Does Negative Energy Balance (NEBAL) Limit Milk Synthesis in Early Lactation?

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▪ Take Home Message

- Early lactation cows are in negative energy balance and this is associated with metabolic problems and reduced reproduction.
- Negative energy balance also probably limits peak milk yield.
- Maximizing energy/nutrient intake in early lactation will improve transition success

▪ Introduction

Energy balance (EBAL) is the difference between energy consumed and energy used for both maintenance and production (milk, meat, reproduction, etc.). For a detailed description of the different methods of calculating EBAL see our recent review (Moore et al., 2005). Frequently in a cow's life cycle, there are instances when energy availability, or more specifically a lack of available energy, may limit milk or milk component synthesis, reduce reproductive performance and prevent body condition replacement. Examples include the transition period in both TMR and pasture-based systems, periods of poor feed quality and adverse environmental situations such as heat stress and drought. Incidentally this bioenergetic phenomenon is not exclusive to dairy cows, as most female mammals experience a similar nutrient imbalance after parturition and in fact, the severity of this nutrient inequality is quite minor in cows compared to a large number of other species (see our recent review, Collier et al., 2005).

Cows in early lactation typically cannot consume enough calories to meet the energetic requirements of maintenance and copious milk secretion, and consequently enter into a state of negative energy balance (NEBAL). In fact, reduced feed intake and NEBAL can be observed 7-10 days prior to calving.

Post-calving the severity, magnitude and day of NEBAL nadir (~4-9 days in milk) are closely associated with metabolic disorders and reproductive failures (Butler, 2000; Drackley, 1999; Buckley et al., 2003; Rhoads et al., 2005). The impact of NEBAL on reproductive parameters is even more critical in strict pasture-based systems as pasture allowance is restricted and calving patterns must coincide with forage availability to maintain farm sustainability (Rhodes et al., 2003). Attempts to improve or alleviate NEBAL traditionally involve increasing dietary energy density via the addition of concentrates or fats (Schingoethe & Casper, 1991; Hayirli & Grummer, 2004). However, the effectiveness of these dietary strategies is frequently inconsistent and is associated with potential drawbacks (i.e. acidosis and reduced DMI; Hayirli & Grummer, 2004). There are a number of reviews concentrating on the benefits and limitations of increasing the dietary content of grains and fats with regards to EBAL and they will not be discussed further in this paper.

Interestingly and contrary to what is often reported (Broom, 1995; Veerkamp, 1998; Veerkamp et al., 2000; Heuer, 2004; Oltenacu & Algers, 2005), genetically superior or higher producing cows have similar calculated NEBAL parameters (severity, magnitude etc.) and blood energetic variables when compared to their lesser producing herd mates (Vicini et al., 2002; Crooker et al., 2006). The increased milk yield associated with genetic progress is accompanied by homeorhetic mechanisms that favor increased feed intake during early lactation (Crooker et al., 2001; Crooker et al., 2006). It is logical to predict that selecting animals for increased milk production simultaneously selects animals capable of coordinating metabolism to sustain evolutionary advantages. Furthermore, the fact that genetic selection for milk yield doesn't intensify NEBAL parameters, jeopardize health or cause cow "burn out" is due to natural coordinated homeorhetic mechanisms as we recently described (Collier et al., 2005).

▪ Metabolic Adaptations to Reduced Nutrient Intake

The early lactation cow is a classic example of lactation-induced NEBAL resulting from an inability of the cow to consume enough feed to meet the energy demands of lactation and maintenance requirements (Moore et al., 2005). Negative energy balance is associated with a variety of metabolic changes that are implemented to support the dominant physiological condition of lactation (Bauman and Currie, 1980). Marked alterations in both carbohydrate and lipid metabolism ensure partitioning of dietary-derived and tissue-originating nutrients towards the mammary gland, and not surprisingly many of these changes are mediated by endogenous somatotropin which is naturally increased during periods of NEBAL (Bauman and Currie, 1980). One characteristic response is a reduction in circulating insulin coupled with a reduction in systemic insulin sensitivity. Compared to a well-fed cow in positive energy balance, the reduction in insulin action allows for adipose lipolysis and mobilization of non-esterified fatty acids (NEFA; Bauman and Currie, 1980). Increased circulating NEFA are typical in "transitioning" cows and represent a significant source of energy (and precursor for milk fat synthesis) for cows in NEBAL. Post-absorptive carbohydrate metabolism is also altered by the reduced insulin action during NEBAL with the net effect of reduced glucose uptake by systemic tissues (i.e. muscle and adipose). The reduced nutrient uptake coupled with the net release of nutrients (i.e. amino acids and NEFA) by systemic tissues are key homeorhetic (an acclimated response vs. an acute/homeostatic response) mechanisms implemented by cows in NEBAL to support lactation (Bauman and Currie, 1980).

▪ Bioenergetics of Production

It is well known that animals primarily eat to meet their energy requirements (Church and Pond, 1988), but this is slightly complicated in ruminants due to the effects of forage quality and gut fill (Van Soest, 1982) and the hepatic oxidation hypothesis of feed intake regulation (Allen et al., 2005). Nonetheless, if an animal is in positive EBAL (PEBAL), providing additional metabolizable energy (ME) should not theoretically increase milk yield, but rather decrease feed intake and thus improve efficiency. In contrast, if an animal is in NEBAL, adding additional ME would logically increase milk production without altering feed intake. Both of the above scenarios assumes that calculated net whole animal EBAL is tightly linked with the mammary gland's energetic and nutrient requirements to synthesize milk. Adding additional energy (or any nutrient for that matter), if milk synthesis wasn't limited by nutrient availability, can not "push" milk as milk synthesis itself "drives/pulls" nutrient and energy intake (i.e. DMI; Bauman & Currie, 1980; Collier et al., 2005). As demonstrated in Figure 1, predicting the effects (milk yield, DMI and feed efficiency) of enhanced ME probably depends on whether or not the animal is in NEBAL or PEBAL.

During established lactation, decreased energy and nutrient availability (either experimentally induced or due to poor feed quality [drought, heat stress, spoiled feed, etc.]) is closely matched by a coinciding decrease in milk yield. As a consequence of the reduction in milk synthesis, actual calculated net EBAL remains near zero. When nutrient supply or the level of nutrition increases, milk yield parallels the enhanced nutrient state. Therefore, clearly in mid to late lactation, nutrient/energy availability can limit or restrict milk synthesis.

During early lactation the connection between nutrient supply and milk production appears uncoupled. This is especially obvious during the first 10 days in milk (DIM) where milk yield is increasing at a steep slope while calculated EBAL is simultaneously decreasing towards its nadir (see theoretical diagram in Figure 1). Milk yield continues to increase until peak

(~40-70 DIM) while cows are still in calculated NEBAL (albeit progressing towards PEBAL; Figure 1). Obviously tissue mobilization accounts for the energy deficit in early lactation, but it's interesting that there is a stark contrast between dietary energy/nutrient supply and milk production during early vs. later lactation. Why doesn't tissue mobilization compensate for the decrease in nutrient supply and thus maintain production in later lactation, even temporally?

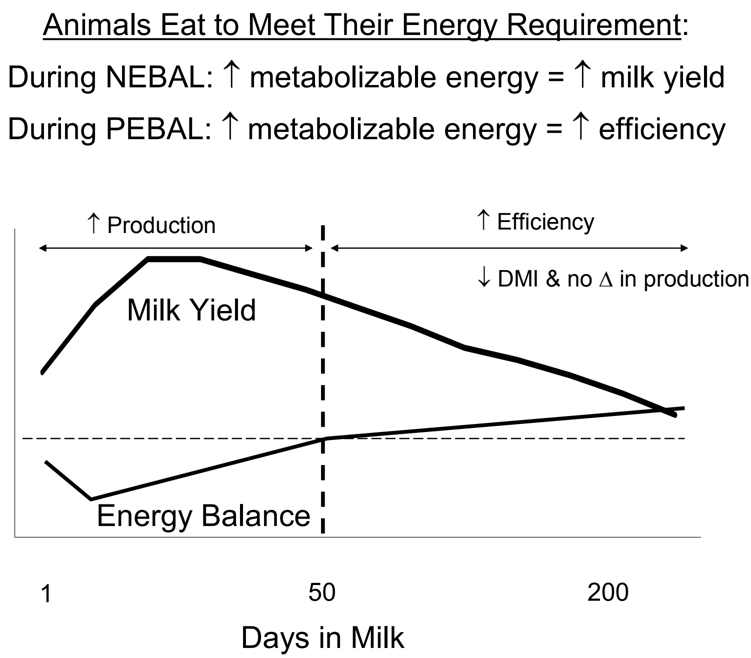

Figure 1. Theoretical lactation and energy balance curves. Bioenergetics would predict that increasing metabolizable energy will have different effects on production parameters depending upon calculated energy balance status.

Although early lactation NEBAL is frequently blamed for a variety of metabolic and reproductive disorders (Drackley, 1999; Butler, 2000), whether or not it limits or prevents maximum milk yield is not clear. Attaining a high milk yield in early lactation and specifically peak milk yield, is thought to "prime" the gland for the entire lactation, and retrospective statistical analysis indicates that for every one unit (kg or lb etc.) increase at peak lactation equates to a 127 unit increase in total lactation yield (Dr. Bob Everett, Cornell University; Personal Communication). A variety of different approaches have attempted to alter or improve EBAL and they include 1) supplemental fats, 2) additional concentrates, 3) reduced milking frequency (i.e. 1x/d), 4) propylene glycol, 5) monensin and 6) conjugated linoleic acid induced milk fat depression (CLA-

MFD). The first four approaches have limitations (i.e. palatability, acidosis, mammary function, etc.) that create difficulties when evaluating their effect on EBAL.

▪ Conjugated Linoleic Acid Transition Trials

A unique approach to improve transition period EBAL is to decrease the milk energy content, thus manipulating the energy expenditure side of the EBAL equation, rather than the energy intake portion. Fat is the most energetically expensive milk component to synthesize (50% of total milk energy; Tyrell & Reid, 1965) and the milk parameter most easily manipulated by management (Bauman & Davis, 1974; Bauman et al., 2001). Therefore, governing milk fat via controlled MFD offers a novel technique/opportunity to improve EBAL through the transition period.

We've conducted three CLA-MFD trials during the transition period (Moore et al., 2004; Kay et al., 2004; Odens et al., 2006), with the two latter trials designed to evaluate the effects of CLA-MFD on EBAL parameters and production variables. As we predicted (Baumgard et al., 2002), both trials indicate that when EBAL is improved due to CLA-MFD, milk yield is enhanced (Figures 2 and 3). Furthermore, during experimentally induced NEBAL in established lactating cows, CLA-MFD increases both milk yield and milk protein synthesis (DeVeth et al., 2006; Kay et al., 2007). As would bioenergetically be predicted by Figure 1, CLA-MFD does not increase milk yield during established lactation when cows are in PEBAL (Geisy et al., 2002; Perfield et al., 2002). Our studies demonstrate that a dietary supplement of CLA reduces milk fat synthesis immediately postpartum and may be useful as a management tool to alleviate NEBAL and improve milk production in TMR and pasture-fed dairy cows.

▪ Monensin Transition Trials

Another dietary approach to improve transition EBAL that has recently become available to dairy producers is monensin (Rumensin, Elanco Animal Health, Greenfield, IN). Feeding ionophores, specifically monensin, alters rumen metabolism/physiology to favor a more energetic fermentation pathway (see reviews by Schelling, 1983; Ipharraguerre & Clark, 2003). A number of papers demonstrate an improved energy status (NEFA, ketones, glucose etc.) with monensin (Ipharraguerre & Clark 2003) and this is especially apparent in early lactation (Green et al., 1999; Duffield et al., 2003; Melendez et al., 2004; Gallardo et al., 2005; Zahra et al., 2006). As would bioenergtically be predicted by Figure 1, monensin feeding typically increases milk yield with no effect on feed intake during early lactation (Hays et al., 1996; Beckett et al., 1998; Gallardo et al., 2005). In contrast, during later lactation, monensin improves feed efficiency (little or no change in milk yield coinciding with small reductions in feed intake; see reviews by Ipharraguerre & Clark, 2003 and McGuffey et al. 2003.

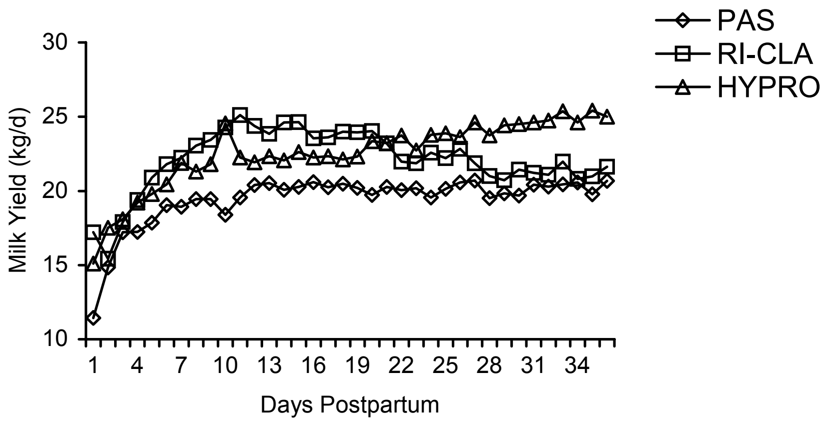

Figure 2. Effects of pasture fed cows (PAS) supplemented with rumen inert palm oil (HYPRO) or CLA on milk yield in transitioning lactating dairy cows. Adapted from Kay et al. 2006.

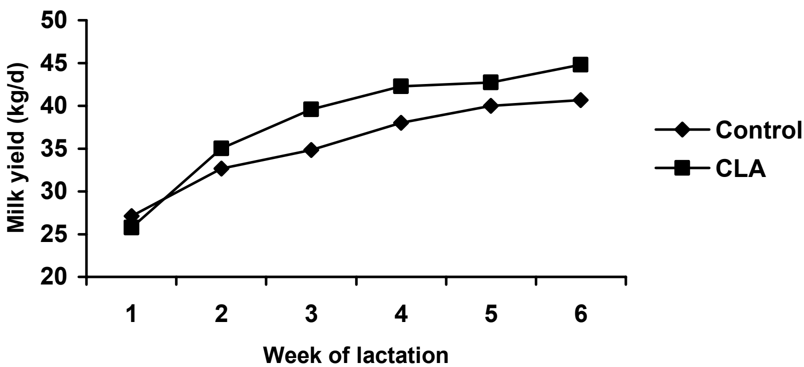

Figure 3. Effects of rumen inert CLA on milk yield compared to cows fed a rumen inert palm oil. Adapted from Odens et al., 2007

▪ Summary

Based on evidence from transition period CLA-MFD and monensin trials, it appears that milk yield in early lactation is limited by a lack of energy intake. Obviously anything that increases ME during this stage of lactation would potentially benefit milk production, whereas increasing ME during mid to late lactation, a period when cows would presumably be in PEBAL, wouldn't logically increase milk yield but probably increase feed efficiency.

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