Review: Effects of Negative Energy Balance on Health and Milk Yield of Lactating Dairy Cattle

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Abstract
During early lactation, there were elevated demand for energy for more milk production, but a lag in feed intake created negative energy balance. The cow drew from body reserves for milk which led to release of free fatty acids and production of ketone bodies; acetone, acetoacetate and beta-hydroxybutyrate, that served as a source of energy when carbohydrate levels were low. The accumulation of these compounds could have lead to ketosis, a condition that found to reduce milk yields. A loss of 25% per lactation during clinical ketosis and 1-1.5kg/day of milk production for subclinical ketosis was reported. Clinical ketosis occurred in the first six to eight weeks post calving and resulted in loss of body condition and decrease in milk. The milk fat of ketotic cows increased due to the availability of beta-hydroxybutyric and fatty acids. Cows with clinical ketosis showed nervous signs, such as licking and blindness. Subclinical ketosis caused increased levels of circulating ketone bodies in serum, milk and urine. Negative energy balance had direct correlation to energy metabolisms, which could have been determined by measuring the amount of None- Esterified fatty acids in the blood and thus identify cows at risk.

Keywords: Negative energy balance, Milk yield, cow disorder

Introduction
Selective breeding of dairy cattle has led to a dramatic increase in milk yield per cow where it has more than doubled in the past 40 years. This increase in yield has been accompanied by declining ability to reproduce, increasing incidence of health problems and declining longevity in modern dairy cows (Oltenacu and Algers, 2005). Immediately after parturition cattle produce a lot of milk, ideally the animal attains its peak production in the first few weeks following parturition. The energy expended in producing the milk, however, is not commensurate to the amount of energy derived from the feed consumed. To compensate for the deficit the cow begins to mobilize its energy reserves, although, this does not enable it to meet the requirement and therefore goes to a state of negative energy balance. The amount of energy...
for milk production and maintenance exceeds the energy derived from the feed intake and body energy reserves. Soon after parturition, the cow’s diet changed from dry cow feed, which is relatively low to a high-energy one, however the cow’s low appetite and capacity cannot allow her to consume adequate amounts required for energy for production of milk and body maintenance.

During this struggle, cows are in a state that is referred to as negative energy balance as depicted in figure 1, where daily energy balance is determined by the amount consumed (feed energy) as compared to the requirements for milk production and maintenance.

![Figure 1: Typical Energy Curves for the Lactating Dairy Cow](source)

**Source:** Agriculture and Agri-Food Canada Dairy and Swine Research and Development Centre in Lennoxville, Quebec

After the stress of calving, dairy cows have to deal with an extremely quick change in diet from that designed to provide low in energy and protein with mainly roughage for the dry period to a high-energy, high protein one designed for peak yields in early lactation. Often cows are unable to consume enough feeds to meet the amount of energy required for body maintenance and production of large quantities of milk that is why they begin to use adipose tissue to account for their insufficient intake.
Review

High yielding dairy cows have been selected and bred to produce more milk through their ability to mobilize stored fat and muscle in order to support high yields during early lactation when the appetite has not picked up to facilitate high feed intake. This normally results into loss of body condition and is associated with alteration in body metabolites and hormone profiles, which in turn influences fertility (Kadakowa et al., 2000). Two studies conducted in 1998 and 1997 covering 10,569 and 33,732 lactating cows respectively provided the data in table 1 that shows the genetic correlations between milk production level (305-day milk yield), health, welfare and fertility traits in dairy cattle.

Table 1: Genetic correlation between milk yield and various traits
(Pryce et al., 1998)

<table>
<thead>
<tr>
<th>Trait</th>
<th>0.28 ± 0.06</th>
<th>0.50 ± 0.06</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calving interval (days)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Days to first service (days)</td>
<td>0.41 ± 0.06</td>
<td>0.43 ± 0.08</td>
</tr>
<tr>
<td>Conception at first service</td>
<td>-0.12 ± 0.08</td>
<td>-0.19 ± 0.11</td>
</tr>
<tr>
<td>Somatic cell score</td>
<td>0.16 ± 0.04</td>
<td>not reported</td>
</tr>
<tr>
<td>Mastitis</td>
<td>0.29 ± 0.05</td>
<td>0.21 ± 0.06</td>
</tr>
<tr>
<td>Milk fever</td>
<td>not reported</td>
<td>0.19 ± 0.06</td>
</tr>
<tr>
<td>Lameness</td>
<td>0.13 ± 0.06</td>
<td>0.29 ± 0.11</td>
</tr>
</tbody>
</table>

Through studies, it has been possible to determine maximum daily difference between milk production and feed intake, length of time it takes for a cow to reach a positive energy balance, total amount of energy lost during the period of early lactation and the economic loss incurred during the period of negative energy balance (McGuire et al., 2004). These researchers found that high yielding dairy cows return to positive energy balance 6 to 7 weeks postpartum.

The cow needs to be evaluated frequently during early lactation when body condition, as it reflects energy reserve, has its greatest impact on the health, production and fertility of the dairy cow (Parker, 1994). There are also other significant observations associated with negative energy balance that include, general disorders, Laminitis, digestive disorders such as Ketosis, displaced abomasums and Milk fever.

Laminitis

About 50% of all dairy cows go through a temporary period of sub-clinical ketosis in their first month of lactation (Knop et al., 2009). Low energy intake during early lactation may lead to high rates of fat mobilization and increased risks of accumulation of fat in the liver which may lead to ketosis.
Hyperalgesia (increased sensitivity to pain) occurs in chronically lame cows and may persist for a long period after healing of the lesion. If the dietary supply of proteins and glucose is insufficient, fatty acids will accumulate in the liver and ketones in the blood. Fat accumulation in the liver will impair it from functioning leading to decrease efficiency of utilization of nutrients. Accumulation of ketones in the blood affects its acidity, which decreases the efficiency of utilization of nutrients and energy by the brain leading to nervous symptoms and death (Whay et al., 1998).

The state of negative energy balance is associated with welfare of the individual animal overall drop in milk production during the lactation period. Much of the fatty acids released from the breakdown of fat reserves are transported into the liver and converted to Ketones, an alternative fuel for body functions when other nutrients are used for milk production. Proteins are required for transportation of fatty acids and glucose to convert ketones to energy (weaver, 2000).

In addition to defining relationships between energy balance and health, 86% of the first cases of laminitis occurred during the period of lactation when negative energy balance was the most severe. Laminitis is probably not a direct result of negative energy balance, but rather a consequence of a complex of metabolic factors that affect a cow's ability to eat sufficient amounts of dry matter in early lactation. An insufficient amount of roughage dry matter intake in early lactation can cause acidosis and the repercussions of this digestive disease can indirectly affect blood flow to the hoof eventually causing laminitis (weaver, 2000).

Dairy farmers gain revenue from the production of large quantities of milk. Therefore, it is not surprising that this incentive to improve milk production has dominated the dairy cattle breeding industry. Dairy cattle breeders have been extremely successful in improving the dairy cow's ability to produce milk. However, concerning the individual cow, the financial advantage of striving for high milk yield could result in undesirable consequences (Mongate et al., 2007).

Amory et al (2008) found that high yielding cows were more likely to become clinically lame with sole ulcer or white line disease and that the milk production of affected cows fell to below the mean of unaffected cows and remained low after diagnosis; the loss of milk yield attributable to these conditions was about 370kg to 570kg over the lactation. Approximately 75% of cases of laminitis occur in the outer claw of the hind feet due to uneven load on the outer and inner claws, as a result of the greatly distended udder in modern high yielding cows, undoubtedly predisposes to lameness (Webster, 2004).
Metabolic Disorders
Metabolic or production diseases are a manifestation of the cow’s inability to cope with the metabolic demands of high production. According to Webster (1994), in most practical circumstances, the capacity of the mammary gland to synthesize milk exceeds the capacity of the cow upstream to find, eat and digest enough feed to supply the mammary gland with nutrients, leading to her feeling hungry and physically tired.

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Metabolic or production diseases occur when the cow is unable to meet the acute or chronic metabolic demands of maintenance, pregnancy and lactation. In the most acute forms such as milk fever or grass staggers, the cow simply runs out of calcium or magnesium respectively and, if untreated is lethal, other conditions such as ketosis and fatty liver syndrome are due to abnormal demands on energy, especially fat metabolism (Rauw et al., 1998).

Cattle are adapted for a high fibre, low energy forage-based diet. The use of low fibre, high energy concentrate-based diets, in an attempt to meet the nutrient requirements of the high yielding cow, can lead to a range of production diseases, including rumen acidosis (Morgante et al., 2007).

Longevity
The drive to increase milk yield in the modern dairy cow has resulted in declining average longevity in many high genetic merit dairy herds in the UK. Not only has the welfare of the cow suffered, but the process is ultimately self-defeating for the farmer because the margin of milk sales over feed costs in the first three lactations is usually not large enough for the cow to make a profit so a cow becomes profitable only when she reaches her fourth lactation (Esslemont and Kossaibati, 1997). Optimal lifetime efficiency is reached after five or six lactations for cows yielding 12,000 litres and the loss in efficiency is 5% and 10% for lifetimes of three and two lactations respectively (Webster, 2000).

Infertility, mastitis and lameness are major causes of culling and therefore important factors in the declining longevity of the dairy cow. Nørgaard et al. (1999) concluded that a higher level of physiological stress due to higher milk yield and concentrate consumption has led to increased mortality in dairy cattle.

Studies have established that the more severe negative energy balance became more health problems tended to occur. In addition, these cows had a 50% increase in the difference between peak milk yield and the amount of feed they were able to consume to support that production, compared to average cows in the herd. Cows that suffered from digestive problems tended
to have extremely severe negative energy balance. They tend to take nearly two weeks longer to return to a positive energy balance and loose over 20% more energy in total in early lactation, compared to average cows in the herd. Cows with more severe or sustained periods of negative energy balance that tended to lose more body condition, compared to average cows in the herd, were also more likely to suffer from metabolic and locomotive disorders.

Theoretical Analysis

The main problems that may arise through breeding, feeding, housing or manipulation of cows for high productivity include: acute metabolic disorders, due to an imbalance between nutrient supply and demand; Chronic discomfort, through bad housing and loss of condition; restricted movement due to distortion of body shape and pain, increased susceptibility to infectious or metabolic disease and physical exhaustion after prolonged high production.

The extend of negative energy balance and the rate of recovery of energy balance appear to be very important. In well fed cows, negative energy balance begins to improve on the 4th week of lactation, but picks on the 10th week. Recovery of energy balance from its most negative state may be a signal of initiation of ovarian activity. First ovulation usually occurs at 17 to 42 days after parturition. The greater the level of milk production, the slower the cow is to first ovulation, leading to increased calving interval and lowered total milk yield for the herd (Leslie et al., 2003).

Cows that suffer from laminitis generally take a week longer to come out of negative energy balance, and have a 15% greater total energy loss compared to the average cow in the herd. The direct effects of pain as a result of lameness include weight loss, reduced milk yield and an increased risk of infertility, mastitis and culling.

Energy balance is measured by either direct or indirect calorimetry, however these methods are not complicated, labour intensive but are also very expensive. An alternative method is to measure or estimate the energy balance is to calculate the difference between energy consumed and the energy required for maintenance and milk production. The method is cheap and easy to carry out; it also does not require sophisticated equipment. The major disadvantage being due to the fact the results are but estimates. The result’s accuracy can be enhanced by ensuring accuracy in the determination of energy of the feeds consumed and the amount of milk as well as energy for maintenance.
Measuring feed intake in early lactation is necessary for the estimation of energy balance. Cows fed using an automated feeding system allow daily individual feed intakes to be recorded. In addition to daily feed intake and milk production, complete health and reproductive information are necessary.

Computation of the difference between the energy derived from the feed intake, the total energy required for maintenance, and milk production was used to determine the energy balance, which is often negative during early post-partum.

**Application**

The feeding program of early lactation targets to achieve maximum dry matter intake, high ration digestibility and supply adequate amount of proteins for the supply of sufficient amino acids, normally the cow has limited protein reserves to draw from for utilization of ketone bodies and milk production.

Cows with larger body dimensions produce more milk, more efficiently due to their ability to consume larger quantities of inexpensive forages. Traits associated with frame and capacity, size, and stature are considered positively breeding programs.

In spite of the potential health problems, there seem to be some advantages to breeding dairy cattle for size and capacity. Larger cattle tend to grow faster and reach breeding size at a younger age than smaller cattle. Larger cattle will yield a higher salvage value when culled. Larger, deeper cattle have the capacity to eat more roughage that is inexpensive and therefore have the potential to produce higher quantities of milk. On the other hand, while these larger cows may have the capacity to eat more, their maintenance requirements are also higher.

Preventing excessive mobilization of body fat in the first 4 weeks of the dairy cow’s lactation is of primary importance for subsequent fertility. Cows will tolerate a loss of approximately 1 body condition scoring unit in the first 4 weeks after calving; more extreme condition loss will result in lower conception rates at first service. One unit change in body condition score represents about 60 kg of body weight change and about 400 Mcal of energy.

Feeding management that maximizes dry matter intake is also essential to minimize body condition loss and to reinitiate ovarian cycles within approximately three weeks after calving. Ideally, the second ovulation will
occur by 50 days after calving when uterine involution and repair will also be complete. Increased negative energy balance may delay first ovulation 60 to 75 days or longer extending the postpartum effects and recovery of the uterine environment.

**Conclusion**

Selective breeding for increased milk yield is the root cause of declining longevity and unacceptably high levels of lameness and metabolic diseases. Dry matter intake is important in managing the degree and severity of the impacts of negative energy balance in the first 6 weeks of lactation. The stimulation of appetite to ensure adequate dry matter intake in normal, healthy cows is essential to provide nutrients for maximum milk production, follicular growth, ovulation, uterine involution, and the initiation of pregnancy. Nevertheless, dairy cows with greater dry matter intake, despite having a negative energy balance, produced more milk, lost less body weight, and ovulate earlier postpartum than those with lower intake.

Increased feeding frequency and better feed trough management to maintain a fresh, adequate supply of feed and multiple sources of clean water are critical for stimulating appetite and maximizing dry matter intake.

**References**


