Feeding to Minimize Nutrient Requirements for Maintenance and Increase Milk Production

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Introduction

Feed costs represent greater than 50% of the costs of producing milk. Several practical strategies have been applied to help minimize costs, including reduced feed losses during storage, reduced shrink at feed out, and determining favorable pricing for commodity feeds. Much less attention has been directed towards improving feed efficiency in dairy cattle. Although recognized as an important component of profitability, feed efficiency is a difficult trait to describe, measure, and subsequently improve through management strategies or genetic selection.

Efficiency of feed utilization is a function of several biological processes, environmental influences, and genetic factors. The principle components of energy requirements are the costs associated with maintenance, body composition changes, and production (growth, reproduction, and lactation). When these terms are matched with energy intake, a measure of energetic efficiency can be determined. This review will explore some of the factors that impact maintenance energy costs, including new information on biological processes that may alter maintenance requirements and therefore improve efficiency of capturing nutrients in products, including milk. This discussion will focus on energetic efficiency, although a similar discussion could be developed that is specific to the efficiency of protein utilization.

Components of Maintenance

As summarized by Baldwin (1995), maintenance is the physiological state in which there is no net change in body energy or alternatively when energy balance is zero. The components of maintenance include the energy required for basal metabolism; energy of thermal regulation; the energy costs associated with digestion, absorption and assimilation of meals at maintenance intake; and the energy associated with waste production.

Basal metabolism is essentially equal to fasting heat production **(FHP)** or the heat production of an animal in a postabsorptive state in a thermoneutral environment in an inactive (lying or standing with no activity) state (Baldwin, 1995). Fasting heat production has been referred to as the "heat of idling" (Kellner, 1909). While this term is a gross oversimplification of biology, it is a useful analogy to understanding the main concept underlying FHP and its relationship to maintenance.

Fasting heat production, described as the heat production in an animal in a postabsorptive state, is the energy required to maintain life. There is considerable variation in values associated with fasting heat production and adaptability in the energy associated with FHP. A portion of the differences in FHP are due to differences in sex, breed, physiological state, level of production, and previous plane of nutrition. The importance of the latter is highlighted in experiments where sheep were shifted

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from a high nutritional status to low nutritional status. The observed maintenance requirements were 32% greater than when shifting animals to the opposite diet sequence (reviewed by Baldwin, 1995). These data point to the importance of plane of nutrition and can be explained by a high correlation between FHP and weight of the major digestive organs (primarily liver and gastrointestinal tract). As discussed below, recent information using divergent lines of mice selected for differences in FHP suggests an inherent link to organ size that is independent of the previous plane of nutrition.

Maintenance requirements can be divided into 2 broad categories: the cost of feed digestion and nutrient absorption, and the components of FHP. There can be either equal or a markedly disproportionate contribution of each process to the overall maintenance requirement and the balance depends on diurnal patterns and several other physiological factors. The former includes the energy costs associated with eating, feed digesta, propulsion of digestion through the gastrointestinal tract, synthesis of digestive enzymes, nutrient absorption across the gastrointestinal wall and into blood, and the assimilation of nutrients into the storage form (fat, glycogen, and others). The latter accounts for the energy required to maintain tissue and cellular functions within a given physiological state.

Factors Affecting Maintenance Requirements

The adjustment to maintenance requirements for lactating cows includes the effect of activity, terrain, and level of feed consumption (NRC, 2001). These adjustments recognize the increased overhead maintenance requirements associated with additional physical activity and the energetic costs associated with increased nutrient digestion and absorption. For heifers, the impact of growth, thermal loss due to cooling, body composition, coat condition, and heat stress are all recognized as adjustments to maintenance requirements. Although these are also recognized as an added cost of maintenance for lactating cows, they are used in adjustments to maintenance requirements in the current version of the NRC (2001).

Adjustments to maintenance for thermal stress in cold environments appear to be minimal, but during heat stress, the energy used to dissipate heat to the environment can increase maintenance energy by as much as 25%. For a 1600 lb cow, this translates to 3.4 Mcal /day of NE_L. An increase in maintenance energy requirements, when coupled with a voluntary reduction in feed intake and altered hormonal status, results in a decrease in energy available for milk production during heat stress.

Some breeds of cattle appear to exhibit different abilities to adapt to environmental changes and nutritional levels. For example, Africander cattle respond to declining feed quality by reducing FHP more than Bos Taurus cattle (Ferrell and Jenkens, 1985). Variation among breeds of cattle with regard to maintenance requirements may reflect differences in response to selection pressure during the evolution of each breed. For example, in temperate environments, Brahman steers consumed less feed but gained body weight at rates similar to Hereford cattle (Moran, 1976). In pen feeding studies in a controlled environment, Bos taurus cattle consumed more feed and gained weight more rapidly than Bos indicus steers (Frisch and Vercoe, 1977). Remarkable breed differences do not appear to exist for dairy cattle, perhaps due to the close geographical proximities with regard to their origins.

Other information confirms the lack of impact of breed on FHP. Data from lactating Hereford × Angus beef cattle using respiration calorimetry indicate that the estimates of maintenance energy requirement obtained from the regression of NE_L/kg $BW^{0.75}$ on ME/kg $BW^{0.75}$ are almost identical in lactating Hereford × Angus heifers and lactating Holstein-Friesian cows. Although differences between these breeds exist in the nonlactating state, they appear to be abolished due to the metabolic changes associated with lactation (Tyrrell and Reynolds, 2004).

The balance between energy intake and output can have major consequences for immune function and can be influenced by immune status. Immune functions exact a toll on maintenance energy costs. One of the challenges in animal nutrition is in understanding how energy is partitioned among physiological processes. There is a paucity of research that directly examines the impact of immune challenges on maintenance energy expenditure; however, it is well recognized that sub-acute disease exacts a toll on productivity. Therefore, it is reasonable to assume that a portion of the costs of an immune challenge are reflected in increased maintenance costs. Parallels between the energetic costs in response to mounting a fever in humans and the additional maintenance energy in cattle have been previously described (Goff and Kimura, 2002). It has been suggested that if cows respond by increasing basal energy expenditure (maintenance energy) in a manner similar to humans during an immune challenge that maintenance energy expenditure may increase by as much as 40%. This increase in energy requirements is equivalent to the energy in approximately 5.5 lb/day of feed (assuming 0.75 Mcal/lb of diet) or alternatively a loss of 12 lb of energy-corrected milk output.

Effects of Nonexercise Activity and Visceral Organ Size on Maintenance

The maintenance requirement associated with increased nonexercise activity **(NEAT)** has recently been recognized as a substantial contributor to the variance observed between human subjects for basal energy expenditure. Simple ‘fidgeting’ or NEAT results in as much as 30% more basal energy during non-exercise activities (Levine et al., 2000). Obesity-resistant rats have significantly greater spontaneous physical activity than obesity-prone rats, and spontaneous physical activity has been shown to predict BW gain (Kotz et al., 2008). The level of spontaneous physical activity is important in determining propensity for obesity in human and rodents as models of human health, but the opposing situation could be applied to domestic livestock. Selection for a low nonexercise activity or creating an environment where NEAT is minimized is likely to enhance growth rate and milk production by reducing basal energy expenditure.

Central to the discussion of maintenance requirements is the observation that visceral organ size plays a critical role in determining energy expenditure. Liver represents approximately 1.6% of empty BW but it receives 30% of cardiac output and is responsible for 25% of FHP (Baldwin, 1995). Therefore, a small change in liver size or metabolic activity may have a tremendous impact on maintenance requirements. For example, liver weight is greater in lactating compared to nonlactating cows (20 vs. 25 lb for a 1400 lb cow). Most of this 25% increase in liver size is needed to accommodate the increased needs for gluconeogenesis and ureagenesis that accompany lactation. The accompanying increase in maintenance energy represents 2.5% of basal energy expenditure (Baldwin, 1995). Almost 50% of the change in basal energy expenditure in lactating cows can be accounted for by increased relative organ weight.

The close relationship between basal metabolic rate and visceral organ size is highlighted in laboratory mice that have been subjected to divergent selection for a high and low basal metabolic rate **(BMR)** (Ksiazek et al., 2004). Mice were bred for 19 generations under selection pressure for divergent metabolic rate. Open circuit calorimetry was used to determine BMR during the selection process and food intake, digestibility, and body composition were measured during the growth phase. Upon termination, body composition and organ sizes were determined. Body weight did not differ for divergent lines of mice. Food consumption was greater for high BMR mice, and organ weights were also greater when expressed either as absolute weight or as a portion of lean body mass (Ksiazek et al., 2004). Liver weights changed more than any other tissue. The percentage change for liver was 17%, and greater liver weights were associated with greater BMR. The fact that BW did not differ between these lines of mice but BMR was clearly different indicates the importance of visceral tissue to the whole body maintenance requirement.

Impact of Residual Feed Intake on Maintenance

Residual feed intake **(RFI)** has been defined as energy intake minus predicted energy requirements based on lactation performance, metabolic live weight, and liver weight change (Veerkamp and Emmans, 1995). It has been suggested as a measure of productive efficiency and a potential tool when selecting for efficient feed utilization. Although there is considerable variation in RFI for swine, it appears to be a promising genetic selection tool (Cai et al., 2008). Similar efficiency measures have been proposed for dairy cattle, including simple relationships of milk yield per unit of DM consumed or 3.5% fat-corrected milk **(FCM)** per unit of DM consumed (Britt et al., 2003) and RFI (Veerkamp et al., 1995). Differences exist in the experimental approaches to measuring RFI and some evaluations are based on DM intake (Kennedy et al., 1993), while others are based on ME intake (Veerkamp et al., 1995). Because the underlying basis for evaluation of efficiency is in determining the components of maintenance and partial efficiency of feed energy for product, it is important to distinguish between the measures of RFI. For swine and poultry, this may be a minor issue due to the high proportion of grains in the diets. The negative association of NDF with gross measures of dairy efficiency (Britt et al., 2003) indicates that an adjustment for digestibility, or energy content of feed, may be a critical component of applying RFI to dairy cattle.

Because feed costs account for such a large portion of the variable costs of producing milk, it would be advantageous to select cows that are most efficient in converting nutrients into milk. The RFI is a ratio of the measured energy intake of an animal to the calculated energy that is needed for maintenance, production, and body condition change (Veerkamp et al., 1995). This measure reflects the difference between observations for individual animals and estimates of energy use based on values for the population. Therefore, it is an indication of the variation associated with the observed performance and the predicted performance. the RFI is an attempt to holistically identify animals that are more efficient in converting feed energy to milk. The biology underlying these differences may be related to differences in the partial efficiencies of use of energy for maintenance, lactation, or BW gain. Using RFI focuses on identifying animals that are more efficient in converting feed to product but does not identify the reasons for these differences. Heritability estimates for RFI have been proposed and are between 0.30 and 0.38 (Veerkamp et al., 1995). Because of the close association between intake and milk production, the value in using RFI as a genetic selection tool has been questioned (Kennedy et al., 1993).

The coefficient of variation for maintenance for cows under controlled conditions is 8 to 10% (Van Es, 1961). Therefore within the concept of RFI, this variation could represent an opportunity to select animals with an inherently low maintenance requirement, and therefore, a high potential efficiency for channeling nutrients to milk or tissue gain. Because RFI is defined as the actual ME intake minus the estimated ME requirement, any lack of precision in calculating ME requirements for maintenance and production would be reflected as RFI. The value of RFI for an individual animal may differ from the population means due to either a difference from the population with regard to inherent efficiency of nutrient use for maintenance, lactation, or body gain (loss) or some unexplained factor. The latter might be a consequence of some of the factors described above, such as exercise activity or differences in visceral organ mass relative to BW. Little work has been attempted to determine if these traits are heritable in dairy cattle and their net contribution to efficiency of energy use over time.

Effects of Early Life Events on Maintenance Requirements

Considerable data indicate that events during certain critical periods of gestation can have a lasting impact on the metabolism of the offspring (Barker and Clark, 1997; McMillen et al., 2001). The fetal programming hypothesis of metabolic diseases has evolved from epidemiological data that linked low BW, maternal nutrition, and increased prevalence of adult disease (Barker and Clark, 1997). Several animal models have been developed to characterize the *in utero* events leading to these changes in metabolism, and one of the most widely used models of fetal programming is the pregnant sheep.

It is becoming increasingly obvious that epigenetic inheritance, or non-DNA based forms of heritability, may also be part of the fetal programming puzzle (Bogdarina et al., 2004). It appears that a portion of these changes may involve alterations in BMR. Although these effects have not been specifically documented for dairy cattle, the available evidence suggests that the potential exists in this regard.

A study in mature human subjects identified a correlation with body composition and energy expenditure that is linked to fetal growth and birth weight (Kensara et al., 2006). Specifically, low birth weight individuals displayed less fat free body mass as adults and had lower resting energy expenditure. The latter is not surprising based on the fact that low birth weight is often linked to increased risk of overweight and obesity and that the metabolic requirements of adipose tissue are less than for lean body mass. However, when resting energy expenditure is adjusted for weight and height, these differences of 12 to 15% for resting energy expenditure were still apparent between the groups, and most of the differences in energy expenditure were accounted for by altered lipid metabolism. Although the research cited here is related to human health and the risks associated with adult metabolic diseases, it provides an excellent example of the potential changes in biology that can lead to shifts in maintenance energy requirements. Similar programming effects may exist for dairy cattle and may impact requirements for maintenance, production, or both.

Application to Feeding Dairy Cattle

The conceptual framework of energy metabolism is the basis for the estimate of maintenance energy described by the NRC (2001) for dairy cattle. Values are based on measures in mature dry cows at 0.73 Mcal /kg $BW^{0.75}$ and allow for an adjustment for activity of 10% so that the values used are 0.80 Mcal /kg $BW^{0.75}$. Additional adjustments are made to maintenance based on conceptus weight and increased activity levels of grazing animals

The concept of maintenance assumes little variation among cows with regard to basal metabolism, and for dairy cattle, a lack of difference between breeds for maintenance energy requirements is assumed; however, there is considerable evidence to suggest differences in maintenance requirements among beef breeds (NRC, 1996). Early experiments suggested a similar scenario for dairy breeds (Van Es, 1961), but a more recent comparison of Holstein and Jersey cattle indicates that although milk production was greater for Holstein cows, the energy requirements per unit of metabolic weight were the same for both breeds (Tyrrell et al., 1991). Several other studies have failed to demonstrate appreciable differences in energetic efficiency between the Jersey and Holstein breeds.

The NRC (2001) accepts a lack of variability due to breed in assigning maintenance energy requirements, but it recognizes the effect of BW. The latter adjustment accounts for the fact that the energetic requirements for maintenance in a 1200 lb cow differ from a 1600 lb cow, but when expressed per lb of BW, the requirement is similar. This adjustment assumes that the effect of body composition on maintenance requirement is negligible. In laboratory species, it has been well characterized that body composition profoundly impacts basal metabolism. Lean body mass, due to the greater associated metabolic activity, is positively correlated with basal energy expenditure (Speakman et al., 2004). Perhaps a portion of the breed effect on maintenance requirements in beef cattle is due to inherent differences in lean tissue as a fraction of total BW among breed types. Likewise, similarities in lean mass percentage among dairy cattle breeds may be one of the underlying biological effects that obviate a breed adjustment for maintenance requirement.

Summary

Because feed costs represent a large portion of the costs of producing milk, factors that impact the efficiency of conversion of feed to milk are of considerable importance. Maintenance energy needs are a priority in the animal. Increased maintenance costs have a direct impact on the efficiency of conversion of feed to milk or tissue deposition. Conversely, a decrease in maintenance requirements or a dilution of maintenance in cows that are capable of producing greater amounts of milk is a management and selection goal in the dairy industry. Current management strategies, including cow cooling, reduced disease challenges, and eliminating stressors that might lead to increased nonexercise activity, all have an impact on maintenance requirement and therefore ultimately result in repartitioning of nutrients to milk production.

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