

Nutritional Management of Transition Dairy Cows

James K. Drackley, PhD

Department of Animal Sciences, University of Illinois at Urbana-Champaign, email: drackley@illinois.edu

Abstract

Nutrition and management during late gestation impact periparturient health problems and influence subsequent milk production. Obesity at calving is a known risk factor for health problems and suboptimal production. Our evidence indicates that higher energy-density close-up diets do not increase subsequent milk production or energy balance. Our data indicate that even modest overfeeding results in changes analogous to obesity, with elevated insulin and NEFA and poor dry matter intake before calving, but substantial body fat mobilization, increased liver fat deposition, and prolonged increases in blood ketone bodies after calving. Modest energy excess during the dry period can lead to substantial internal fat deposition even without detectable changes in body condition. We conclude that requirements for energy (and other nutrients) should be met but not greatly exceeded during the dry period. This can be achieved by limit-feeding of moderate-energy diets or ad libitum feeding of high-roughage low-energy diets. Requirements for energy for dry cows and first-gestation heifers are modest (ca. 100 MJ ME or 14 Mcal NE per cow daily) and can be met with relatively low-energy diets. Conversely, diets high in starch from corn silage or whole-crop cereals and supplemented with additional concentrates result in excess energy intake relative to requirements, as cows do not regulate intake to meet energy needs over the short-term. Dilution of those diets with low-quality roughages such as cereal straws can control energy intake to near cow's requirements. Careful feeding management is critical to ensure that formulated nutrient intakes are actually achieved in practice.

Résumé

L'alimentation et la gestion en fin de gestation jouent un rôle dans les problèmes de santé en péripartum et influencent la production subséquente de lait. L'obésité au vêlage est un facteur de risque bien connu pour les problèmes de santé et de production suboptimale. Nos travaux indiquent qu'une alimentation riche en énergie en fin de gestation n'augmente pas la production subséquente de lait ni le bilan énergétique. Nos données indiquent qu'une suralimentation même modeste entraînent des changements similaires à l'obésité, tels qu'un niveau élevé d'insuline et d'acides gras non-estérifiés et une prise alimentaire moindre de matière

sèche avant le vêlage, et une mobilisation substantielle du gras corporel, un dépôt accrue de graisse dans le foie et un accroissement prolongé des corps cétoniques dans le sang après le vêlage. Un excès modeste d'énergie pendant le tarissement peut entraîner un dépôt interne substantiel de graisse sans que des changements de la condition corporelle soient détectables. Nous en concluons que les besoins énergétiques (de même que ceux pour les autres nutriments) doivent être comblés sans trop d'excès durant la période du tarissement. Ceci est réalisable en contraignant l'alimentation, en donnant une alimentation modérément riche en énergie ou en permettant l'alimentation à volonté avec une diète riche en fourrage grossier mais pauvre en énergie. Les besoins énergétiques des vaches taries et des taures en première gestation sont modestes (approximativement 100 MJ ME ou 14 Mcal NE par vache par jour) et peuvent être comblés avec une alimentation relativement pauvre en énergie. Au contraire, une alimentation riche en amidon provenant de l'ensilage de maïs ou de céréales de culture supplémentée avec des aliments concentrés peut causer un apport excessif d'énergie par rapport aux besoins car les vaches ne contrôlent pas leur prise alimentaire pour combler leur besoin énergétique à court terme. La dilution de cette alimentation avec du fourrage grossier de faible qualité, comme la paille de céréales, peut ajuster l'apport énergétique au niveau requis par la vache. Une bonne gestion de l'alimentation est essentielle afin que l'apport planifié des nutriments soit réalisé concrètement.

Introduction

Periparturient diseases and disorders are strongly associated with negative energy balance after calving. Research has demonstrated that elevated blood concentrations of nonesterified fatty acids (NEFA) and β -hydroxybutyrate (BHBA), which indicate negative energy balance, are strongly associated with increased disease, decreased milk production, and decreased fertility.³⁷ Over the last 15 to 20 years, a great deal of emphasis has been placed on maximizing energy intake during the close-up or pre-fresh period in an attempt to improve energy balance. This approach was designed on the basis of research showing advantages in adaptation of the rumen microbial population and rumen papillae to higher nutrient diets fed after calving, decreased body fat mobilization and fat deposition in liver, and maintenance of blood calcium concentrations. Although each

of these ideas were sound and based on good research data, the ability of higher-energy close-up or “steam-up” diets to minimize production diseases in research trials and field experience has been disappointing.¹⁰ It has now become clear that this approach does not lead to improved postpartum energy balance or transition outcomes, despite increased energy intakes before calving.

The transition or periparturient period is recognized as the most critical period for profitability of dairy farms.⁹ The transition period has been the focus of intensive research over the last 20 years, yet practical management strategies to minimize health problems while still promoting high milk production have remained controversial. Many dairy operations continue to struggle with a high incidence of metabolic disorders and infectious diseases around calving. Transition health problems have a large negative effect on profitability and animal welfare through increased veterinary expenses, decreased milk production, impaired reproductive performance, and premature culling or death.

Much has been learned about the underlying biology of the transition,^{9,11} as well as nutritional strategies to minimize health problems and promote high milk production.¹⁰ Feeding management during the dry period and into early lactation is one of two critical general areas in minimizing health disorders and promoting productive lactations; the other factor is minimizing stressors in the cows’ environment. Although not the focus of this paper, management to minimize stressors such as overcrowding, insufficient feeding space, uncomfortable housing, and excessive movement among groups is emerging as likely the most important determinant of transition success.^{3,4}

The concept of controlled-energy diets during the transition period, introduced by our research group a number of years ago,⁷ has become well accepted, although implemented with varying degrees of success. Other groups have confirmed the validity of our approach,^{1,17,39,43} although not all studies have shown clear benefits.⁴⁵ Over the last few years, our group has uncovered much of the underlying biology of why the controlled-energy approach yields better outcomes than feeding aggressive “steam-up” diets during the late dry period. This paper summarizes the logic of controlling energy intake during the dry period, discusses methods for practical implementation, and describes some of our recent research into the physiological and metabolic mechanisms behind its success.

Important Aspects of Periparturient Physiology

Negative energy balance after calving is driven mainly by dry matter intake (DMI), and thus energy intake, and is poorly related to milk production or milk energy secretion.^{11,47} In response to negative energy bal-

ance, cows mobilize stored triglycerides (TAG) in adipose tissues as an energy supply for milk production and maintenance. Glycerol released from lipolysis is used by the liver for gluconeogenesis. The fatty acids released circulate as NEFA and are distributed with blood flow to all body tissues.¹³ When NEFA concentrations are elevated during early lactation, the mammary gland takes them up efficiently and converts them to milk fat. As a consequence, high milk fat concentrations, or high milk ratios of fat to protein, are useful indicators of ketosis in dairy cows.

The liver receives about one-third of all blood flow from the heart. Consequently, the liver is flooded with NEFA when blood concentrations increase around calving. The liver takes up NEFA in proportion to their concentration in blood. Within liver cells, NEFA can be 1) oxidized to CO₂ with the generation of ATP for the liver’s energy needs, 2) partially oxidized to the ketone bodies BHBA and acetoacetate, which results in ATP for the liver and a water-soluble energy source for muscle and heart, or 3) re-converted to TAG. Because ruminant animals are unable to effectively move TAG out of the liver as very low density lipoproteins,²⁶ TAG can accumulate and cause fatty liver. Increased ketone body production can result in ketosis if severe.¹³

Lipolysis (fat breakdown) in adipose tissue is stimulated mainly by the sympathetic nervous system in the presence of low insulin concentrations.³³ The sympathetic nervous system responds to energy shortage or chronic stressors with greater activity. Although stressors and severe limitations in DMI can lead to negative energy balance before calving, the degree is much less than what occurs following parturition. To prevent disease problems associated with negative energy balance, management and nutrition practices should focus on minimizing the presence of stressors and the extent and duration of postpartum negative energy balance to minimize the mobilization of NEFA from adipose tissue TAG around calving. For example, prepartum treatment of cows with a thiazolidinedione drug that decreased NEFA promoted greater DMI and a smoother transition.⁴⁰ Key focus areas in management are decreasing stressors in the cows’ environment and providing pre-calving diets that promote consistent and adequate energy intakes.

Controlling Energy Intake During the Dry Period

As we have argued elsewhere, the simplest and most easily defended principle of nutrition for dairy cows during the dry period and transition is to feed to meet, but not greatly exceed, the cows’ requirements.¹⁰ This concept in many ways is nothing new, as it centers on formulating dry cow rations to dietary energy densities

that were established many years ago by the National Research Council (NRC). Rethinking what these data and previous knowledge tell us about dry cows has led us to a new interpretation relative to the existing dogma, and to develop practical systems suitable for modern dairy management practices on both small and large dairies.

Our research group has investigated whether controlling energy intake during the dry period might lead to better transition success.^{5,6,8,9,11,13,15,19,20,30,31,38} Our research drew from earlier reports that limiting nutrient intakes to requirements of the cows was a preferable strategy to overfeeding.²⁷ We also relied on our ideas and observations, as well as field experiences by others such as Dr. Gordie Jones. The data we have collected demonstrate that cows fed even moderate-energy diets (1.50 – 1.60 Mcal NE_L/kg DM) will easily consume 40 to 80% more NE_L than required during both far-off and close-up periods.^{5,6,8,20} Cows in these studies were all less than 3.5 body condition score at dry-off and were fed diets based on corn silage, alfalfa silage, and alfalfa hay with some concentrate supplementation. We have no evidence that the extra energy and nutrient intake was beneficial in any way, except for increasing fat content of milk during the first four to six weeks postpartum.²⁰ More importantly, our data indicate that allowing cows to over-consume energy, even to this degree, may predispose them to health problems during the transition period if they face stressors or challenges that limit feed intake.

We have collected a variety of data indicating that prolonged over-consumption of energy during the dry period can result in poorer transitions. Our evidence includes whole-animal responses important to dairy producers, such as lower post-calving DMI and slower starts in milk production.^{5,8} We also have demonstrated that overfeeding results in negative responses of metabolic indicators, such as higher NEFA and BHBA concentrations in blood and more TAG in the liver after calving.^{8,19} From a mechanistic standpoint, there are alterations in cellular²⁹ and gene-level responses³⁰⁻³² that potentially explain many of the changes at cow level. In the liver, overfeeding increases the proportion of NEFA that are re-esterified to form TAG, while the capacity for fatty acid oxidation decreases.²⁹ Using a cDNA microarray and RT-PCR, we showed that genes encoding enzymes involved in TAG formation were upregulated in liver of overfed cows and genes encoding enzymes of fatty acid oxidation were decreased.³¹ Microarray measurements in subcutaneous adipose tissue demonstrated that overfeeding during the dry period increased lipogenic genes compared with cows fed to requirements.²¹ Most recently we have shown that overfeeding increases adipose expression of mRNA for both lipogenic and lipolytic proteins.²⁵ Controlling energy intake during the dry period also positively affects neutrophil function postpartum¹⁴ and so may lead to better immune function.

Our data demonstrate that allowing dry cows to consume more energy than required, even if they do not become noticeably over-conditioned, results in responses that would be typical of overly fat cows. Because energy that cows consume in excess of their requirements must either be dissipated as heat or stored as fat, we speculate that both may be happening. We have recently demonstrated that moderate overfeeding of non-lactating cows for 57 days leads to greater deposition of fat in visceral adipose tissues (omental, mesenteric, and perirenal) than in cows fed a high-straw diet to control energy intake at requirements.³⁵ The NEFA and signaling molecules released by some of these visceral adipose tissues go directly to the liver, which may cause fatty liver, subclinical ketosis, and other secondary problems with liver function. Humans differ in their tendencies to accumulate fat in different locations, and central obesity is a greater risk factor for disease. Similarly, cows might also vary in the degree to which they accumulate fat internally. The mechanisms we have been studying in dry cows are similar to those from human medical research on obesity, type II diabetes, and insulin resistance.

Our work has extended ideas that in themselves are not necessarily new to show that over-consumption of energy is common, even when feeding typical dry-period diets thought to be “safe” and in cows that are not overconditioned. Moreover, this overfeeding may be a predisposing factor to poor health, even in the absence of overconditioning. We also have extended the ideas of limit-feeding moderate energy diets or ad libitum feeding of high-straw, low-energy rations as simple and practical approaches to achieve the control of energy intake.

Strategies to Control Dry Period Energy Intake

In light of the apparent desirability of feeding to allow cows to meet, but not greatly exceed, their requirements for energy during the dry period, there are at least three approaches that could be implemented to achieve this goal. The first is to feed cows only poor-quality roughages and other dietary ingredients that would minimize the potential for excessive energy intake. This concept was the default management option on many farms several decades ago. However, the dangers are that excessive variation of ingredient quality may promote inconsistent intake of nutrients, the ration may provide imbalanced nutrient profiles, and such feeds may be contaminated with molds or toxins. This is not a desirable mindset or approach, and it will not be considered further here.

Limit-Feeding Dry Cows

A second and better approach is to formulate a diet of moderate energy density (1.50 – 1.60 Mcal NE_L/kg DM) and limit-feed it in amounts of dry matter (DM)

that would meet the average Holstein cow or heifer requirement of 14 to 15 Mcal daily. Note that we are not advocating limiting cows below their requirements as we have done in some of our experiments,^{5,6,8} although those cows almost always have the most favorable metabolic profile after calving. One study that implemented limit-feeding to requirements found favorable results,¹⁷ whereas a more recent study showed little difference between limit-feeding or ad libitum feeding.⁴⁵ It should be noted in the latter study, however, that cow numbers were limited and three of nine cows assigned to the ad libitum (over-consumption) group developed health problems at calving, and so did not contribute postpartum data to the evaluation.

Conceptually, limit feeding is a workable method for controlling energy intake. In practice, however, it requires a high level of management to implement successfully. Limit feeding works only where cows are housed individually (rare) or where group-feeding systems allow an abundance of feeding space. Feed must be delivered over bunk space that is adequate to allow all cows access to feed. Implementation requires that dairy producers become as adept at managing feed bunks as beef producers are. The goal is to formulate rations for target DM intakes that would take cows at least 18 hours per day to consume. In other words, dry cows should be fed to a clean bunk shortly before the next feeding. Given the dynamic nature of cows moving in and out of single-group dry cow pens or close-up pens, and perhaps variable total numbers of cows, management of limit-feeding often is more challenging on dairy farms than in beef feedlots.

High-Bulk, Low-Energy Diets for Dry Cows

A third solution to the potential for cows to over-consume energy is to formulate rations of relatively low energy density (1.30 – 1.38 Mcal NE_L/kg DM) that cows can consume free choice without greatly exceeding their daily energy requirements. The principle is to feed cows a diet of sufficient fiber (bulk) content that cows will only meet their requirements consuming all the DM they can eat. The target intake thus allows neither too much nor too little energy, but rather just the right amount to match requirements.

To accomplish the goal of controlled energy intake requires that some ingredient or ingredients of lower energy density be incorporated into diets containing higher-energy ingredients such as corn silage, good quality grass or legume silage, or high quality hay. Cereal straws, particularly wheat straw, are well-suited to dilute the energy density of these higher-energy feeds, especially when corn silage is the predominant forage source available. Lower quality grass hays also may work if processed appropriately, but still may have considerably greater energy value than straw, and thus are not as effective in decreasing energy density.

We are not aware of any controlled data comparing different types of straw, but it is the general consensus among those who have years of experience using straw that wheat is preferred. Barley straw is a second choice, followed by oat straw. While reasons for these preferences are not entirely clear, wheat straw is more plentiful, is fairly uniform in quality, and has a coarse, brittle, and hollow stem that processes easily, is palatable, and seems to promote desirable rumen fermentation conditions. Barley straw lacks some of these characteristics. Oat straw is softer, and as a result does not process as uniformly. In addition, oat straw generally is somewhat more digestible and thus has greater energy content.

It is critical that the straw or other roughage actually be consumed in the amounts desired. If cows sort out the straw or other high bulk ingredient, then they will consume too much energy from the other ingredients and the results may be poor. A TMR is by far the best choice for implementing high-straw diets to control energy intake. Very few TMR mixers can incorporate large amounts of straw without pre-chopping and without overly processing other ingredients. Straw may need to be pre-chopped to 2-inch or less lengths to avoid sorting by the cows.

Advantages and Benefits

Based on our research and field observations, adoption of the high-straw, low-energy TMR concept for dry cows might lead to the following benefits:

- Successful implementation of this program essentially eliminates occurrence of displaced abomasum. This may result from the greater rumen fill, which is maintained for some period of time even if cows go off feed for some reason, from the stabilizing effect on feed intake or through alteration of dietary cation-anion balances and potassium status.^{19,22}
- Field survey data collected by the Keenan Co. in Europe (courtesy of D. E. Beever, Richard Keenan and Co., Borris, Ireland) indicate strongly positive effects on health. In 277 herds (over 27,000 cows) in the United Kingdom, Ireland, France, and Sweden, changing to the high-straw, low-energy TMR system decreased assisted calvings by 53%. In addition, the change decreased milk fevers by 76%, retained placentas by 57%, displaced abomasum 85%, and ketosis by 75%. Using standard values for cost of these problems, the average increase in margin per cow in these herds was \$114 just from improved health alone. While these are certainly not controlled research data, they are consistent with the results in our research, as well as field observations in the USA.

- The same sources of observational data indicate that body condition, reproductive success, and foot health may be improved in herds struggling with these areas. A recent meta-analysis underway of our studies in this area shows that controlling energy intake decreases time to conception by 10 days compared with overconsumption of energy (Cardoso *et al*, 2011, unpublished data).
- Although data are limited, milk production appears to be similar to results obtained with higher-energy close-up programs.^{38,42} There is some evidence that persistency may be improved, with cows reaching slightly lower and later peak milk. Therefore, producers should be careful to not evaluate the system based on early peaks and should look at total lactation milk yield, daily milk, and, over time, indices of reproduction and other non-milk indicators of economic value.
- Straw and corn silage generally are lower in potassium and calcium, and thus help control the dietary cation-anion difference (DCAD) without excessive addition of anionic salt mixtures. Blood calcium concentrations decrease less when energy intake is controlled before calving (Dann *et al*, Janovick *et al*, unpublished data).
- The program may simplify dry cow management and ration composition in many cases.
- Depending on straw cost, rations based on corn silage and straw likely will be no more expensive than the average cost of traditional far-off and close-up diets, and could be cheaper where straw is plentiful. Remember that even when straw appears expensive, it is replacing something else in the diet so *marginal* cost is the key criterion. Furthermore, total DMI per cow may be lowered by addition of straw, so that daily feed cost per cow can actually be decreased substantially.

Single Group Dry Cows

Our most recent research,^{18,20,38,42} as well as considerable field experience, indicate that a single-diet dry cow program can be successful using these principles. Dry matter intakes remain more constant as cows approach calving when fed the high-straw, low-energy diets^{5,20,38} than in cows fed high-energy close-up diets.¹⁶ Single-group systems would have the advantage of eliminating one group change, which may decrease social stressors as described by University of Wisconsin researchers.³ Single-group management may work particularly well for producers managing for shorter dry periods.

A variation is to maintain far-off and close-up groups with essentially the same diet for both except

that a different concentrate mix or premix is used for the close-ups, which may incorporate anionic salts, extra vitamins and minerals, additional protein, or selected feed additives. The optimal high-forage low-energy dry cow ration will contain the primary forages and grains to be fed in the lactation diet, but diluted with straw or low-quality forage to achieve the desired energy density. In this way, the rumen remains adapted to the types of ingredients to be fed after calving without excessive energy.

If producers desire to maintain the conventional two-group or “steam-up” philosophy for dry cow feeding, our research has shown that the most critical factor is to ensure that the energy density of the far-off dry period diet is decreased to near NRC³⁴ recommendations (NE_L of 1.25 – 1.30 Mcal/kg DM) so that cows do not overconsume energy.⁵ In this research, wide extremes in close-up nutrient intake had very little effect compared with the effect of allowing cows to consume excess energy during the far-off period.

We recently completed two experiments designed to determine whether moving dry cows to a higher-energy, close-up diet at three weeks before calving would confer any benefits to cows during the transition compared with a single high-bulk diet fed all the way through to calving.^{38,42} In the first experiment, we also included an overfed group, which received the higher-energy close-up diet during the entire dry period.³⁸ The overfed group had greater DMI during the dry period but not during lactation; cows gained body condition during the dry period but lost more body condition after calving. Overfed cows had increased fat in the liver, greater and more prolonged increases in NEFA and BHBA after calving, and had greater milk fat production than the other two groups. The single-diet group had the least change in DMI around calving, and the lowest concentration of fat in the liver after calving. Surprisingly, the group provided the close-up diet had fat content in the liver that was intermediate to the single-diet group and the overfed group.

In the second experiment, cows were fed a single-group controlled-energy diet or a two-group far-off and close-up system.⁴² Milk fat content was 0.2 percentage units higher for the group fed the close-up diet, but there were no other advantages. Serum NEFA concentrations were higher in the cows fed the close-up diet, which likely explains the greater milk fat content. These two experiments, therefore, yielded little evidence that the two-group strategy offered any advantage compared with the single-diet (controlled-energy high-fiber) strategy, with the exception of slightly greater milk fat content. The economic value of that, however, is offset by the greater diet cost during the dry period and greater risk of health disorders for the close-up dietary strategy.

Mechanistic Data: Why Do these Diets Work?

In addition to the factors mentioned earlier, our recent research has focused on two aspects of controlled-energy diets that are proving to be very important in explaining their benefits. The first of these is the concept of “insulin resistance” and changes in adipose tissue that result in more NEFA mobilization after calving. The second relates to increased deposition of mesenteric and omental adipose tissues (visceral or internal fat) and its effects on delivery of NEFA, cytokines, and adipokines to the liver.

Increased Adipose Lipolysis

As mentioned earlier, the peripartal metabolic dysfunction in cows bears many similarities to the “metabolic syndrome” in humans. A major component of the syndrome in humans is insulin resistance, which progresses from liver to muscle to adipose tissue. We have referred generically to the changes resulting from overfeeding energy during the dry period as typical of those in insulin resistance or insulin insensitivity. Indeed, some of the results appear consistent with development of greater insulin resistance, such as the higher insulin with similar glucose concentrations in blood,⁶ which results in a lower “RQUICKI” index¹⁸ for example (unpublished data). However, no direct measurements of insulin responsiveness have been made with these diets.

Recently we attempted to provide direct tissue-level evidence of decreased insulin action in adipose tissue of peripartal dairy cows. We compared a group of cows fed a single controlled-energy high-fiber diet throughout the dry period with a group fed the same diet during the far-off dry period, but then switched to a higher-energy close-up diet for the last three weeks prior to parturition.²⁵ Biopsies of subcutaneous adipose tissue were obtained at 10 days before calving and at seven and 21 days postpartum. Adipose tissue was incubated in vitro in the absence and presence of insulin to determine the phosphorylation of insulin receptor substrate-1 (IRS-1), which is the first step inside the cells that transmits the signal from insulin binding to its cell membrane receptor. Phosphorylation of IRS-1 decreased sharply for both groups of cows after calving, demonstrating the well-known increase in insulin resistance that accompanies the start of lactation. Surprisingly, however, the higher-energy close-up diet actually tended to *increase* IRS-1 phosphorylation before calving, indicating if anything that the adipose tissue was actually *less resistant* to insulin than in the controlled-energy cows. Thus, classical insulin resistance of adipose tissue does not seem to be induced by overfeeding during the dry period.

What we did find, however, is that overfeeding increases the mRNA for several enzymes responsible for lipolysis in adipose tissue.²⁵ These changes not

only occurred during the close-up period, but persisted through seven days postpartum. In addition, phosphodiesterase-3B (the main enzyme responsible for the antilipolytic effect of insulin) was down-regulated by overfeeding during the close-up period.²⁵ Thus, it appears that moderate overfeeding, even for the relatively short period of three weeks before calving, increases the metabolic machinery to mobilize body fat and decreases the machinery involved in insulin’s ability to decrease that mobilization. The result would be increased NEFA concentrations postpartum, exactly what we have observed in our in vivo studies.

Mesenteric Fat Deposition

In human medicine, increased fat accumulation in the mesenteric adipose depot is thought to be the most potentially harmful.⁴⁶ At least part of this is attributable to the greater secretion of various pro-inflammatory “adipokines” synthesized within the mesenteric adipose depot.⁴¹ Dairy cattle have relatively greater accumulation of fat in internal depots than do beef cattle. We recently demonstrated that non-lactating cows overfed during an eight-week period had about 75% more mass in the visceral adipose depots, including almost a doubling of the mesenteric fat, compared with cows fed for the same period on a controlled-energy diet.³⁵ We showed that the visceral depots, especially the mesenteric, have a greater expression of cytokines and other adipokines that can adversely affect liver function.²⁴ Although overfeeding did not result in greater expression of the pro-inflammatory cytokines,^{24,25} the larger mass of mesenteric and omental fat would mean more inflammatory mediators reaching the liver since the venous drainage of these depots is via the portal vein. Others have found greater concentrations of pro-inflammatory cytokines such as TNF- α in blood of cows with greater body condition.³⁶ Inflammatory mediators such as TNF- α can decrease fatty acid oxidation, increase esterification, and result in greater fat accumulation in the liver.²

Specifications for High-Bulk Dry Period Diets

The controlled energy system works best for producers relying on corn silage as the primary forage. Typical rations generally contain roughly one-third of the DM as corn silage, one-third as chopped straw, and the remaining third split between some other hay or silage and a small amount of concentrate to meet protein, mineral, and vitamin needs. The combination of straw and corn silage is complementary for many reasons, including energy content, low potassium contents, starch content, and feeding characteristics.

The NE_L requirement for 1500 lb (680 kg) Holstein cows is between 14 and 15 Mcal (58 to 63 MJ) per day.³⁴ This equates to approximately 100 MJ of ME daily. Some

suggested guidelines for formulation of controlled energy diets to meet that requirement are as follows, on a total ration DM basis.

- Dry matter intake: 25.3 to 27.5 lb (11.5 to 12.5 kg) per day. For far-off cows, intakes by individual cows often exceed 29.7 lb (13.5 kg) DM per day.
- Energy density: 1.30 – 1.38 Mcal NE_L/kg DM.
- Protein content: 12 to 15% of DM as CP; >1,000 g/day of metabolizable protein as predicted by the NRC³⁴ model or CNCPS/CPM Dairy model. This may require addition of high-RUP sources such as blood meal or heat-treated soybean meal. Target 1100 g/d of metabolizable protein for mature cows in herds where metabolic disorders are a problem.
- Starch content: ~14% of DM (range 12 to 16%). If starch is poorly fermentable diets should be at the upper limit.
- Forage NDF: 40 to 50% of total DM, or 9.9 to 12.1 lb (4.5 to 5.5 kg) daily (0.7 to 0.8% of body weight). Target the high end of the range if more higher-energy fiber sources (like grass hay or low-quality alfalfa) are used, and the low end of the range if straw is used.
- Total ration DM content: 45 – 48% (add water if necessary). Additional water will help hold the ration together and improve palatability. When ration DM exceeds 55%, DMI will decrease and sorting may increase.
- Follow standard guidelines for mineral and vitamin supplementation. For close-ups, target values are 0.40% magnesium (minimum), 0.35 – 0.40% sulfur, potassium as low as possible, a DCAD of +25 to +50 meq/kg, 0.27 – 0.35% phosphorus, and at least 1,500 IU of vitamin E. Calcium is typically set at about 0.9% of DM.

As long as the lactation diet is formulated appropriately, there seems to be little difficulty in transitioning to the lactation diet immediately after calving. Many producers have found that inclusion of 0.55 to 2.2 lb (0.25 to 1 kg) of chopped straw in the lactation diet improves rumen function and animal performance, particularly when physical fiber is borderline adequate. Addition of the straw postpartum also may help to ease the transition from the lower-energy dry cow diet.

Common Problems in Field Implementation

Three factors are critical to successfully implement this approach: 1) prevention of sorting, 2) ensuring continuous and non-crowded access to the TMR, and 3) careful monitoring of DM content and attention to detail. Where problems have been reported, one or

more of these factors has been faulty, not the dietary approach itself.

The straw must be chopped into a particle size that cows will not sort out of the ration. In general, this means less than 2 to 2.7-inch (5 to 7 cm) particles. If the straw is pre-chopped, an appropriate chop is indicated by having about one-third of the particles in each of the three fractions of the Penn State shaker box. Because of the bulky nature of straw and the resulting TMR, producers may think that cows are sorting excessively when they are not. To verify that cows are not sorting, the feed refusals should be monitored carefully and compared to the original TMR. One simple way to evaluate sorting is to shake out the TMR with the Penn State box and then repeat the analysis on the feed refusals the next day. Results should not differ by more than 10% from TMR to refusal. Another way to monitor sorting is to collect samples of the feed refusal from several areas of the feedline and have it analyzed for the same chemical components as the TMR fed. Again, composition of NDF, CP, and minerals should not vary by more than 10% between ration and refusal if cows are not sorting. If cows sort the straw, some cows will consume a higher energy diet than formulated, and some (the more timid cows) will be left with a much lower quality ration than desired. Herds where sorting is a problem will be characterized by pens of dry cows that range widely in body condition: some will be over-conditioned and some under-conditioned, while of course some may be “just right”.

Another common pitfall is barn design or poor feedbunk management that limits the ability of cows to consume feed ad libitum. Because of the bulky nature of the diet, cows may have to spend more time eating to consume enough feed to meet requirements for energy and nutrients. Recent research has documented that cows spend longer eating these high-bulk diets compared with traditional higher-energy close-up diets.⁴⁴ Bunk space must be adequate and feed pushed up frequently. If feed is not pushed up, cows likely will be unable to consume what they need to meet requirements. Other common problems arise when the DM content of straw, hay, and silages changes markedly from assumed values. This may happen, for example, if the straw is rained on or the DM content of silage changes without the feeders knowing it. Changes in DM of the ingredients means changes in the DM proportions of the total diet unless the mix is corrected. Thus, energy intake may increase or decrease relative to the target, and an outbreak of calving-related health problems may occur until the situation is corrected.

Other Considerations

As mentioned earlier, the combination of straw and corn silage, along with other lactation ration ingredients,

works well because of the complementary features of the components in the total diet. Straw has many desirable characteristics that seem to improve health and digestive dynamics in the rumen. The slow digestion and passage rate of straw certainly seems to be important in prevention of displaced abomasum. Control of energy intake is a critically important factor in maintaining a more constant energy intake during the dry period and in preventing other disorders around calving, such as ketosis and fatty liver.

Whether other low-energy ingredients will produce the same desirable results remains uncertain. We are not aware of research that has compared other low-energy ingredients such as poor-quality hay, oat hulls, cottonseed hulls, corn stalks, soybean residue or flax residue to straw or to conventional rations, although we have anecdotal reports from producers and nutritionists with varying reports of success. With roughage-type materials, the key consideration is uniform processing and palatability so that cows do not sort and the formulated profile of nutrients is actually consumed. Care must be taken to not use moldy or weather-damaged materials or those that have excessive amounts of soil contamination. For concentrate-type or finely ground ingredients, energy content is low but particle size is so small that rate of passage can be too fast, allowing particles to escape more quickly even though they are not digested. In this case, DMI by the cows may increase so that total energy intake still exceeds requirements considerably.

Just because straw or other low-energy ingredients are “low quality” by conventional standards of evaluation based on protein or energy content does not mean that other measures of “quality” can be ignored. Straw or other feeds that are moldy, severely weather-damaged, or have fermented poorly should not be fed to dry cows, especially the close-ups. Producers are advised to lock in supplies of high-quality and consistent straw to minimize these problems. As use of high-straw diets has increased, the relative amount of poor-quality material on the market has increased and farmers forced to “shop the open market” are often confronted with material that should only be used as bedding, and not fed.

Conclusions

We have learned much more about the biology of cows during the critical periparturient period, and how they respond to different dietary approaches. Many different nutrition programs can be successful during the dry period and transition. However, limit-feeding and high-straw (or high-bulk) low-energy rations are exciting for their potential to markedly improve health during the transition period. The key concept is to strive to meet the requirements of cows for energy and all other nutrients, but to not allow cows to exceed their require-

ments for energy by large amounts for the duration of the dry period. Provided that high-straw low-energy rations are formulated, mixed, and delivered properly, results have been positive and consistent. Research and field observations indicate that the rations result in better energy balance after calving, with subsequent reductions in lipid-related health disorders. Milk production is maintained, and field observations suggest that reproductive success may be improved also, although data are lacking to date. Research is needed to explore other low-energy bulky ingredients as options to straw.

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