.47	0.22	4.01	+620	-10 to +700
Bread	0.20	0.08	1.11	0.16	0.64	0.34	-50	
Brewers grain	1.32	0.35	0.16	0.09	0.02	0.64	+70	
Dried distillers grain (wheat)	0.15	0.05	0.09	0.23	0.08	0.12	+103	
Canola meal	0.75	0.51	0.03	0.63	0.09	1.31	-30	-50 to +50
Whole cottonseed	0.18	0.36	0.08	0.25	0.03	1.19	+140	0 to +240

*Chemical composition expressed on a dry matter basis.
#Note that mineral composition of feeds may vary widely depending on source, fertiliser history and season and examples are indicative only. Feed analysis via wet chemistry methods must be conducted on a representative sample of feed to be included in transition cow rations.

Conversion factors needed to calculate DCAD from % DM are shown in Table 5.7. Example DCAD calculation for typical wheat hay as per Table 5.7, using the short DCAD equation:

DCAD in mEq/kg DM

= [(0.08% * 434.98) + (1.77% * 255.74)] – [(0.53% * 282.06) + (0.16% *623.75)]

= 487.5 – 249.3

= 238.2 mEq/kg DM

It is important to note that an equivalent reflects the amount of substance that can react in a chemical equation with another substance. In transition ration formulation, we are interested in the potential to interact with hydrogen in an acid-base reaction. For example, $CaCl_2$ has two equivalents of chloride (which are negative) to one of calcium (positive), hence it has a negative DCAD. The conversion factors in Table 5.7 reflect the atomic weights and the valence of the element.

Table 5.7 Conversion factors from percentage dry matter to mEq/kg DM

Element	To convert % DM to mEq/kg DM: multiply by
Sodium	434.98
Potassium	255.74
Chloride	282.06
Sulphur	623.75

Table 5.8 Risk level of feeds commonly used in pre-calving transition diets for milk fever

Low	Moderate	High
Low potassium molasses	Maize silage	High potassium molasses
Grains	Cereal hays (these can still be high)	Pasture treated with effluent
Most grain-based byproducts	Whole cottonseed	Legume pastures
Protein meals		Sodium bicarbonate
Brewers grains		

CHAPTER 6

HARMFUL AGENTS TO AVOID

Endophyte alkaloids and other mycotoxins

Perennial rye grasses, particularly older cultivars, may be high in the endophyte alkaloids ergovaline and lolitreme (and others). The presence of these alkaloids at elevated levels may have extensive effects on production, reproduction and health of dairy cattle (Lean, 2005). While no studies have examined the effect of these alkaloids on cattle when fed specifically during the peri-partum period, there are many potential pathways whereby a negative effect on subsequent productivity may be exerted. Random surveys of pastures in south-west Victoria have demonstrated levels of alkaloids in excess of those required to cause disease in cattle in approximately 30% of samples (Reed, 2005). Similarly, Loudon et al. (2018) found a very high prevalence of mycotoxin infected pastures on King Island with evidence of exophytic and endophytic fungi that were associated with dark cutting in beef.

Surveys of pastures in south-west Victoria and on King Island have demonstrated levels of alkaloids in excess of those required to cause disease in cattle.

Of the many other mycotoxins that exist, zearalenone has recently gained some notoriety. Zearalenone has been demonstrated to have serious negative effects on the fertility of sheep in New Zealand (di Menna et al., 1987). Similar observations have been made in Australia (D. Moore, personal communication) and the effect of zearalenone and other mycotoxins on animal health may have been substantially underestimated in the past.

Effective mycotoxin binders are readily available and may be an important component of the pre-calving diet in some specific circumstances. However, documented evidence of the effectiveness of some products ability to bind specific mycotoxins is lacking.

Poor quality silage

The negative effects of poor-quality silage are not limited to the effects of mycotoxins alone, but include the effects of harmful yeasts (*Candida, Hansenula, Pichia, Issatchenkia* and *Saccharomyces*), bacteria (Clostridia spp. and other bacilli) and increased concentrations of acetate and butyrate and other toxic metabolites (Kung and Muck, 2017). Experience suggests that feeding poor quality silages around calving can contribute to negative health, production and reproductive outcomes mediated through decreased dry matter intake (DMI), decreased fibre digestion and destruction of the rumen fibre mat.

Black or off-colour silages must not be fed to transition cows, including the edges of silage stacks.

CHAPTER 7

POTENTIAL NEGATIVE EFFECTS OF IMPROVED TRANSITION

Mastitis

One study (DeGaris et al., 2010) found a greater risk of clinical mastitis in the first 180 days of lactation with increasing time spent on a transition diet formulated to deliver a positive energy and protein balance. It is likely this increase in risk is associated with higher milk production and is analogous to the greater risk of mastitis seen with increased milk production associated with genetic merit (Koivula et al., 2005) or recombinant Bovine Somatotrophin (rBSt) administration (Dohoo et al., 2003). However, neither meta-analysis (Lean et al., 2019; Santos et al., 2019) found an increased risk of mastitis with decreased DCAD intake. It should also be noted that rBST is not currently available in Australia.

Transition feeding may increase the risk of mastitis. However, the risk can be easily minimised by ensuring cows calve in a clean, dry paddock or calving area/ facility, the use of an internal teat sealant at dry off and applying teat disinfectant daily during the pre-calving transition period.

There is anecdotal evidence that feeding transition diets may increase the risk of milk leaking pre-partum and increase the risk of peri-partum mastitis. However, the appropriate formulation and balancing of transition diets can allow for daily pasture allocations allowing cows to calve in clean areas and hence reducing the risk of environmental mastitis. The use of internal teat sealants at dry off, daily teat disinfection during the pre-calving transition period, and milking cows that develop marked ventral udder oedema or leak milk pre-calving also appears to address this problem. Cows that are milked pre-calving due to udder oedema should be considered to have completed their pre-calving transition feeding and can be fed lactating cow diets. Calves born to cows milked pre-calving will need to receive colostrum from another source. For more information on management of udder oedema see Table 7.1.

Table 7.1 Managing udder oedema

	Intervention		
	Milking	**Concentrates**	**Water**
Critical comment	If cows show ventral oedema (swelling in front of the udder) or are uncomfortable, milk them even if they have not yet calved.	Limit the amount of concentrate to less than 25 to 30% of DMI. Limit sodium and potassium in the diet to less than 0.25% salt.	Test water to ensure quality is high. Monitor intakes and observe cows to ensure they are drinking.
Other comments	Save colostrum from other cows but check colostrum from the cow to determine if it is ok to use.	Slower fermenting grains (e.g. maize) are safer.	Test water for high potassium and sodium in water.
Other considerations	Cows appear to calve well even if put onto a lactating cow diet pre-calving. Monitor carefully.	Check the non-fibre carbohydrate (NFC) level of the diets as corn silages and some hays high in sugars can increase this.	Ensure cows have adequate access to water (sufficient trough space and volume).
Feeding period	From -21 to 0 days in milk	-21 to 0 days in milk	-21 to 305 days in milk

If cows show oedema of the ventral abdomen or discomfort before calving, commence milking them. Ensure that after calving, their calf gets a sufficient volume of high-quality colostrum from another cow.

Colostrum quality

It is possible that transition cow nutrition could influence colostrum quality. Studies in beef cattle have shown that pre-partum protein nutrition does not affect colostral immunoglobulin (IgG) concentration (Belcha et al., 1981, Burton et al., 1984, Hough et al., 1990) but pre-partum diets low in protein and energy may result in reduced calf absorption of immunoglobulins (Burton et al., 1984, Hough et al., 1990). Other studies have reported no effect of pre-partum nutrient restriction on the absorption of colostral immunoglobulins (Fishwick and Clifford, 1975, Halliday et al., 1978, Olsen et al., 1981a, Olsen et al., 1981b). However, the volume of colostrum produced at the first milking is negatively correlated with IgG concentration (Pritchett et al., 1991). Anecdotal evidence suggests the volume of first milking colostrum is increased in cows fed well-formulated transition diets and it is possible that immunoglobulin concentration is negatively affected through dilution. There tended to be a greater yield of colostrum for cows fed 3 mg/d of calcidiol ($P < 0.1$) and no effect of DCAD on colostrum yield for cows on a positive (130 mEq/kg) compared to negative DCAD (-130 mEq/kg) diet (Rodney et al., 2018a).

Anecdotal evidence suggests the volume of first milking colostrum is increased in cows fed well-formulated transition diets and it is possible that immunoglobulin concentration is negatively affected through dilution.

Joyce and Sanchez (1994) highlighted the possibility that cows fed a low DCAD diet pre-partum may deliver calves that are more severely metabolically acidotic for longer and this may reduce absorption of colostral immunoglobulins. However, Tucker et al. (1992) failed to demonstrate an effect of DCAD on the acquisition of passive immunity. Morrill et al. (2010) found no difference in colostrum concentrations and absorption between cattle fed acidogenic salts before calving and those fed a positive DCAD diet (DCAD difference 177 mEq/kg from -100 compared to 77 mEq/kg).

Calf birth weight and dystocia

The impact of pre-partum nutrition on calf birth weight and dystocia is again an area requiring further investigation with most studies examining the effects of inadequate or restricted nutrition on birth weight. While a few studies have shown a negative effect of nutrient restriction on calf birth weight (Corah et al., 1975) and/or a positive relationship between pre-partum nutrition and calf birth weight (Boyd et al., 1987), the vast majority have failed to show any effect (Ferrell et al., 1976, Prior and Laster, 1979, Anthony et al., 1986, Carstens et al., 1987, Stalker et al., 2006, Martin et al., 2007).

The relationship between transition feeding and calf birth weight requires further investigation.

CHAPTER 8

POST-CALVING TRANSITION PERIOD

The focus of transition management of the dairy cow tends to be on the pre-calving period. However, the transition period extends to the first three weeks of lactation. While a detailed discussion on the nutritional requirements of the dairy cow during this period is beyond the scope of this review, the nutrition and management of the post-calving transition cow is of equal importance as that of the pre-calving transition cow. During this period there is substantial up regulation of all metabolic processes that drive continued udder development, recovery of appetite and immune function and the resumption of reproductive activity.

All the concepts of sound nutrition that are important in the pre-calving transition period are equally important in the post-calving transition period. Continued ruminal adaptation to high concentrate diets is critical to control the risk of lactic acidosis. Careful attention to macro and micro mineral metabolism as well as energy and protein metabolism is essential for a successful lactation. A process of gradual adaptation in the diet helps; ideally cows should get pasture in the diet before calving if they are fed pasture after calving; similarly, it is important not to abruptly remove cereal hays after calving if fed before calving, nor to increase the grain in the diet too rapidly after calving.

A process of gradual adaptation to the post-calving diet is important. Ideally cows should:

- Get pasture in the diet before calving if they are fed pasture after calving
- Not have cereal hay abruptly removed after calving if fed this before calving
- Not have grain increased in the diet too rapidly after calving.

Again, the concept of homeostatic and homeorhetic change are crucial, with failure to adequately support one area of metabolism, inevitably resulting in negative impacts on other metabolic processes. Careful attention to minimise the depth and length of negative energy and protein balance are equally as important as the provision of adequate calcium, magnesium, and phosphorus. Recommendations for diet formulations for the post-calving transition diet are described in Table 5.2.

CHAPTER 9

LENGTH OF EXPOSURE

If the goals of the transition diet are met, the outcomes are substantial. The results of a large Australian exposure study, whereby the effect of exposure to pre-calving diets in over 1000 Gippsland cows in three different calving periods was explored, demonstrated economically important increases in milk production and reproductive performance (DeGaris et al., 2008, 2010).

The variable studied was the length of time a cow spent on the pre-calving transition diet, formulated to deliver a positive energy and protein balance, as well as control the risk of hypocalcaemia. The pre-calving diets contained 16.0% crude protein (CP) and 9.9 MJ ME/kg DM delivering an estimated MP balance of + 286 g/day and a DCAD of -147 mEq/kg DM. Dietary calcium, magnesium and phosphorus were 0.5%, 0.3% and 0.5% respectively (note dietary magnesium was lower than currently recommended). The early lactation diets contained 16.9 % CP, 11.8 MJ ME/kg DM delivering an estimated MP balance of -102g/d. All diets contained either monensin and tylosin or virginamycin.

Length of exposure to the transition diet was a consistently significant variable in models developed by Lean et al. (2006) and acted to substantially modify coefficients for calcium and magnesium. Increasing exposure to the diet before calving from 20 to 30 days increased risk of milk fever by 42%. The magnitude of the increase varied with dietary calcium concentration from minor at low and high concentrations and substantial at the 1.2 to 1.5% level. The optimum time spent on the transition diets was determined to be 22 to 25 days based on fat and protein corrected milk production (DeGaris et al., 2008). This is shown in and is shown in Figures 9.1, 9.2 and 9.3, which display the four-day moving average and 95% confidence intervals of predicted milk, fat, and protein yield with increasing days of exposure to the pre-calving transition diet. Statistically significant increases of 3.75 litres of fat and protein corrected milk and 100g of milk protein per day for the first 180 days of lactation were seen with increased exposure to the transition diet up to the optimum of 24 days exposure. While there were no detrimental effects of exposures greater than 24 days, there was no further increase in production.

Figure 9.1 The effect of days exposed to pre-calving transition diet on predicted milk yield

(DeGaris et al. 2008)

Figure 9.2 The effect of days exposed to pre-calving transition diet on predicted fat yield

(DeGaris et al. 2008)

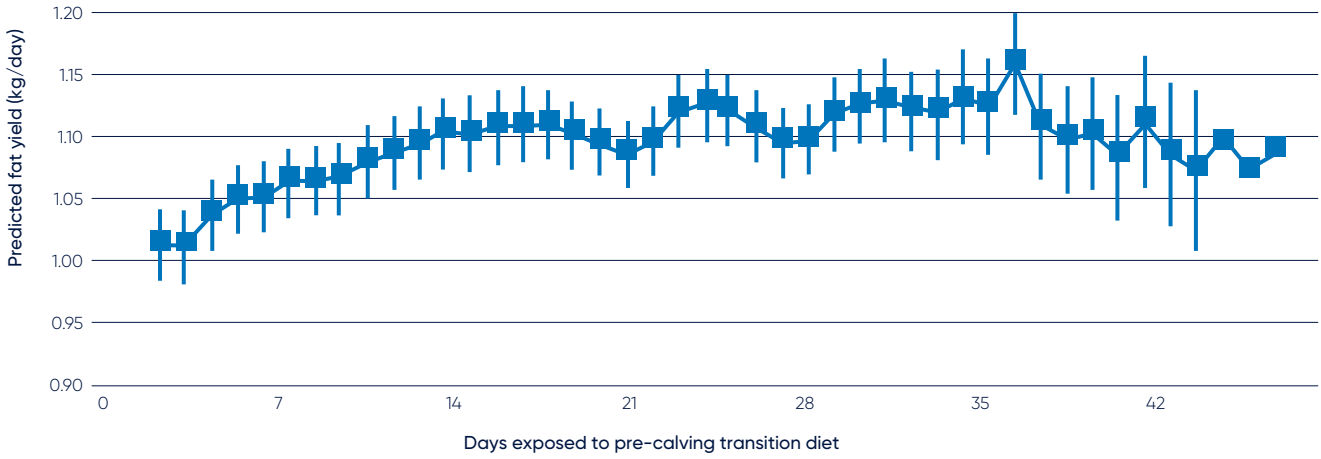
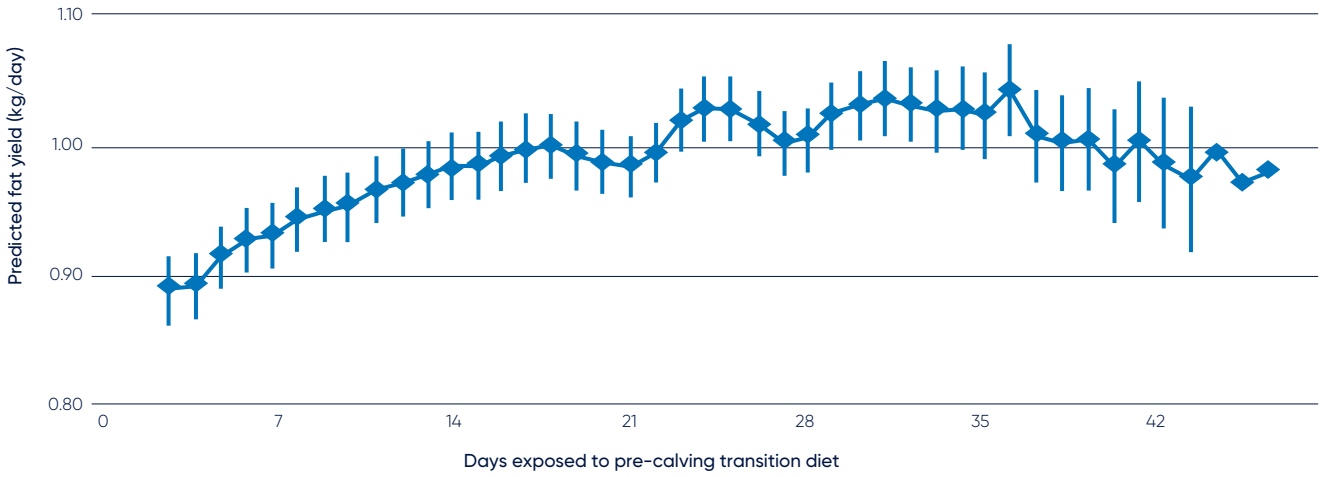


Figure 9.3 The effect of days exposed to pre-calving transition diet on predicted protein yield

(DeGaris et al. 2008)



A 21 versus 42 day transition feeding period was equally effective in increasing milk production, however the study was too small to evaluate effects on milk fever (Weich et al., 2013). In a larger study (Lopera et al., 2018) using 114 animals, increasing the duration of feeding from 21 to 42 days reduced milk production and tended (P = 0.06) to reduce the probability of cows getting pregnant over time. The latter result differs from DeGaris et al. (2008) and DeGaris et al. (2010) who found a reduction in time to pregnancy associated with increased exposure to the transition diet beyond 20 days.

In terms of DCAD, there are two probable pathways by which future production is influenced:

1 The reduction in disease is an important pathway through which production can be influenced. Retained placenta and severe puerperal metritis also reduce milk production (Rajala and Gröhn, 1998). Anti-inflammatory agents can increase milk production for a prolonged period of lactation and are described in more detail in Chapter 5. Milk fever reduces milk production.

2 The links between bone metabolism with energy metabolism are evident and may explain a substantial amount of the increase in milk response. A negative DCAD through the effects on calcium metabolism may overcome the previously described lack of response to insulin in the periparturient period.

This study also examined the effects of time spent on transition diets on reproductive measures and animal health. Continual improvements in the calving to conception interval were seen with increasing time spent on the transition diets (Figure 9.4), which resulted in improvements in six-week in-calf rate and not-in-calf rate. Similar benefits were also seen on the proportion of cows that either died or were culled from the study herds (Figure 9.5).

Although the reproductive and health benefits of feeding a balanced transition diet are likely to improve with increasing days cows are fed a transition diet, the potential negative effect on the risk of milk fever and the lack of a benefit on production of feeding cows for more than 24 days, means the recommendation of 21 days on a transition diet is sound. To achieve this target, accurate predicted calving dates are essential. This necessitates early and accurate pregnancy diagnosis to get the optimum benefit.

It is recommended to feed the transition diet for 21 days. To achieve this, early and accurate pregnancy diagnosis is essential.

Figure 9.4 The effect of days exposed to pre-calving transition diet on reproductive performance

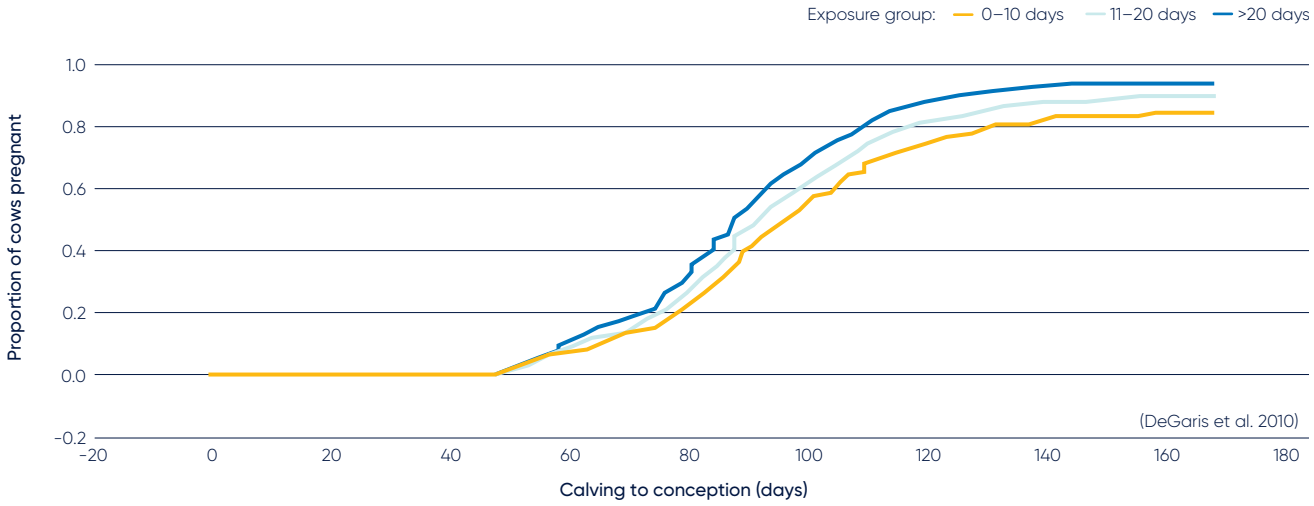
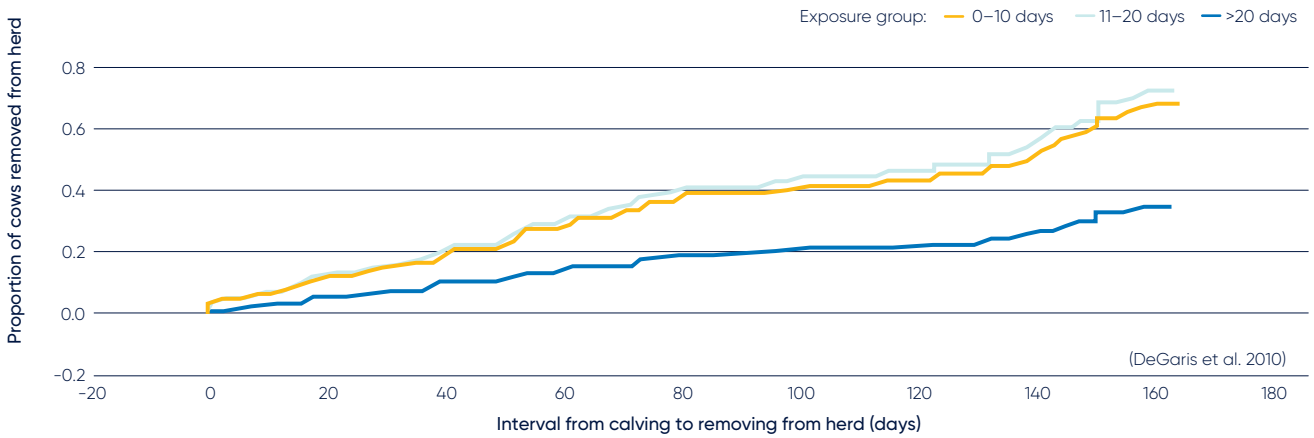


Figure 9.5 The effect of days exposed to pre-calving transition diet on risk of culling and death



CHAPTER 10

ALTERNATE TRANSITION FEEDING STRATEGIES

Low calcium and zeolite A for control of milk fever

An alternative approach to controlling hypocalcaemia and milk fever is to feed a pre-partum diet that contains calcium at a level below the maintenance requirements of the cow (Boda and Cole, 1954), resulting in the stimulation of calcium homeostatic mechanisms prior to calving. While this approach was commonplace historically, it fell out of favour as it become increasingly difficult to formulate diets that were very low in calcium while delivering enough energy and protein to meet the demands of the transition dairy cow (Block, 1984). The feeding of calcium binders was developed as a method to reduce the calcium availability in the pre-partum diet to below maintenance levels (Thilsing-Hansen and Jørgensen, 2001). The binding of calcium results in a negative calcium balance which should stimulate calcium homeostatic mechanisms in preparation for the onset of lactation. The binder is removed from the diet at calving.

The binding of calcium using a product such as zeolite A results in a negative calcium balance which should stimulate calcium homeostatic mechanisms in preparation for the onset of lactation.

The most commonly fed calcium binder is zeolite A. Zeolite A was first manufactured by Union Carbide in the 1950s (Breck et al., 1956) and has the chemical formula $Na_{12}[(AlO_2)_{12}(SiO_2)_{12}].27H_2O$ (Breck et al., 1956). Zeolite A has a very low toxicity, however, dust arising from the synthetic zeolites can produce transient irritation of the eyes and nasal passages (Thomas and Ballantyne, 1992). Zeolite A binds cations (positively charged ions) including calcium, magnesium, and phosphorus in the rumen, however, the binding capacity for each cation is unclear. Zeolite A has the potential to bind 110 mg/g of calcium at pH 11; with a lower pH the calcium binding capacity is reduced, but the phosphorus binding capacity may be increased (Thilsing et al., 2006). Although zeolite A has a high affinity for zinc and cobalt (Breck et al., 1956), its potential to bind other important trace minerals in transition cows is unclear.

Studies on feeding zeolite A in the pre-partum dry period are outlined in Table 10.1. The effects of feeding zeolite A on hormones that influence calcium homeostasis have not been investigated in detail. Increases in circulating calcitriol and parathyroid hormone (PTH) were found pre-partum in cows fed zeolite A (Thilsing-Hansen et al., 2002, Thilsing et al., 2007). However, these responses may depend on the calcium and phosphorus content of the pre-partum diet (Thilsing et al., 2007).

Feeding of zeolite A is often associated with dramatically variable effects on dry matter intake (DMI). It is unclear what drives DMI pre-partum in cattle fed zeolite A, however, the reduction in blood phosphorus may be important (Grabherr et al., 2009) as evidenced by a significantly lower depression of feed intake in pre-partum cows fed 600 g/d of zeolite A in a high (136g/cow/day) phosphorus diet (11% feed refusal) compared to a low (36g/cow/day) phosphorus diet (21% feed refusal) (Thilsing et al., 2007). Low dietary phosphorus has been shown to depress DMI in lactating dairy cows (Kincaid et al., 1981).

The feeding of zeolite A often results in a reduced dry matter intake. The mechanism by which this occurs is not well understood.

Positive effects on reproductive performance of feeding zeolite A during the pre-partum period have been demonstrated (Kerwin et al., 2019); however, the power of this study to show differences in reproductive measures was extremely low and it is premature to determine whether a benefit would be routinely observed.

While feeding zeolite A has reduced milk fever and improved blood calcium levels over the calving period, there are limited data on the effects on subsequent milk production, health or reproduction. Large field studies comparing zeolite A based diets to DCAD based diets are needed as are detailed physiological studies to further elucidate the effects of zeolite A on metabolism and DMI. The interaction between DCAD and dietary calcium, magnesium and phosphorus when feeding zeolite A needs investigating. Basic research is needed to determine the binding capacity of zeolite A for a range of cations at physiologically relevant pH in biological systems. The effects of zeolite A on blood, tissue and milk production also need further investigation. The length of time for which zeolite A continues to bind calcium, phosphorus and Magnesium following cessation of supplementation is also unknown.

Zeolite A has been shown to reduce milk fever incidence and improve blood calcium levels over the calving period but there are limited data on the effects on subsequent milk production, health, or reproduction.

Table 10.1 Studies on feeding zeolite A in the pre-partum dry period

Measure	Effect	References
Blood calcium pre-partum, at parturition and post-partum	Increased	(Thilsing-Hansen and Jørgensen, 2001, Thilsing-Hansen et al., 2002, Pallesen et al., 2008, Kerwin et al., 2019)
Sub-clinical hypocalcaemia	Decreased	Thisling-Hansen and Jørgenson 2001; Pallesen et al., 2008; Kerwin et al., 2019
Milk fever	Decreased	(Thilsing-Hansen and Jørgensen, 2001, Pallesen et al., 2008, Jorgensen and Theilgaard, 2014)
Peri-parturient blood phosphorus concentration	Decreased	(Thilsing-Hansen et al., 2002; Pallesen et al., 2008; Kerwin et al., 2019)
Peri-parturient blood magnesium concentration	Decreased	(Thisling-Hansen et al., 2002; Kerwin et al., 2019)
Pre-partum dry matter intake (DMI)	Decreased	(Thisling-Hansen et al., 2002; Grabherr et al., 2009; Kerwin et al., 2019)
Peri-parturient blood Aluminium concentration	Increased	(Thilsing et al., 2007)
Milk yield and composition	No effect	(Thilsing-Hansen et al., 2002; Grabherr et al., 2009; Kerwin et al., 2019)
Effects on immune cell function	Down regulated Neutrophil gene expression (CXCR1 and S100A8)	(Crookenden et al., 2020)

The current Australian guidelines for feeding zeolite A are shown in Table 10.2. It is important to formulate pre-partum transition diets to deliver a positive metabolisable energy (ME) and metabolisable protein (MP) balance along with adequate macro and trace minerals and vitamins in line with best practice guidelines. Wet chemistry feed testing of all forages is still important to accurately determine macro-mineral concentrations.

Table 10.2 Current recommendations for feeding zeolite A from the Australian supplier

Feed	Inclusion rate (per cow per day)	Comments
Zeolite A	500g	Feed for 14 days pre-partum mixed in concentrate
Concentrate	2 to 3kg	Avoid feeding high calcium concentrate
Magnesium oxide	40 to 50g	
Hay	3kg DM	Pasture or cereal hay
Pasture	5 to 6kg DM	
Trace minerals/vitamins	As per NRC guidelines	

Approach to feeding over-conditioned cows in lot fed herds: A focus on rumen fill

One approach is feeding lower energy density, high rumen fill diets. This approach developed because cattle could gain excessive body condition over the dry period and controlling energy intakes appears to have benefits on health and production. It is important to note that this is rarely a problem in pastured cattle and restricting feed intake during the dry period should not be undertaken without very good reason.

Excessive body condition is rarely a problem in pastured cattle and restricting feed intake should not be undertaken without very good reason.

These approaches were developed based on studies examining responses to additional feed intake and starch. Though study results from Bertrics et al. (1992) suggested greater dry matter intake (DMI) could reduce non-esterified fatty acid (NEFA) mobilisation and decreased risk for hepatic fatty infiltration, other studies indicated moderate feed intake could also show similar positive post-partum responses (Grum et al., 1996, Holcomb et al., 2001, Agenas et al., 2003, Douglas et al., 2006). Cows moderately restricted in feed intake (80% of energy requirement) had lower NEFA concentrations pre-calving, less hepatic fat content and greater post-partum intake. Ensuing studies suggested energy consumption in the early dry period (greater than 30 days prior to expected calving) also had significant effects on post-partum health and lactational performance (Dann et al., 2005, Dann et al., 2006, Douglas et al., 2006, Janovick and Drackley, 2010, Janovick et al., 2011). Excessive energy intake may predispose the cow to greater maternal tissue insulin insensitivity coupled with the physiologic insulin concentration decline occurring just prior to calving, thus permitting more exaggerated NEFA mobilisation and subsequent metabolic derangements. Out of these observations a feeding management approach controlling total energy consumed and moderately restricting intake throughout the pre-partum period has been advocated (Drackley and Janovick, 2007a).

Restricted feed intake diets are intended to provide sufficient energy to meet daily needs (maintenance), but not to supply excessive energy intake that results in further weight gain. Cereal straw forage or mature grass hay is used to "dilute" dietary energy provided from other more energy dense ingredients. These diets are typically based on maize silage. Use of lactation diet feed ingredients can be achieved by dilution allowing for easy adaptation to post-partum diets. Wheat straw is preferred due to its consistency and better neutral detergent fibre (NDF) digestibility compared to other straw products. The bulking ingredient is used to allow for ad libitum intake rather than management attempting restricted intake. To be successful, the bulking ingredient should be properly incorporated into the diet and not fed separately. To ensure intake and to minimise sorting, the hay or straw should be chopped to achieve a consistent particle size of 4 to 6cm. The straw or hay should be of high quality and palatable. An important aspect of controlled energy diet success is ensuring adequate protein intake. Drackley and Janovick (2007a) recommends supplying more than 1000 grams of metabolisable protein (MP), which can often be achieved in diets formulated for 12-14% crude protein. To achieve delivery of this amount of MP, some bypass product source will need to be included in the diet. Protein meals of animal origin are often used in the USA; these are illegal in Australia.

Use of controlled energy diets should be perceived as a complete dry cow program (Drackley and Janovick, 2007a). The use of straw typically will control dietary potassium concentration, thus reducing risk of disrupted calcium homeostasis. Application of these diets in the field supports the contention that these diets can be successfully fed as single dry cow group systems, thus reducing some group/pen changes during transition. Research and field experience with these diets suggest reduced post-partum disease problems and potentially improved reproductive performance (Dann et al., 2005, Beever, 2006, Douglas et al., 2006, Janovick et al., 2011). Similar health and production responses were seen in a series of studies using grass hay or wheat straw feeding either *ad libitum* or restricted (Litherland et al., 2012). Van Saun (1993) used similarly formulated high fibre diets, but in a two group dry cow feeding program. Diets were formulated to provide either 1100 or 1300 g MP/d to multiparous cows. Although the study cows were generally over conditioned (body condition score greater than 6 out of 8), similar positive effects on health and reproduction were observed.

In summary, a key factor with pre-partum DMI is to optimise intake to minimise any dramatic decline in intake just prior to calving. Significant intake declines stimulate greater NEFA mobilisation which adversely affects critical metabolic adaptations to lactation. Differing dry cow diet feeding strategies have been applied in the field with similar success suggesting other factors beyond nutrient content need to be considered. Grouping strategies, group/pen movements, environmental stressors, and feeding management will play significant roles in the success or failure of any given dry cow feeding strategy.

CHAPTER 11

APPROACHES TO TRANSITION FEEDING

There are several approaches to transition feeding used on Australian farms. Seven commonly used approaches are:

1. Pasture and hay
2. Pasture, hay and acidogenic salts in fodder or water
3. Pasture, hay, and a grain-based concentrate
4. Pasture, hay, and zeolite A in grain
5. Pasture, hay, acidogenic salts in a grain-based concentrate
6. Pasture, hay and a professionally formulated acidogenic feed (e.g. lead feed)
7. Total mixed ration or partial mixed ration (fully integrated transition diet)

Each of these approaches varies in terms of the extent to which it helps the cow deal with the challenges to successful adaptation to lactation.

Approach 1 (Pasture and hay) typically carries a very high risk of milk fever or hypomagnesaemia (grass tetany) when pasture dominates, and high risks for low production and pregnancy toxaemia when hay dominates.

The best ways to achieve some basic control over milk fever and hypomagnesaemia are to spray molasses and up to 120-150 grams per cow per day of magnesium sulphate or magnesium chloride onto hays or silages. Measured amounts of the magnesium salts can be applied in water through a calibrated dispenser but may result in highly variable intake (Approach 2).

The inclusion of grain (Approach 3) in the pre-calving adapts the rumen to grain and provides additional energy and metabolizable protein by addition of protein and presence of fermentable carbohydrate. This option can also allow less palatable acidogenic salts to be included in the grain to provide a lower DCAD and more markedly, reduce risk of metabolic disease. Rumen modifiers can be added as well, with benefits to health and production.

Approach 4 includes zeolite A in the diet to control milk fever through binding of calcium. Rumen modifiers can be added as well, with benefits to health and production. It should be noted that reductions in dry matter intake (DMI) with this approach have varied between less than 1% and up to as high as 20% in the literature.

Incorporating acidogenic salts in a grain-based concentrate (Approach 5) allows less palatable salt inclusions to provide a lower DCAD and more markedly reduce risk of metabolic disease. Rumen modifiers and other feed additives can also be added as well with benefits to health and production. Some of the mineral acidogenic salts have a very low palatability. Feed manufacturers can manage this to some degree by using flavour and aroma enhancing agents including molasses.

A professionally formulated, commercially produced acidogenic transition supplement (lead feed) fed with pasture and hay (Approach 6) or a partial or total mixed ration (Approach 7) can allow precise control over the diet. It offers the ability to reduce DCAD more readily and provide the transition cow with all the components of a fully integrated transition diet (energy, protein, macrominerals, microminerals, rumen modifiers and other additives) to achieve the optimal milk production and reproductive benefits possible.

Table 11.1 provides a summary comparison of these commonly used approaches to transition feeding with respect to:

- the extent to which they meet specific challenges to adaptation to lactation and improve animal health, milk production and fertility, and
- their overall effectiveness in helping the transition cow establish a successful lactation.

Additional considerations for a successful transition period

There are several considerations for transition cow management in addition to diet formation.

Dairy Australia has prepared:

- A **checklist** to assist farmers, nutritional professionals, veterinarians, and farm advisers to implement the key steps for a successful transition period; and
- A **review sheet** which outlines a step-by-step process to help collate, interpret, and prioritise information and develop a workable plan to improve transition programs in future.

More copies of the checklist and review sheet can be downloaded from the Dairy Australia website **dairyaustralia.com.au**.

Table 11.1 Description of different transition feeding options and their relative effectiveness

Description	Applicable production systems (1 to 5)*	Ease of use	Effectiveness (1 to 4)**	Provides for needs of transition cow								Comments
				Milk fever control	Other metabolic disease control	Improved animal health	Improved production	Improved reproduction	Rumen adaptation	Positive metabolisable protein balance	Positive metabolisable energy balance	
Pasture and hay	1 & 2	✓✓✓✓✓	1	✓	✓	✓	✓	✓	✓	✓	✓	Does not address needs of the cow
Pasture, hay, acidogenic salts	1 & 2	✓✓✓✓	2	✓✓	✓	✓✓	✓✓	✓	✓	✓	✓	Acidogenic salts delivered in water may reduce water and feed intakes
Pasture, hay, concentrate	1 & 2	✓✓✓	2	✓	✓✓	✓✓	✓✓	✓	✓✓✓	✓	✓✓✓	Does not address control of macromineral disorders
Pasture, hay, concentrate, zeolite A	1, 2, 3 & 4	✓✓✓	2 to 3	✓✓✓✓	?	✓✓✓	✓✓✓	✓✓	✓✓✓✓	✓✓	✓✓✓✓	Impact on production, reproduction and health not currently understood.
Pasture, hay, grain, acidogenic salts	1, 2 & 3	✓✓✓	2 to 3	✓✓✓	✓✓✓✓	✓✓✓	✓✓✓	✓✓	✓✓✓✓	✓✓	✓✓✓✓	Can be difficult to control macromineral disorders
Pasture, hay, commercial lead feed	1, 2, 3 & 4	✓✓✓	3 to 4	✓✓✓✓✓	✓✓✓✓✓	✓✓✓✓	✓✓✓✓	✓✓✓	✓✓✓✓✓	✓✓✓	✓✓✓✓	Can be a highly effective strategy
TMR/PMR (fully integrated transition diet)	3, 4 & 5	✓✓✓	4	✓✓✓✓✓	✓✓✓✓✓	✓✓✓✓✓	✓✓✓✓✓	✓✓✓✓✓	✓✓✓✓✓	✓✓✓✓✓	✓✓✓✓✓	Highly effective strategy

* Production systems: 1. Pasture, other forages and low grain/concentrate feeding in bail; 2. Pasture plus other forages and moderate to high grain/concentrate feeding in bail; 3. Pasture plus PMR with or without grain/concentrate feeding in bail; 4. Hybrid system; 5. Total mixed ration (TMR) system.

** Effectiveness: 1. Does not address any of the needs of the transition cow. 2. Addresses some of the needs of the transition cow. 3. May address all the needs of the transition cow. 4. Addresses all the needs of the transition cow.

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Checklist for Transition Cow Management

Use this checklist to help you implement the key steps for a successful transition period.

1 Decide whether you will use a low DCAD approach (recommended) or a low calcium (zeolite A) approach

2 Feed the transition diet for as close to 21 days (low DCAD approach) or 14 days (low calcium zeolite A approach) as possible

- ☐ This relies on accurate calving dates. Early pregnancy testing all cows and heifers by a skilled operator between 5-15 weeks of gestation will enable this.

3 Sourcing and testing forage

- ☐ Obtain a single consignment of forage from one source if possible.
- ☐ Test forage with both a standard feed test and wet chemistry mineral analysis.
- ☐ Test pasture if it will comprise more than 2kg DM/cow/day in the transition diet.

4 Balancing the diet*

- ☐ Attend a Putting Transition Cow Management into Practice workshop.
- ☐ Work with a nutrition advisor or use the Transition Diet Milk Fever Risk Calculator to adjust feeding levels to meet energy and protein requirements and manage milk fever risk.
- ☐ If feeding a concentrate designed for milkers, check that it doesn't contain bicarbonate as a buffer.

* Do you plan on using a commercial lead feed pellet, DIY acidogenic salts (e.g. mag chloride), zeolite A or something else? Use the same concentrate type as you will use after calving (e.g. grain or pellets).

5 Choosing your springer paddock(s)

- ☐ Chose paddocks that have not been irrigated with effluent or received heavy applications of potassium fertilisers. Rotating calving paddocks is good practice to avoid nutrient loading.
- ☐ Repair leaking troughs, boggy gateways and restrict access to dams to manage mastitis risk. Also scrape or wash down feed pad regularly (if applicable).
- ☐ Calculate daily pasture mass[1] and strip graze to manage intakes especially if it will comprise more than 2kg DM/cow/day in the transition diet.
- ☐ If applicable, ensure you have enough trough space (at least 75cm per cow) and/or hay rings (at least 1 per 20 cows) to ensure all cows and heifers have equal access to transition diet.
- ☐ Use a mineral dispenser if putting DIY salts (e.g. mag chloride) in water troughs. These are available from most rural stores. Calibrate regularly according to manufacturer's directions.
- ☐ Ensure free access at all times to high quality water

6 Staff

- ☐ Ensure staff have been adequately trained in their required tasks and simple, written Standard Operating Procedures (SOPs) are available to them.

7 Feeding out

- ☐ Ensure you've made realistic allowances for wastage (may be up to 35% when fed on bare ground).
- ☐ Start milking cows and heifers early if they have udder oedema or are running milk.

If feeding concentrates through the dairy:

- ☐ Check and calibrate feed systems regularly.
- ☐ Observe for mastitis and apply teat disinfectant to all surfaces of teats daily.

8 Monitor the success of your program

- ☐ Use Cow Health Problems at Calving Tally Sheet or existing herd recording system to monitor cow health.
- ☐ Use Transition Program Review Worksheet to assess how well the program worked and plan any changes.

For more information on transition cow management **click here**

1 Average pasture intake per cow can be estimated as follows:
Intake (kg DM per cow per day) = $\frac{(A \times (B - C))}{D}$
Where:
A = area of paddock (ha)
B = estimated kg DM per ha in paddock pre-grazing
C = estimated kg DM per ha in paddock post-grazing
D = number of cows in paddock

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Transition program review

WORKSHEET

How well has the transition program implemented on this farm performed? What changes need to be made?

Enter the result achieved for each of the key parameters below and compare it to the target.

FARM NAME:

Date:

1 Pre-calving transition diet fed

	Aim for	Result	Comment
Average days cows fed diet	21 days (low DCAD approach) 14 days (low calcium zeolite A approach)		
Average days heifers fed diet	21 days (low DCAD approach) 14 days (low calcium zeolite A approach)		
Daily DM intake per cow	10–16kg/day		
Diet specifications:			
Metabolisable energy	Greater than 11 MJ ME/kg DM 100-120 MJ ME/day		
Crude protein	14 to 16% DM		
NDF	Greater than 36%		
Calcium	0.5-0.7% (low DCAD approach) Less than 0.2% (low calcium zeolite A approach)		
Phosphorus	0.25-0.4% (low DCAD approach) Less than 0.25% (low calcium zeolite A approach)		
Magnesium	At least 0.45%		
DCAD	Less than 0 mEq/kg DM (low DCAD approach)		

2 Fresh cow health problems

	Aim for	Result	Comment
Milk fever	Less than 1% (8 years of age or less) Less than 2% (greater than 8 years of age)		
Retained placenta/RFMs	Less than 3%		
Assisted calvings	Less than 2%		
Displaced abomasums (LDAs/RDAs)	Less than 1%		
Ketosis	Less than 1%		
Mastitis	Less than 5 cases/100 cows in first 30 days		
Grass tetany	0%		
Lameness	Less than 2% with Score 2 or 3		
Ruminal acidosis	Less than 1%		
Endometritis/vaginal discharge after 21 days	Less than 3%		

3 Milk production, milk quality, herd reproductive performance and body condition

	Aim for	Result	Comment
Average litres/kg milk solids per cow at first herd test	More than last year		
Average fat % at first herd test	More than last year		
Average protein % at first herd test	More than last year		
% of cows with a Fat : Protein Ratio more than 1.4 at first herd test	Less than 40%		
% of cows with a Fat : Protein Ratio less than 1.0 at first herd test	Less than 10%		
Body condition	**Aim for**	**Result**	**Comment**
Average Body Condition Score – late lactation/dry off	4.5–5.5		
Average Body Condition Score – calving	4.5–5.5		
Average Body Condition loss between calving and mating	Less than 0.6 BCS units		

Seasonal/split calving herd	**Aim for**	**Result**	**Comment**
6-week in-calf rate	More than 71%		
3-week submission rate	More than 86%		
Year-round calving herd	**Aim for**	**Result**	**Comment**
100-day in-calf rate	More than 58%		
80-day submission rate	More than 73%		

4 Physiological parameters

	Aim for	Result	Comment
Urine pH	6.2-6.8 (Holstein) 5.8-6.3 (Jersey)		
Serum albumin (3-5 days post-calving)	More than 35 g/L		

What happened and what you learnt

What you planned to do	What happened	What you will do differently from now on

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CHAPTER 12

COSTS AND BENEFITS OF DISEASE CONTROL DURING THE TRANSITION PERIOD

The cost of a disease at the farm level can be broken down into direct costs and indirect costs. Direct costs are the cost of diagnosing and treating the disease. Indirect costs are those related to subsequent losses incurred through reduced production, reproductive failure, and premature removal from the herd.

Both cost categories vary substantially between countries, production systems and individual farms. Indirect costs are particularly difficult to quantify as they also vary within farm depending on individual animal genetic merit, age, stage of lactation and time to accurate diagnosis and treatment. At an industry level, costs also include somewhat intangible costs incurred through damage to public perception of animal welfare and wellbeing.

The advantages and disadvantages of implementing a transition feeding program are outlined in Table 12.1.

It is well recognised that the transition period is the most significant risk for disease and culling of adult cows, and as such, significant reductions in the cost of many diseases can be achieved through implementation of integrated transition cow programs. Estimates of the costs of various diseases of the transition period are shown in Table 12.2 and achievable targets for disease incidences were presented earlier in Table 1.2 (Chapter 1) along with levels at which farmers should seek help.

Table 12.2 Estimated costs of disease in the transition period

Disease	Estimated cost/case	Range
Milk fever	$400	$249–$408
Subclinical hypocalcaemia	$125	
Clinical ketosis	$240	$138–$348
Left displaced abomasum	$650	$375–$650
Lameness	$200	$180–$500
Retained foetal membranes/metritis	$300	$263–$472

Table 12.1 Advantages and disadvantages of transition feeding

Area of farm performance	Disadvantage	Advantage
Labour use/costs	Increased planning including structured time taken to feed cows and plan diets ahead of time.	Reduced labour and markedly less time spent on treating cows. Time is freed up during calving periods for other tasks such as colostrum management.
Animal health	Potential to increase mastitis.	Other diseases controlled and culling reduced. Increased reproductive performance.
Milk production	Need to feed well post-calving to support increased performance.	Milk and milk protein production (kg) is increased.
Profit	Need to allocate funds to transition costs (up to $3 per cow per day or $60 per cow or a $30 increase over basic costs (poor forage plus grain) needed to meet maintenance.	Literature suggests returns may be 10:1 profit markedly increased.

Around 80% of cow health problems occur and disease costs are incurred within 4 weeks of calving. It is also a peak period for involuntary culling and deaths.

The improvement in milk production from feeding a low DCAD transition diet has been the subject of meta-analyses and is between 1.1 kg/d (Lean et al., 2019) and 1.7 kg/d (Santos et al., 2019). These responses were based on relatively short periods, but there is strong evidence that the responses persist throughout lactation.

The cost of feeding a commercial lead feed, whether it be a low DCAD or a zeolite A based feed, ranges from $1.80 to $2.50 per cow per day. Current recommendation for these approaches is to feed the rations for 21 days (for low DCAD) and 14 days (for zeolite A) prior to calving, which equates to a cost of $3,500 to $3,800 per 100 cows. Based on this, the milk production gains from a low DCAD diet are expected to recoup the costs of a transition cow program in 40 to 60 days excluding any consideration of improvements in animal health or reproduction. Goff (2020) estimated the return on investment (ROI) of an acidogenic salts-based transition cow program, estimated on increased milk production alone, to be 5:1.

The average prevalence of cows treated for milk fever in Australia has been estimated to be between 5% (Beggs et al., 2015) and 10% (Brunner et al., 2019). Reducing this to 1%, an achievable target, (see Table 1.2, Chapter 1) will recoup a third to three quarters of the cost of a well-structured transition cow program without considering the reduction in relative risk of dystocia, retained placenta, ketosis, left displaced abomasum (LDA) and mastitis that is related to improved milk fever control (Curtis et al., 1985). Additional steps to reduce the risk of LDA are outlined in Table 12.3.

The cost of poor reproductive performance has been extensively reviewed by InCalf (Dairy Australia, 2017) and the reader is referred to these projects for more information. Reproductive gains from transition cow feeding are in the order of 2.5 to 5% improvement in 6-week in-calf rate and 21-week not-in-calf rate (DeGaris et al., 2010) which, according to InCalf figures, equates to approximately $2,400 to $4,800 per 100 cows.

Table 12.3 Steps to reduce displaced abomasum

Intervention	Fibre/Chop Length	Concentrates	Beware of toxins	Water
Critical comment	Ensure hay/straw, grass silage at least 2.5cm in length maize silage at least 2cm.	Limit the amount of concentrate to typically less than 25 to 30% of dry matter intake (DMI).	Spoiled silage will destroy the rumen mat and put cows off feed.	Check to ensure quality is high and cows are drinking.
Other comments	Low to moderate DCAD pasture is a good inclusion, but balance for DCAD.	Slower fermenting grains are safer. Step up grain after calving steadily, if possible.	Do not feed poor quality silage.	Where practical a post-calving drench with at least 20L of water, calcium propionate and electrolytes can help.
Other considerations	Balance concentrate intake.	Check the Non-Fibre Carbohydrates (NFC) of the diets as maize silages and some hays can increase this.	Check pastures and silages for toxins and exclude spoiled feeds.	
Feeding period	From -21 to 30 days in milk (DIM).	-21 to 0 DIM.	-21 to 305 DIM	-21 to 305 DIM

APPENDIX A

INTERPRETING FOREST PLOTS

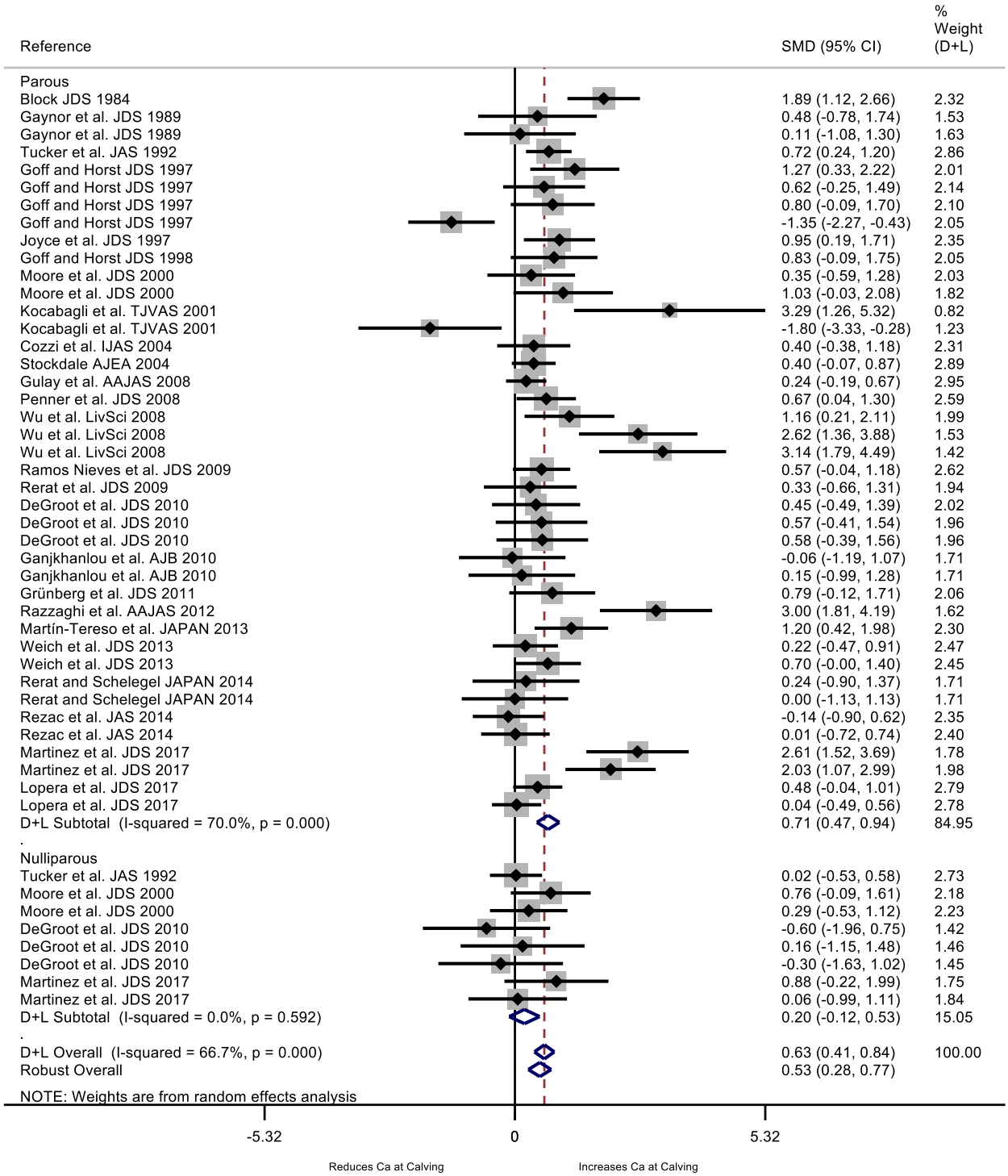
Forest plots are typically used to display epidemiological data and are often used in subject area reviews to summarize previously published findings.

The Forest plot contains the names of the authors of the comparisons between a treatment and control group and the year in which that study was conducted. Sometimes the comparisons may be grouped, for example, by parity.

Each comparison produces an estimate of the difference in response. For example, in Figure AA.1 below, the outcome is plasma calcium; most studies improved this as indicated by most boxes being the right of zero (indicated by the thick, black, vertical line). This is consistent with the X-axis label 'Increases calcium (Ca) at Calving'.

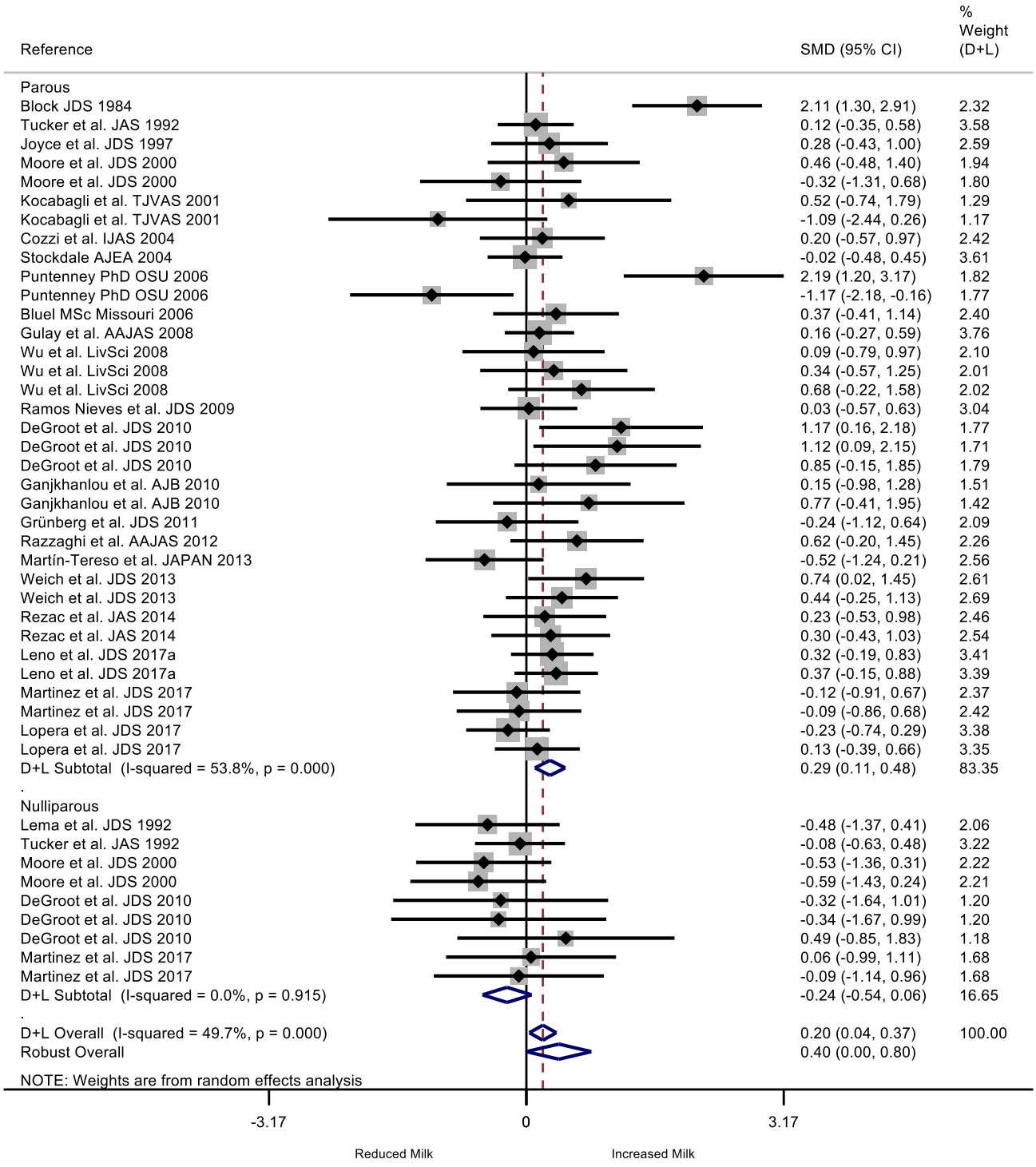
The larger the box and the smaller the whisker running through it, the more effect that a study has on the estimate. The effect of a study is a combination of the number of animals used and the variation in response. Large studies with less variance have more weight and a larger box with shorter whiskers. The pooled effects are illustrated by the diamonds; these are the DerSimonian and Laird meta-analytical models (DerSimonian and Laird, 1986), the Robust estimates or Knapp-Hartung (rarely used here). The Robust estimate is preferred as it is more conservative. The DerSimonian and Laird meta-analytical model (DerSimonian and Laird, 1986) is useful to compare within a plot (e.g. Figure AA.2 Milk yield differences with parity). Lastly, the heterogeneity number I^2 provides an indication of residual study variation. The greater the variation, the less robust the result.

Figure AA.1 Effect of a lowered DCAD intake on calcium in plasma at calving in parous and nulliparous dairy cattle (Lean et al., 2019; Santos et al., 2019).



Each square around the point effect represents the mean effect size for that study and reflects the relative weighting of the study to the overall effect size estimate. The larger the box, the greater the study contribution to the overall estimate. The weight that each study contributed are in the right-hand column. The overall pooled effects size or SMD and 95% CI pooled using the DerSimonian and Laird (D + L; DerSimonian and Laird, 1986) and Robust meta-analytical models methods for random effects models are indicated by the respective diamonds at the bottom. The heterogeneity measure, I^2 is a measure of variation beyond chance among treatments included in the meta-analysis. Calcium in plasma was substantially heterogeneous as indicated by the I^2 of 66.7%, indicating variability in the positive response.

Figure AA.2 Effect of a lowered dietary cation to anion difference (DCAD) intake on milk yield in parous and nulliparous dairy cattle.



The overall pooled effects size or SMD and 95% CI pooled using the DerSimonian and Laird (D + L; DerSimonian and Laird, 1986) and Robust meta-analytical models methods for random effects models are indicated by the respective diamonds at the bottom. Milk yield was moderately heterogeneous as indicated by the I^2 of 49.7%.

APPENDIX B

GUIDELINES FOR FORMULATING LOW DCAD DIETS

The following guidelines are useful when formulating or troubleshooting transition diets and management. Given the multivariable nature of hypocalcaemia and other benefits of correct transition diets, care should be taken not to crudely apply rules of thumb, but to evaluate the diets in total.

Guideline	Notes
Analyse available feeds for macromineral content using wet chemistry methods.	Near infrared (NIR) analysis can be unreliable for determination of mineral composition of forages.
Select feed ingredients that have a low DCAD and calcium.	Target less than 0 mEq/kg. Potassium strongly influences DCAD. Of importance are forages that are low in potassium (ideally less than 2.0%) as well as calcium (target 0.5 to 0.7%). Note that many ryegrass pastures will exceed 2.0% potassium. Select forages that allow adaptation of the cow's rumen to the early lactation diet. It is essential to avoid effluent treated pastures.
Formulate ration to deliver a positive energy and protein balance without placing cows at risk of ruminal acidosis and lactic acidosis. Cows ~1100 to 1200 g metabolisable protein (MP) per day (14-16% crude protein) Heifers ~1300 to 1400 g MP per day for heifers (14-16% crude protein)	Consider strategies that minimise this risk of ruminal acidosis, such as the use of rumen modifiers and fibre, limiting non-fibre carbohydrates (NFC) to 36%, ensuring the NDF is at least 36% of DM, and physically effective fibre is at least 25% of DM. This will necessitate the inclusion of 3 to 5kg of concentrate per cow per day. Do not use straw or poor-quality hays as a substantial source of forage as energy density is insufficient for maintenance. Note that many farms successfully feed 3 to 4kg of concentrate during the transition period.
Calculate DCAD and adjust as required, aim for less than 0 mEq/kg DM. To do this, include formulated acidogenic feeds. If possible, target -100 mEq/kg DM.	A way of achieving this is to include formulated acidogenic feeds such as a commercial lead feed pellet (e.g. 3kg) or concentrate (e.g. 1kg). Mineral acid treated lead feed products (e.g. BioChlor/SoyChlor) lower the DCAD but also increase microbial protein production. Alternatively, add magnesium sulphate ($MgSO_4$) up to 100 grams per cow per day.
Balance sodium for cow requirements	Target 0.12% DM.
Balance sulphur (to ensure substrate for microbial protein synthesis)	Target 0.4% DM but be cautious with higher concentrations. High dietary sulphur concentrations could place cows at risk of disease (polioencephalomalacia). Use $MgSO_4$ up to 100 grams per cow per day.
Balance magnesium	Target is at least 0.45% DM. If magnesium concentration is still low, add magnesium chloride ($MgCl_2$) up to a combined inclusion rate with $MgSO_4$ of 100 grams per cow per day. If magnesium is still needed, balance with magnesium oxide (MgO).
Balance calcium concentration if necessary, using calcium sulphate ($CaSO_4$), calcium chloride ($CaCl_2$) if DCAD is still too high or limestone if DCAD is already less than 0 mEq/kg DM.	This will rarely be necessary as calcium concentration needs to be kept around 0.5 to 0.7% DM. Note that calcium chloride (CaCl2) is very irritant and unpalatable and may reduce dry matter intake (DMI). Be careful, calcium can occasionally be high in cereal hays. Consider raising the calcium concentration of the diet only if it is low (i.e. less than 0.25 to 0.35%) as these diets may result in significant depletion of bone stores, particularly if cows are spending an extended time on the transition diet.
Check phosphorus concentration	Target is 0.25% to 0.4% phosphorus. Additional sources of phosphorus will rarely be required. High phosphorus feeds may need to be reduced in diet.
Check potassium concentration	This should be at least 1.1% but not more than 2.0% to allow for daily requirements of the cow. As a rough guideline, the potassium concentration should be about four times the magnesium concentration. If this ratio is higher (i.e. potassium is greater than 1.8%), consider reducing the high potassium feeds in the diet.
Check chloride concentration	As a guideline, the chloride concentration of the diet is usually about 0.5% lower than the potassium concentration.

Guideline	Notes
Check DCAD	Check DCAD. This should now be around -100 mEq/kg DM. If DCAD is greater than 0 mEq/kg DM go back to the second step and start again.
Ensure free access to high quality water	Low quality water may contribute to poor dry matter intake (DMI) and interfere with micromineral content of the overall diet.
Ensure adequate access to concentrates and hay/silage sources to minimise competition.	A minimum of 75cm of trough space per cow is required.
Ensure thorough mixing of acidogenic salts or commercial lead feeds.	
Ensure pasture intakes are estimated as accurately as possible.	Daily pasture intakes are estimated as accurately as possible considering daily growth which may be significant in some regions (e.g. kikuyu during summer months). Average pasture intake per cow can be estimated as follows:
Intake = [(area of paddock (ha) x (kg DM/ ha in paddock pre-grazing) – (kg DM/ha in paddock post grazing)]/number of cows in paddock	
Ensure heifers are integrated into transition herd at this stage to minimise competition issues after calving.	
Ensure as many as possible of the post-calving feed ingredients are included in the pre-calving diet.	
Aim to have cows on the low DCAD transition diet for 21 days. Requires accurate pregnancy test data.	

APPENDIX C

GUIDELINES FOR FORMULATING LOW CALCIUM ZEOLITE A DIETS

Guideline	Notes
Analyse available feeds for macromineral content using wet chemistry methods.	Near infrared (NIR) analysis can be unreliable for determination of mineral composition of forages.
Select feed ingredients that are low in calcium.	Target 0.5% to 0.7%. Select forages that allow adaptation of the cow's rumen to the early lactation diet. It is essential to avoid effluent treated pastures.
Formulate ration to deliver a positive energy and protein balance without placing cows at risk of ruminal acidosis and lactic acidosis. Cows ~1100 to 1200 g metabolisable protein (MP) per day (14-16% crude protein) Heifers ~1300 to 1400 g MP per day for heifers (14-16% crude protein)	Consider strategies that minimise this risk of ruminal acidosis, such as the use of rumen modifiers and fibre, limiting non-fibre carbohydrates (NFC) to 36%, ensuring the NDF is at least 36% of DM, and physically effective fibre is at least 25% of DM. This will necessitate the inclusion of 3 to 5kg of concentrate per cow per day. Do not use straw or poor-quality hays as a substantial source of forage as energy density is insufficient for maintenance. Note that many farms successfully feed 3 to 4kg of concentrate during the transition period.
Include zeolite A	Include 500g per cow per day of zeolite A mixed in a total mixed ration or partial mixed ration (PMR) or in at least 3kg of concentrate.
Balance sodium for cow requirements	Target 0.12% DM
Balance sulphur (to ensure substrate for microbial protein synthesis)	Target 0.4% DM but be cautious with higher concentrations. High dietary sulphur concentrations could place cows at risk of disease (polioencephalomalacia). Use $MgSO_4$ up to 100 grams per cow per day.
Balance magnesium	Target is at least 0.45% DM. If magnesium concentration is still low, add magnesium chloride ($MgCl_2$) up to a combined inclusion rate with $MgSO_4$ of 100 grams per cow per day. If magnesium is still needed, balance with magnesium oxide (MgO).
Check calcium content of ration	Target is below maintenance levels (approximately 2% DM or 20 to 25 grams per cow per day). Note that it is not clear how much calcium 500g of zeolite A is capable of binding. Zeolite A will bind 110 mg calcium per gram of zeolite at a pH of 11.
Check phosphorus concentration	Target is 0.25% to 0.4% phosphorus. Additional sources of phosphorus will rarely be required. High phosphorus feeds may need to be reduced in diet.
Check potassium concentration	This should be at least 1.1% but not more than 2.0% to allow for daily requirements of the cow. As a rough guideline, the potassium concentration should be about four times the magnesium concentration. If this ratio is higher (i.e. potassium is greater than 1.8%), consider reducing the high potassium feeds in the diet.
Check chloride concentration	As a guideline, the chloride concentration of the diet is usually about 0.5% lower than the potassium concentration.
Ensure free access to high quality water	Low quality water may contribute to poor dry matter intake (DMI) and interfere with micromineral content of the overall diet.
Ensure adequate access to concentrates and hay/silage sources to minimise competition.	A minimum of 75cm of trough space per cow is required.
Ensure thorough mixing of zeolite A in concentrate or TMR/PMR to ensure uniform intake.	
Ensure pasture intakes are estimated as accurately as possible.	Daily pasture intakes are estimated as accurately as possible considering daily growth which may be significant in some regions (e.g. kikuyu during summer months). Average pasture intake per cow can be estimated as follows: Intake = [(area of paddock (ha) x (kg DM/ha in paddock pre-grazing) – (kg DM/ha in paddock post grazing)]/number of cows in paddock

Guideline	Notes
Ensure heifers are integrated into transition herd at this stage to minimise competition issues after calving.	
Ensure as many as possible of the post-calving feed ingredients are included in the pre-calving diet.	
Aim to have cows on the low calcium transition diet for 14 days. Additional attention is needed to ensure far off dry cows are receiving a diet that meets their nutritional requirements for energy, protein, minerals and vitamins.	

APPENDIX D

EXAMPLES OF LOW AND HIGH MILK FEVER PRE-CALVING DIETS

a) LOW risk diet																
		Na		K		S		Cl		DCAD	Ca		P		Mg	
Feed ingredient	kg DM	%	g/d	%	g/d	%	g/d	%	g/d	mEq/ kg DM	%	g/d	%	g/d	%	g/d
Ryegrass silage	4.00	0.63	25.20	3.63	145.20	0.19	7.60	1.70	68.00	600	0.59	23.60	0.32	12.80	0.17	6.80
Wheat hay	2.30	0.08	1.84	2.34	53.82	0.11	2.53	1.12	25.76	250	0.19	4.37	0.29	6.67	0.08	1.84
Kikuyu pasture	2.00	0.10	2.00	3.39	67.80	0.24	4.80	1.96	39.20	210	0.50	10.00	0.42	8.40	0.20	4.00
Wheat	2.70	0.00	0.00	0.42	11.34	0.13	3.51	0.12	3.24	-10	0.06	1.62	0.36	9.72	0.12	3.24
Lupins	0.90	0.50	4.50	0.82	7.38	0.20	1.80	0.08	0.72	280	0.29	2.61	0.33	2.97	0.14	1.26
1kg commercial acidogenic concentrate	1.00	1.14	11.40	1.37	13.70	4.14	41.40	6.57	65.70	-3590	0.18	1.80	0.99	9.90	2.13	21.30
Limestone	0.03	0.06	0.02	0.12	0.04	0.04	0.01	0.03	0.01	20	33.00	9.90	0.02	0.01	206	0.62
Magnesium oxide	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	3.07	0.92	0.00	0.00	54.00	16.20
Total diet	12.96	0.35	44.96	2.31	299.28	0.48	61.65	1.56	202.63	0	0.42	54.82	0.39	50.47	0.43	55.26

This diet is LOW risk:

- DCAD is 0 mEq/kgDM
- Ca is close to 0.5% DM as recommended.
- P is very close to max. 0.4% DM as recommended
- Mg is very close to min 0.45% DM as recommended

b) HIGH risk diet (using feeds and minerals typically used in a milker diet)																
		Na		K		S		Cl		DCAD	Ca		P		Mg	
Feed ingredient	kg DM	%	g/d	%	g/d	%	g/d	%	g/d	mEq/ kg DM	%	g/d	%	g/d	%	g/d
Kikuyu pasture	2.00	0.10	2.00	3.39	67.80	0.24	4.80	1.96	39.20	208	0.5	10.00	0.42	8.40	0.20	4.00
Ryegrass silage	4.00	0.63	25.20	3.63	145.20	0.19	7.60	1.70	68.00	604	0.59	23.60	0.32	12.80	0.17	6.80
Wheat hay	2.30	0.08	1.84	2.34	53.82	0.11	2.53	1.12	25.76	249	0.19	4.37	0.29	6.67	0.08	1.84
Wheat	2.70	0.00	0.00	0.42	11.34	0.13	3.51	0.12	3.24	-8	0.06	1.62	0.36	9.72	0.12	3.24
Lupins	0.90	0.50	4.50	0.82	7.38	0.20	1.80	0.08	0.72	280	0.29	2.61	0.33	2.97	0.14	1.26
Limestone	0.06	0.06	0.04	0.12	0.07	0.04	0.02	0.03	0.02	23	37	22.20	0.00	0.00	2.06	1.24
Magnesium oxide	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0	0.00	0.00	0.00	58.00	11.60
Sodium bicarbonate	0.06	27	16.20	0.00	0.00	0.00	0.00	0.00	0.00	11744	0	0.00	0.00	0.00	0.00	0.00
0.5kg commercial milker premix	0.50	6.6	33.00	0.4	2.00	0.15	0.75	0.12	0.60	2846	6	30.00	2.40	14.00	3.00	15.00
Total diet	12.50	0.66	82.80	2.29	287.60	0.17	21.00	1.10	137.5	460	0.75	94.40	0.43	54.60	0.36	45.00

This diet is HIGH risk:

- DCAD is highly positive
- Calcium is above recommended max. 0.7% DM
- P is above recommended max. 0.4% DM
- Mg is below recommended min. 0.45% DM
- Contains sodium bicarbonate which has a very high DCAD

STEPS TO CALCULATE DCAD

1. Analyse all feed ingredients for nutrient and mineral content using wet chemistry methods for minerals.
2. Calculate relative contribution of each feed to total diet mineral content (g/day).
3. Sum total g/d for each mineral delivered in diet.
4. Calculate percentagae of each mineral in total diet.
5. Calculate DCAD in mEq/KgDM using [(Na%* 434.98) + (K%*255.74)] - [(Cl%*282.06) + (S%*623.75)]

APPENDIX E

METABOLIC ADAPTIONS TO CALVING

There have been major recent advances in understanding the metabolic changes that occur over calving. These include the recognition and better understanding of:

- The links between skeleton and energy metabolism
- The roles of serotonin and the mammary gland in vitamin D and calcium metabolism
- The actions of vitamin D
- The role of inflammation that can be both positive and negative

Many of the changes in hormone metabolism before calving were described by Bauman and Currie (1980) and Bell (1995). Bauman and Currie (1980) noted the following adaptive changes to lactation:

- Increased lipolysis (breakdown of fats)
- Decreased lipogenesis (fat synthesis)
- Increased gluconeogenesis (glucose synthesis)
- Increased glycogenolysis (breakdown of glycogen to provide energy)
- Increased use of lipids and decreased glucose use as an energy source
- Increased mobilisation of protein reserves
- Increased absorption of minerals and mobilisation of mineral reserves
- Increased dry matter intake and increased absorptive capacity for nutrients

Examining the homeorhetic and homeostatic responses to lactation assists in understanding the factors influencing the risk of disease. The following hormones influence the initiation of lactation and are associated with profound changes in metabolism.

Progesterone and oestrogens

The precipitous decrease in plasma progesterone levels that occurs at calving (Delouis et al., 1980) is a key stimulus for the onset of milk production (Cowie et al., 1980, Kuhn, 1983). Oestrogen levels increase rapidly in the last week of gestation and may play an important role in the initiation of lactation (Erb, 1977).

Prolactin and placental lactogen

Prolactin is important to the development of the mammary gland prior to lactation in cattle (Akers et al., 1981). However, in dairy cattle, prolactin does not appear to play an important role in the maintenance of lactation (Plaut et al., 1987).

Somatotropin

Somatotropin plays a key lactogenic role in the bovine as evidenced by milk production responses to exogenous somatotropin (Asimov and Krouse, 1937, Bauman et al., 1985) and the positive relationships between production and somatotropin levels in comparisons of high and low yielding cattle (Hart et al., 1978, Hart et al., 1979). These studies and those finding that genetic selection for high milk yield is associated with higher somatotropin levels (Barnes et al., 1985, Kazmer et al., 1986), provide evidence that somatotropin is possibly the most important hormonal determinant of increased milk yield in cattle.

Evidence of the importance of somatotropin is provided in Table 1.3 (Chapter 1). There are also links between bone hormones and IGF-1; which are a critical part of the somatotropic axis that increases milk production (Rodney et al., 2018b).

Increased somatotropin triggers release of IGF-1 in well-fed cows. IGF-1 markedly increases milk production through a series of co-ordinated changes in metabolism.

Insulin and glucagon

These hormones play a central role in the homeostatic control of glucose. There is evidence, however, that expected responses to insulin are not found in early lactation; this concept requires revisiting considering recent studies (Martinez et al. 2014).

A transitory hyperglycaemia occurs at calving, but does not appear to stimulate insulin release (Blum et al., 1973, Schwalm and Schultz, 1976). Hove (1978) found evidence that the insulin responses of hypoglycaemic and ketonaemic cows were less to both glucose infusions and feeding than normal cows. Metz and van den Berg (1977) found that the response of adipose tissue to insulin in the periparturient cow was altered, as insulin addition did

not reduce rates of lipolysis in vitro. Lipogenic activities of adipocytes were reduced by one third following calving (Pike and Roberts, 1980). However, Martinez et al. (2014) used an induced hypocalcaemia protocol to demonstrate that hypocalcaemic cows were insulin resistant and that this increased dependence on NEFA mobilisation and ketone production during the period of hypocalcaemia. The hypocalcaemic cows had impaired immunocyte function.

It is very likely that diets used in earlier studies had a positive DCAD. The positive DCAD probably caused hypocalcaemia and an incorrect interpretation of responses i.e. that all cows are insulin resistant post-calving. It is very probable that periparturient cows will be sensitive to insulin if they are normocalcaemic.

There is a clear physiological link between low blood calcium and increased risk of lipid mobilisation and ketosis and impaired immune function; cows around calving may not be insulin resistant if they have normal blood calcium concentrations.

Glucagon plays a gluconeogenic role in the bovine (Brockman, 1984, De Boer et al., 1986), but may not stimulate lipolysis to the same extent as in non-ruminant species (Etherton et al., 1977).

Thyroid hormone

The role of thyroid hormone in lactation is still being defined. Thyroid hormone has a lactogenic function either when supplied orally or when injected (Davis et al., 1987, Davis et al., 1988a, Davis et al., 1988b) and has been used in experimental protocols to induce ketosis (Hibbitt, 1966). However, thyroxine levels either decrease or are unchanged following calving (Bines and Hart, 1978, Walsh et al., 1980, Blum et al., 1983). Thyroxine concentrations do not appear to follow systematic daily trends or increase with food deprivation (Bines et al., 1983) and are negatively correlated with changes in milk yield (Hart et al., 1979). Thyroid releasing hormone can also increase milk yield and releases somatotrophin (Bourne et al., 1977, Smith et al., 1977, Beck and Tucker, 1979).

Glucocorticoids

Glucocorticoids are important in parturition, the initiation and maintenance of lactation (Delouis et al., 1980). Plasma cortisol concentrations increase in the immediate periparturient period and are associated with a transient hyperglycaemia at calving.

Bone hormones

While bone metabolism has always been considered to be important in the adaptations to lactation, it is now clear that it has a pivotal role in the homeorhetic adaptations to lactation mediated through links between bone, energy and protein metabolism, fat deposits and brain peptides (Figure AE.1). Studies in mice identified these links (Lee et al., 2007) and many of these have been identified in humans (Wolf, 2008) and cattle (Lean et al., 2014a, Rodney et al., 2018b).

Osteocalcin (OC) is produced by mature osteoblasts (OB) and is important in bone matrix calcification and mineralisation (Davicco et al., 1992). There are two forms of OC; a carboxylated form of OC (cOC) with a high affinity for bone which has been considered biologically inactive, and an uncarboxylated, active form (uOC). The transformation from OC to the more metabolically active uOC is favoured by acidic conditions in the lacunae of bone and depends on vitamin K.

Uncarboxylated OC is released during bone mobilisation and promotes pancreatic β-cell proliferation and insulin secretion, independently increases peripheral tissue insulin sensitivity to increase glucose uptake, and stimulates adiponectin secretion by adipose cells (Lee et al., 2007). Rodney et al. (2018b) found very strong associations between both forms of OC and IGF-1 and with blood glucose, suggesting that in cattle both forms of OC may be active.

Fat cell hormones

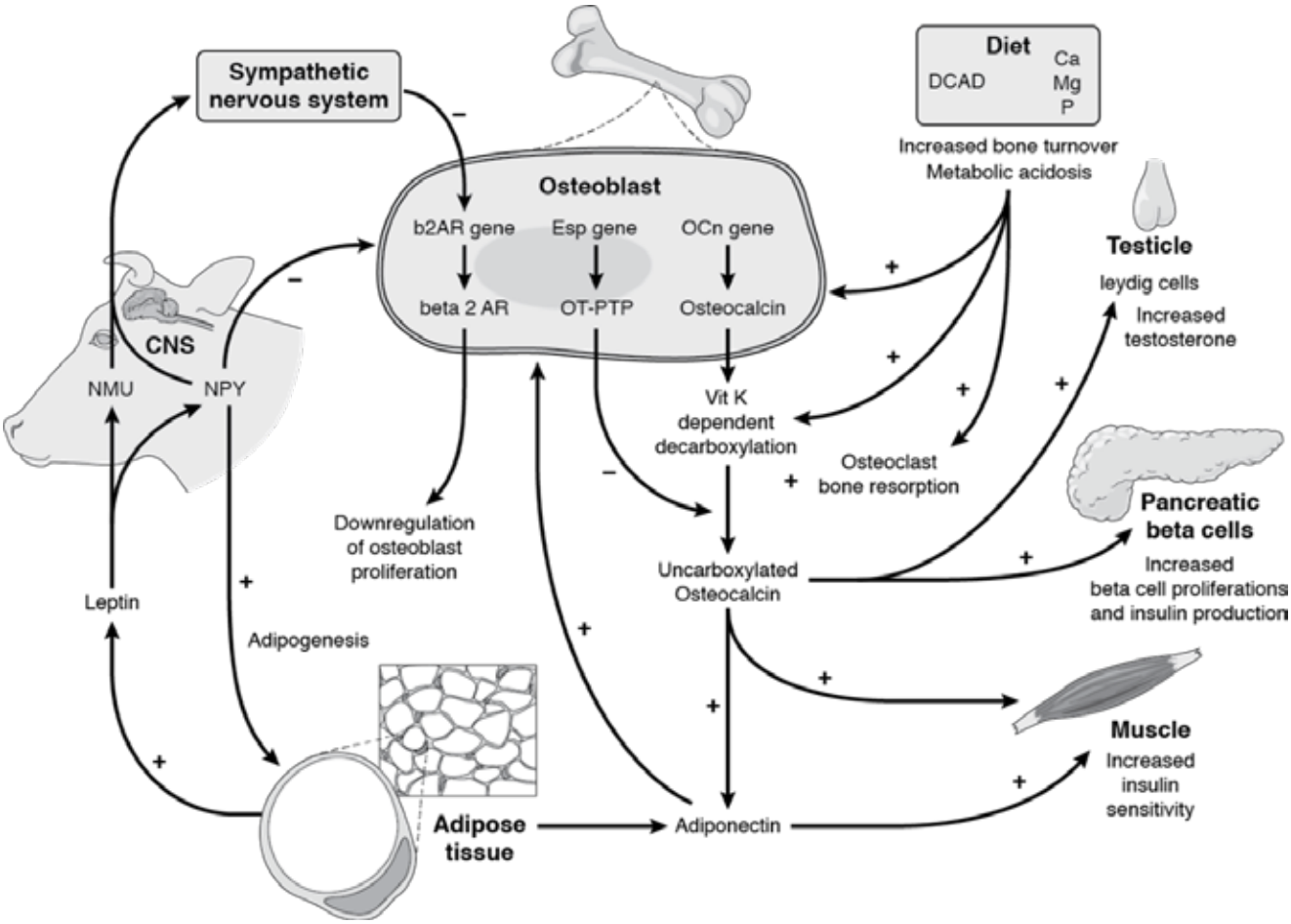
As often happens with metabolism, there is a feedback loop to reduce the risk that processes get out of control. In this case, feedback to control bone mobilisation is exerted through fat cell hormones and brain peptides.

The hormone adiponectin, produced by adipose tissue, muscle and the brain, increases OB proliferation and differentiation (Berner et al., 2004) and increases bone deposition (Kanazawa et al., 2007). Further, adiponectin increases glucose uptake by skeletal muscle and may suppress hepatic gluconeogenesis (Yamauchi et al., 2002). Rodney et al. (2018b) were not able to detect these effects in cattle.

Leptin, produced by adipocytes, acts to inhibit bone mass accrual through the action of the sympathetic nervous system on osteoblast b2-AR receptors after central processing involving neuropeptide Y (NPY) and neuromedian U to inhibit osteoblast activity (Takeda et al., 2002). Neuropeptide Y acts directly to inhibit OB and stimulate adipogenesis through non-hypothalamic Y1 receptors (Baldock et al., 2007). These actions help provide the feedback to control bone resorption and the effects of the bone hormones on metabolism. These mechanisms are supported by the observations that cattle in high BCS (greater than 4 out of 5) are at greater risk of milk fever.

Figure AE.1. modified from Wolf (2008) shows the relationships between skeleton and energy metabolism. The potential role for acidifying or negative dietary cation anion difference diets has been included and the effects of skeleton on reproductive metabolism, identified to date, are outlined.

Figure AE.1 The relationship between skeleton and energy metabolism (from Lean et al., 2014)



Vitamin D

The role of vitamin D has undergone a considerable increase in understanding over recent times, however, a pivotal moment was the Australian discovery of the hormonal action of the vitamin (Fraser and Kodicek, 1970, Lawson, 1971).

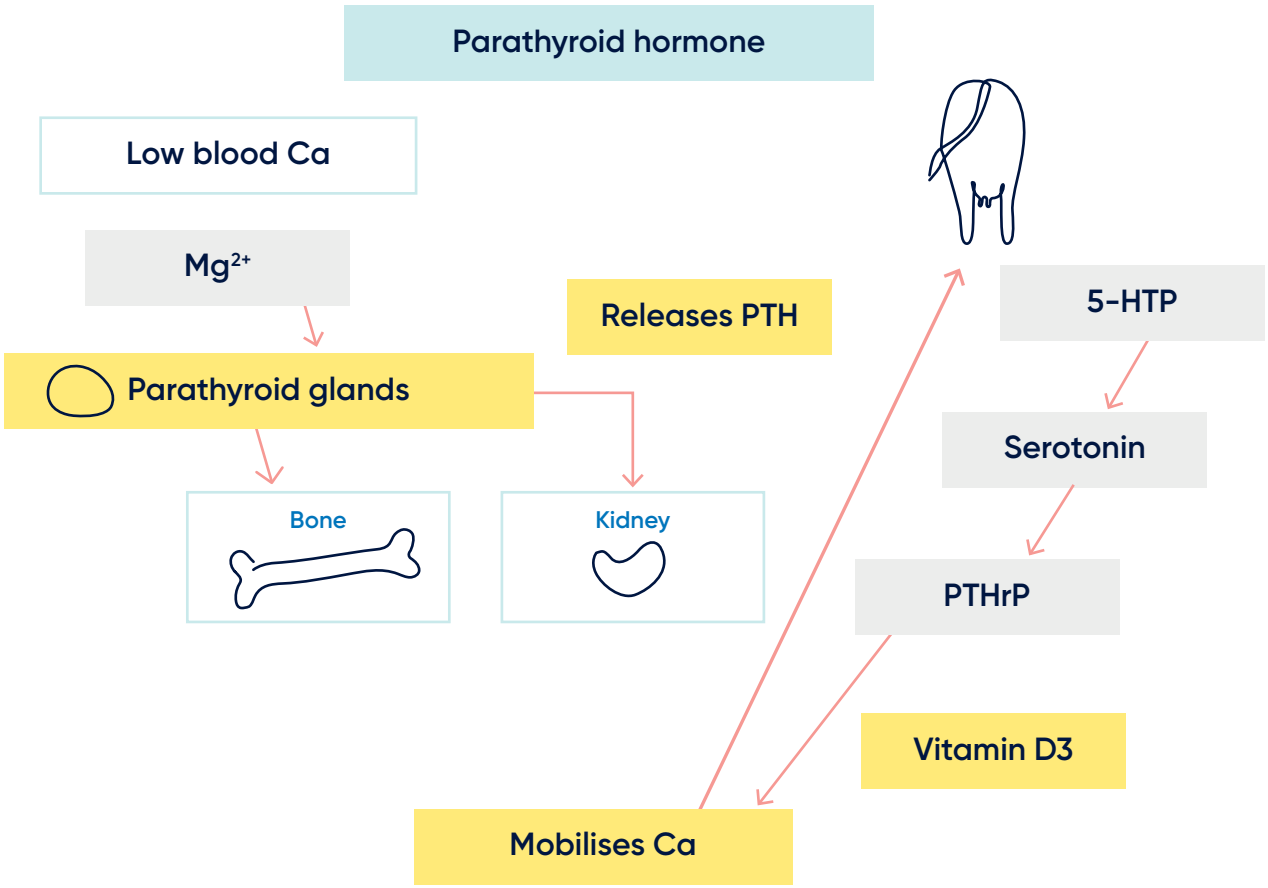
In regions with ample sunlight, vitamin D synthesis is initiated in the epithelial cells from acetate producing 7-dehydrocholesterol. Exposure to ultra-violet light produces vitamin D_3 (cholecalciferol), which is then converted to 25-hydroxyvitamin D_3 (calcidiol) in the liver. This is converted in the kidney to calcitriol which is the most active form of the vitamin (Figure AE.1).

There is evidence that calcidiol acts both as a storage form of vitamin D and may have an active role in metabolism, itself. Cows can obtain vitamin D_2 from their forages and fungi, but this may not be efficiently converted to the active forms of vitamin D.

Perhaps the most important role of vitamin D is to increase uptake of calcium from the intestine through upregulation of a calcium binding protein. However, the roles of vitamin D extend well beyond this; rickets is prevented by providing vitamin D and calcium and vitamin D are intimately involved in the maintenance of blood calcium and phosphorus levels and immune function (Nelson et al., 2016).

The hormonal actions of vitamin D are regulated through feedback mechanisms (Wilkens et al., 2020). The presence of calcitriol inhibits production of the 1-α hydroxylase (CYP27B) that converts cholecalciferol to calcidiol. The calcitriol also produces fibroblast growth factor 23 that acts to decrease plasma concentrations of calcitriol. Figure AE.2 shows the pathways that influence vitamin D and calcium metabolism. Importantly, magnesium Mg^{2+} is required for parathyroid hormone (PTH) release and that 5-hydroxytryptophan (5HT) is a precursor for serotonin and PTH releasing peptide.

Figure AE.2 Pathways that influence vitamin D and calcium metabolism



Serotonin

A further series of pathways have been identified that influence calcium status around calving (Laporta et al., 2015; Wilkens et al., 2020). These relate to the controls over calcium excretion in the mammary gland but have a wider influence on calcium metabolism. While the clinical significance of these pathways is yet to be determined, their existence adds an important new dimension to our understanding of calcium metabolism. Figure AE.2. provides details on these pathways.

Tryptophan is an essential amino acid primarily provided in forage, especially high protein grasses and legumes. The amino acid is converted into 5-hydroxytryptophan by hydroxylation and then to serotonin by decarboxylation in tissues including liver, nervous tissue, and the mammary gland. Serotonin stimulates release of parathyroid hormone (PTH) releasing peptide (PTHrP) in the mammary gland and infusions of 5-hydroxytryptophan (5HT) have reduced calcium concentrations in blood (Laporta et al., 2015, Hernández-Castellano et al., 2017), increased calcium concentrations in milk and lowered calcium loss in urine. Further, blood glucose concentrations increased while NEFA and BHB were lower with treatment in the Laporta et al. (2015) study. This pathway has the potential to influence calcium metabolism through PTHrP influencing PTH release and possibly by increased calcium loss through milk. It is possible that these pathways are independent of responses to vitamin D as supplementation with calcidiol did not influence blood serotonin concentrations in peri-parturient cows (Rodney et al., 2018a). In some species this pathway may be more important than the PTH-vitamin D pathway (Wilkens et al., 2020).

Calcitonin

While calcitonin plays a role in calcium metabolism, questions remain with regards to its importance. Calcitonin is released from cells within the thyroid gland. When calcium concentrations increase, calcitonin concentrations increase and there is an increase in calcium deposition in bone. Interestingly, increased plasma calcitonin concentrations were identified in cows with blood calcium concentrations of 1.5 to 1.85 mmol/L (Rodríguez et al., 2016). It is possible that calcitonin acts to protect maternal calcium stores in bone, but further studies are needed to evaluate this possibility.

APPENDIX F

SUGGESTED DEFINITIONS FOR COMMON CONDITIONS OF DAIRY CATTLE

Modified from Lean et al. 2015

Condition	Definition	Reference	Validation of definition, concerns and comments
Clinical hypocalcaemia ('milk fever')	Blood Ca less than 1.8 mmol/L, accompanied by weakness, recumbency, muscle fasciculation, depressed mentation.	Horst et al. (1997) Ender et al. (1971)	Ender et al. (1971) experimentally induced clinical signs of hypocalcaemia at these concentrations during comprehensive calcium balance studies. Clinical signs are not always present below this threshold.
Subclinical hypocalcaemia	Circulating concentrations of calcium demonstrated to be associated with unfavorable outcomes, unaccompanied by clinical signs of hypocalcaemic disease.	Roberts et al. (2012)	A retrospective cohort study by Roberts et al. (2012) identified serum Ca less than 2.0 mmol/L in week 1 postpartum (pp) was associated with increased odds of culling less than 60 days in milk.
		Chapinal et al. (2011)	Less than 2.2 mmol/L in week 1 postpartum associated with increased risk of displaced abomasum; decreased conception rate at 1st AI
		Chapinal et al. (2012)	Less than 2.1mmol/L in week 1 postpartum was associated with decreased milk at first herd test
		Martinez et al. (2012)	Less than 2.15 mmol/L in the first three days postpartum was the optimal cutpoint describing risk of metritis
Subclinical ketosis (hyperketonemia)	Circulating concentrations of ketone bodies associated with unfavorable outcomes but without the presence of clinical signs of ketosis. Thresholds commonly range from 1.0 to 1.4 mmol/L beta-hydroxybutyrate (BHB) in blood or serum depending on the outcome considered, assay used and the timing of sampling in reference to calving *Suggested threshold values for serum biochemistry:* serum BHB greater than 1.0mmol/L week 1 after calving (Note: Enzymatic assay)	Lean et al. (1994)	Lean et al. (1994) and Ospina et al. (2010) note the limitations of using arbitrary thresholds for defining ketotic states in the postpartum cow. Lean et al. (1994) defined ketonemic cows as those with lower blood glucose, higher NEFA and higher BHB than other cows. *Serum BHB threshold and outcome*
		Ospina et al. (2010)	Ospina et al. (2010) used a serum non-esterified fatty acids (NEFA) greater than 0.57mmol/L as a critical threshold for predicting the development of ketosis.
		Walsh et al. (2007)	Greater than 1.0 mmol/L in week 1 postpartum and/or Greater than 1.2 mmol/L in week 2 postpartum, reduced CR at 1st AI
		Walsh et al. (2006)	Greater than 1.0 mmol/L in week 1 postpartum increased risk to be anovular at week 9
		Dubuc et al. (2011)	Greater than 1.2 mmol/L in week 1 postpartum increased risk of subclinical endometritis
		Roberts et al. (2012)	0.7 mmol/L in week 1 before calving; greater than 1.2 mmol/L week 1 postpartum or greater than 1.6 mmol/L in week 2 postpartum increased risk of culling less than 60 days in milk.

Condition	Definition	Reference	Validation of definition, concerns and comments
Clinical ketosis	Inappetence, reduced milk production, central nervous depression, or excitation, with an excess of circulating ketone bodies, in the absence of a concurrent clinical illness (e.g. displaced abomasum or metritis) that may be the primary cause of ketosis	Baird (1982) Lean et al. (1994) Ospina et al. (2010)	The circulating concentration of ketone bodies at which clinical signs appear is variable. Lean et al. (1994) found that serum NEFA concentrations were the most predictive measure for clinical ketosis, which was associated with ketonaemia and clinical signs of disease. Serum NEFA concentrations for clinical ketosis (Lean et al., 1994) are consistent with Ospina et al. (2010) for sub-clinical ketosis.
Hypophosphatemia	Serum or plasma phosphorus concentration of 0.3 to 0.6mmol/L. Preliminary only.	Goff (2000)	Based on values defined in the literature (Goff, 2000). Note that there was no evidence of consequential failures in performance. Status preliminary.
Clinical hypomagnesaemia	*Clinical signs:* Hyperaesthesia, ataxia, recumbency, tetanic muscle spasms, depressed mentation. Potentially progressing to seizures, opistothonus and death. *Threshold value:* Serum Mg less than 0.5mmol/L Aqueous humor Mg less than 0.25mmol/L	McCoy et al. (2001) Alsop and Pauli (1985) Pauli and Alsop (1974)	McCoy et al. (2001), induced hypomagnesemic states in 10 lactating dairy cows. They determined that a serum aqueous humour Mg concentration of less than 0.25 mmol/L was consistent with the development of marked clinical signs including tetany and recumbency. Alsop and Pauli (1985) experimentally induced clinical signs of hypomagnesaemia at 0.5mmol/L.
Subclinical hypomagnesemia	Serum Mg less than 0.6mmol/L unaccompanied by clinical signs but associated with reduced milk production.	Martens and Schweigel (2000)	Martens & Schweigel (2000) note that low serum Mg does not lead to the development of clinical signs in all animals
Retained fetal membranes (retained placenta)	Failure of separation and expulsion of the placenta within 6 hours after calving. Because the exact time of calving is often unknown, a working definition of failure of expulsion of the placenta by 24 h after calving is acceptable.	Van Werven et al. (1992) Sheldon (2004)	Van Werven et al. (1992) systematically reviewed data on placental retention obtained from 1010 cows in 21 commercial dairy enterprises. Within 6 hours, 66% of dams and within 24, 85% had expelled their placentas. Based on production and reproduction outcomes, they proposed definition of retained placenta at 6 hours.
Displaced abomasum	*Clinical:* Persistent abnormal positioning of the abomasum, dorsally and laterally in the abdomen, typically with distension of the abomasum with gas. Clinical diagnosis is based on the presence of a high-pitched, left or right sided tympanic sound ('ping') under the 8th to 13th ribs. Definitive diagnosis is by exploratory laparotomy, revealing a gas- or fluid-filled abomasum that has migrated left or right and dorsally within the abdominal cavity.	Coppock (1973) Shaver (1997)	Coppock (1973) provided gross pathologic description of abomasal displacement based on a survey of 580 carcasses at a Michigan abattoir, in which 33 had the abomasal positions described.
Puerperal metritis	*Histologically:* Evidence of inflammation extending into all layers of the uterus (endometrium, submucosa, muscularis, serosa) *Clinically:* abnormally enlarged uterus and a fetid watery red-brown uterine discharge, associated with signs of systemic illness (decreased milk yield, dullness, or other signs of toxemia) and fever. Greater than 39.5 8oC, within 21 days after parturition	Sheldon et al. (2006)	This definition based on clinical signs is widely used, but the association of each sign with undesirable outcomes and the precision of the diagnostic techniques for these criteria require further validation (Sannman et al., 2012)

Condition	Definition	Reference	Validation of definition, concerns and comments
Clinical metritis	*Histology:* Evidence of inflammation extending into the endometrium, submucosa, muscularis, and serosa (i.e. not histologically distinguished from puerperal metritis). *Clinically*: not systemically ill but have an abnormally enlarged uterus and a fetid or purulent uterine discharge detectable in the vagina, within 21 days postpartum; no fever concurrent with fetid discharge.	Sheldon et al. (2006)	The thresholds of % polymorphonuclear cells (PMN) associated with decreased reproductive performance vary slightly between studies and with time (DIM) of diagnosis. From 28 to 60 days in milk, the threshold is consistently between 5 and 10% PMN (Barlund et al., 2008; Dubuc et al., 2010; Gilbert et al., 2005; Kasimanickam et al., 2004)
Endometritis	*Histologically:* Superficial inflammation of the endometrium, limited in extent to the stratum spongiosum. Some disruption of the surface epithelium is observed, together with infiltration of inflammatory cells and vascular congestion. *Cytologically:* A proportion of neutrophils (poly-morphonuclear (PMN) cells relative to total nucleated cells from an endometrial sample taken by cytobrush or uterine lavage that is associated with impaired reproductive performance (i.e. increased time to pregnancy): (greater than or equal to 6% PMN on cytology greater than 4 weeks postpartum	deBoer et al. (2014)	Based on values defined in the literature (Goff, 2000). Note that there was no evidence of consequential failures in performance. Status preliminary.
Purulent vaginal discharge (PVD)	Mucopurulent or purulent vaginal discharge greater than 3 weeks postpartum	Dubuc et al. (2010) deBoer et al. (2014)	PVD is repeatedly associated with reduced pregnancy rate but PVD is not synonymous with endometritis

Condition	Definition	Reference	Validation of definition, concerns and comments
Mastitis	*Microbiological:* Bacterial invasion of the mammary gland leading to an intra-mammary infection being established, often provoking an inflammatory response. A wide variety of pathogens are implicated in causing infection, and these may be cultured from milk expressed from the mammary gland. *Subclinical mastitis:* Clinical signs are absent and the mammary gland and milk appears grossly normal. Somatic cell count in milk is elevated (greater than 250,000 cells/ml). The bacterial agent responsible for infection may be cultured from expressed milk. *Mild clinical mastitis:* Visibly abnormal (watery, discolored, or containing flakes or clots) milk that persists past three strips. Systemic illness absent. No gross abnormalities (swelling, hardness, redness) of udder. The bacterial agent responsible for infection may be cultured from milk from the exposed quarter. The milk somatic cell count for milk produced from this animal will be elevated. *Moderate clinical mastitis:* Visibly abnormal milk and visibly abnormal udder (swelling, hardness, or redness) with little or no systemic illness; no more than one of the following signs: serum-colored mammary secretion, decreased ruminal contractility, dehydration, elevated temperature, increased heart rate, increased respiratory rate. Bacteria may be cultured from expressed milk, and cell count will be elevated. *Severe clinical mastitis:* Visibly abnormal milk and udder and systemic illness with two or more of the following signs (fever, tachycardia, tachypnea, dehydration, reduced rumen motility). Potential presence of endotoxaemia or in the most severe/advanced cases, recumbency. Bacteria may be cultured from expressed milk, and cell count will be elevated.	Martens and Schweigel (2000)	Roberson (2012) evaluates outcomes of investigations into mastitis scoring systems Wenz et al. (2006) developed a system to categorize the severity of disease present based on several relatively objective parameters.
Lameness	Abnormal posture and/or gait reflecting pain or dysfunction of the foot or leg. Further definition could be based on the associated lesion or specific pathology	Sprecher et al. (1997)	Sprecher et al. (1997) based their system on analysis of locomotion of 66 primiparous and multiparous cattle in a commercial dairy environment. This method of assessment is subjective (Schlageter-Tello et al., 2014) but widely used.

APPENDIX G

DEFINITION OF TERMS

Term	Definition
Acetate	A salt of acetic acid that is formed in the rumen during fermentation. Also referred to as a volatile fatty acid and produced from the breakdown of structural carbohydrates such as cellulose.
Acetonaemia	See ketosis.
Acidogenic salts	Formerly called anionic salts – the salts themselves are not anionic, but act in the body to cause a metabolic acidosis.
Adipocytes	A cell specialised for the storage of fat.
Anion	An ion carrying a negative charge.
Anionic salts	Salts able to contribute chloride or sulphide ions to a diet.
Betaine	The carboxylic acid derived by oxidation of choline. Betaine carries and donates methyl molecules to the body.
Butyrate	A salt of butyric acid that is formed in the rumen during fermentation. Also referred to as a volatile fatty acid and produced from the breakdown of structural carbohydrates such as cellulose.
Calciuria	The presence of calcium salts in the urine.
Cation	An ion carrying a positive charge.
Choline	A quaternary amine that occurs in the phospholipid phosphatidylcholine and the neurotransmitter acetylcholine and is an important methyl donor in intermediary metabolism.
Curvilinear	A line appearing as a curve.
Curvilinear relationship	A non-linear relationship.
Dissociation constant	The tendency of a solute to dissociate in solution.
Endophyte alkaloids	A group of organic, basic substances produced by a symbiotic plant fungi organism living in perennial ryegrass.
Exogenous	Caused by factors outside the organism.
Fermentable carbohydrate	The substrates of digestion in the reticulorumen, including non-structural carbohydrates (starch, sugar, pectin) and structural carbohydrates (cellulose and hemicellulose).
Forest plot	Forest plots are typically used to display epidemiological data and are often used in subject area reviews to summarize previously published findings.
Gluconeogenesis	The synthesis of glucose from non-carbohydrate sources such as amino acids, propionate, and glycerol. It occurs primarily in the liver.
Glycogen	A polysaccharide that is the primary carbohydrate storage material in animals. It is formed and stored in the liver and muscles.
Glycogenolysis	The splitting up of glycogen in the liver or muscles yielding glucose-1-phosphate.
Homeorhetic or homeorhesis	Derived from the Greek for 'similar flow', this is a concept encompassing dynamic systems that return to a trajectory as opposed to systems that return to a particular state, which is termed homeostasis.
Homeostasis	A tendency of biological systems to maintain stability while continually adjusting to conditions that are optimal for survival.
Hyper calciuric	An abnormally increased level of calcium salts in the urine.

Term	Definition
IgG	The abbreviation for a type of immunoglobulins that are a specialised class of serum proteins. Also called antibodies. IgG is one of five types of immunoglobulins (IgG, IgM, IgA, IgD and IgE).
Immunoglobulins	See definition of IgG.
Insulin	A peptide hormone formed in the pancreas; insulin is secreted into the blood in response to a rise in the concentration of blood glucose. Insulin promotes the storage of glucose, increases protein and lipid synthesis, and inhibits gluconeogenesis.
Insulin resistance	A condition where higher-than-usual insulin concentrations are needed to achieve normal metabolic responses.
Insulin sensitivity	A measure of how quickly circulating insulin will decrease blood glucose.
Ion	An atom or group of atoms having a positive (cation) or negative (anion) electric charge by virtue of having gained or lost one or more electrons.
Ketone	Any compound containing the carbonyl group CO. The carbonyl group is within a chain of carbon atoms.
Ketone bodies	The substances acetone, acetoacetic acid and beta-hydroxybutyric acid. They are normal metabolic products derived from excess acetyl CoA from fatty acids within the liver and are oxidised by extrahepatic tissues.
Ketosis	Accumulation in the body and tissues of large quantities of ketone bodies.
Ketosis, pregnancy toxaemia	In ruminants, ketosis is often used synonymously with acetonaemia.
Lactic acidosis	The accumulation of lactate, a strong acid in the rumen. The rumen pH is typically less than 5.5.
Lactogenesis	The production of milk by the mammary glands.
Lead feed	Generic term used to describe many types of concentrate feed used in the transition period. Often, but not always, this term infers the inclusion of acidogenic salts in the concentrate.
Lipogenesis	The transformation of non-fat food materials into fat.
Lipolysis	The splitting up or decomposition of fat.
Meta-analysis	Any systematic procedure for statistically combining the results of many different studies that address a set of related research hypotheses.
Metabolic acidosis	Acidosis caused by metabolic disturbance.
Metritis	Inflammation of the uterus.
Mycotoxin	Poisonous substance produced by a fungus.
NEFA (non-esterified fatty acid)	Any fatty acid that occurs free, rather than esterified with glycerol to form a glyceride or other lipid. Usually because of hydrolysis. The fraction of plasma fatty acids not in the form of glycerol esters.
Neutrophils	A granular leukocyte or white blood cell.
Pathogenesis	The cellular events, reaction and other pathological mechanisms occurring in the development of disease.
Periparturient	A description of the last few weeks of gestation and the first few weeks after birth.
Phagocytosis	The engulfing of micro-organisms or other cells and foreign particles by phagocytes (e.g. neutrophils).
Propionate	A salt of propionic acid and a precursor for carbohydrate in the ruminant. Also referred to as a volatile fatty acid and produced from the breakdown of structural carbohydrates such as cellulose.
Quadratic effect	A curvilinear effect or quadratic effect.
rBSt	Recombinant bovine somatotrophin or bovine growth hormone.
Ruminal acidosis	The accumulation of total volatile fatty acids in the rumen, especially propionate. The rumen pH range is typically 5.5 to 6.0.
Sprecher locomotion scale	A 1-to-5 scale used to assess the severity of lameness in cattle based on the observation of cows standing and walking (gait).

Term	Definition
Transition period	The four weeks before and after calving.
Trigyceride	A compound consisting of three molecules of fatty acids bound with one molecule of glycerol. A neutral fat that is the normal storage form of lipids in animals.
Ureagenesis	The formation of urea in the liver from amino acids and other ammonia compounds.
Volatile fatty acids (VFA)	Short chain acids soluble in water (see acetic, butyric, propionic acids). Formed from the fermentation of structural carbohydrates in the rumen.

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