Manipulation of energy balance and its implications for fertility in dairy cows

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Introduction

High-yielding dairy cows are usually in negative energy balance during the first few weeks of lactation when energy output in milk exceeds energy intake from the diet. As a consequence, body fat reserves are mobilised to make up the energy deficit. Many studies have shown that rapid mobilisation of body fat reserves is associated with fertility and health problems in dairy cows, so it is desirable to minimise the magnitude and duration of negative energy balance. This is not easy to achieve by manipulating lactational diets because, as discussed later, the cow might have a biological drive to mobilise body fat. The most successful strategy for minimising negative energy balance is to manipulate body condition score (BCS) at calving, which influences feed intake and milk yield for the rest of lactation (Garnsworthy, 2006).

Body condition score, dry matter intake and energy balance

Body fat reserves play an important biological role in early lactation by buffering the cow against feed shortages whilst she partitions energy mainly towards milk output. Studies in the 1980s showed that body fat has a negative feedback effect on feed intake. In two experiments, Garnsworthy and Topps (1982) studied cows with BCS (1-4 scale) at calving of 1.7 (Thin), 2.7 (Medium) or 3.7 (Fat). After calving, all cows were offered a high-energy total-mixed ration (TMR) *ad libitum*. There was no effect of BCS at calving on milk yield. Over the first 12 weeks of lactation, cows that were fat at calving lost 0.9-1.0 BCS units; cows with medium BCS at calving lost 0.5-0.6 BCS units; cows that were thin at calving gained 0.4-0.5 BCS units. BCS tended to converge at 2.5 in week 12-15 of lactation (Figure 1a), suggesting that cows have a target BCS that they try to attain in early lactation. Milk yield peaked in week 6 of lactation for all groups of cows (Figure 1b); maximum dry matter intake was reached in week 15 for fat cows, week 11 for medium cows and week 9 for thin cows (Figure 1c). This suggested that feed intake was controlled by physiological feedback mechanisms and that level of body fat had a direct effect on feed intake.

Leptin has subsequently been established as the most likely feedback mechanism (Vernon et al., 2001), although the overall regulatory system is complex. In addition to its effects on feed intake, leptin has been found to modulate nutrient transfer and partitioning by interaction with other hormones including insulin, glucagon, glucocorticoids, growth hormone, insulin-like growth factor-I, cytokines and thyroid hormones (Hill, 2004). Other factors secreted by adipose tissue (tumour necrosis factor α and resistin) have also been shown to interact with leptin in regulation of adiposity (Vernon et al., 2001).

Numerous studies (reviewed by Garnsworthy, 1988; Broster and Broster, 1998; Stockdale, 2001; Garnsworthy, 2006) confirm the strong negative relationship between BCS at calving and change in BCS during early lactation, although the slope of the relationship is lower for recent studies (Figure 2). Each individual dairy cow has a genetically-programmed target BCS that she attempts to reach approximately 10 to 12 weeks after calving. If her BCS is above this target, feed intake is reduced and she loses condition; if her BCS is below this target, feed intake is increased and she gains condition. The biological drive for a cow to attain a target BCS appears to be as strong as the drive to attain a genetically-programmed peak milk yield. The philosophy of getting cows in 'good condition' at calving is, therefore, counter productive. Instead of a high BCS at calving compensating for low feed intake in early lactation, it actually reduces feed intake further and exacerbates negative energy balance.

Body condition score and diet interactions

The relationship between BCS at calving and change in BCS during early lactation applies across all feeding systems. Studies reviewed by Garnsworthy (1988) and Broster and Broster (1998) included cows fed on TMRs, hay plus concentrates, and self-feed silage. Stockdale (2001) extended the review to include grazing studies, which confirmed that pasture-fed cows exhibit the same strong relationship. However, the ability of cows to reach their target BCS is affected by diet composition.

With high-energy diets, thin cows can be in positive energy balance and increase BCS, but fat cows will be in negative energy balance and decrease BCS. With low-energy diets, feed intake is limited by physical capacity of the rumen and thin cows cannot increase energy intake to match milk energy output; fat cows mobilise body condition at a faster rate to support milk production and are in negative energy balance longer than with high-energy diets (Jones and Garnsworthy, 1989). There is scope for reducing BCS loss of fat cows by increasing dietary energy concentration: Chilliard et al. (1991) found that cows offered 1.5 kg/d extra concentrate supplement lost 0.1 units less BCS during the first 8 weeks of lactation; Mao (2004) found that cows on a normal plane of nutrition lost 0.2 BCS units less than cows on a low plane of nutrition.

High-protein diets result in greater loss of body condition by fat cows, but either increase BCS gain or decrease BCS loss by thin cows which use excess protein for gluconeogenesis (Garnsworthy and Jones, 1987; Jones and Garnsworthy, 1988). Low-fibre, high-starch diets increase BCS gain in thin cows and decrease BCS loss in fat cows, probably by increasing insulin status (Garnsworthy and Jones, 1993). High-fat diets decrease BCS loss in fat cows, but do not affect BCS change in thin cows (Garnsworthy and Huggett, 1992). However, a diet with high concentrations of both fat and protein can result in greater losses of body fat than diets that are high in only one of these components (Beever et al., 2004).

Energy balance, health and reproduction

Cows that are excessively fat at calving are more likely to develop fatty liver and ketosis because high BCS depresses appetite severely and body fat is mobilised too rapidly (Reid et al., 1986). Such cows exhibit severe negative energy balance, poor reproductive performance and increased incidence of diseases (Treacher et al., 1986). Risk of fatty liver increases considerably when BCS is above 3.5 at calving (Treacher et al., 1986; Jorritsma et al., 2001). Gillund et al. (2001) found that cows calving with a BCS of 3.5 or greater were 2.3 to 2.8 times more likely to experience ketosis compared with a BCS of 3.25 or lower. Other disease problems have also been linked with BCS. Relationships are variable and inconsistent, but excessive loss of BCS in the dry period or early lactation, low BCS at drying off, and high BCS at calving, have been associated with increased risks of dystocia, retained placenta, metritis, milk fever, mastitis and lameness (see for example: Treacher et al., 1986; Gearhart et al., 1990; Markusfeld, 1997).

Even moderate levels of fat mobilisation are associated with negative energy balance and reduced fertility. Several studies have shown that high genetic merit, negative energy balance, body fat mobilisation, high plasma non-esterified fatty acids (NEFA), and low plasma insulin are all associated with delayed first ovulation postpartum and reduced pregnancy rates (see reviews by Garnsworthy and Webb, 1999; Butler, 2003; Pryce et al., 2004; Butler, 2005). Butler (2005) reported that cows losing less than 0.5 BCS over the first 30 days postpartum took an average of 30 days from calving to first ovulation; cows losing 0.5 to 1.0 BCS took 36 days; cows losing more than 1.0 BCS took 50 days. Bourchier et al. (1987) surveyed 2000 cows in high-yielding herds and found a significant effect of BCS change on conception rate to first service: cows gaining condition during the first 12 weeks of lactation had a 67 % conception rate; cows losing 0.5 to 1.0 BCS had a 55 % conception rate; cows losing more than 1.0 BCS had a 47 % conception rate. A similar relationship was found by Butler (2005), who concluded from several studies that conception rate decreases by 10 % per 0.5 unit BCS loss. In reviewing physiological mechanisms, Butler (2003) reported that negative energy balance is strongly associated with attenuation of LH pulse frequency and low levels of blood glucose, insulin and IGF-I that collectively limit oestrogen production by dominant follicles; with diminished quality of oocytes and capability for embryo development; and with reduced serum progesterone concentrations.

Lopez-Gatius et al. (2003) performed a meta-analysis of 15 papers corresponding to nearly 8,000 cows to examine relationships between BCS and reproductive performance. Compared with cows losing 0 to 0.5 BCS, cows losing 0.5 to 1.0 BCS took 3.5 days longer to conceive, and cows losing >1.0 BCS took 10.6 days longer to conceive; cows gaining BCS took 3.7 days less to conceive.

Energy balance and genetic merit

The biological drive for a cow to attain a target BCS appears to be as strong as the drive to attain a genetically-programmed peak milk yield. It also appears that a cow's biological target BCS is determined by genetics. In a classic study reported by Holmes (1988), cows of high genetic merit showed a lower target BCS than cows of low genetic merit; both groups of cows achieved their targets, whether they had a high or low BCS at calving (Figure 3).

Jones et al. (1999) found significant phenotypic and genetic differences among bulls in the shape of the BCS curves followed by their daughters (Figure 4). These data suggest that it should be possible to select bulls on the basis of BCS curves of their daughters, but whether genetic BCS curves are related to fertility remains to be seen.

Dechow et al. (2002) examined correlations between BCS and BCS loss in 310,000 lactation records. Phenotypically, an increase in BCS at calving was associated with more BCS loss in early lactation, as expected if cows are attempting to reach biological targets for BCS. Genetically, however, higher BCS at calving was correlated with less BCS loss during early lactation. In other words, management conditions that increased BCS at calving resulted in greater BCS loss, but genetically fat cows maintain BCS in early lactation. Differences between phenotypic and genetic relationships are seen also for fertility traits and BCS (Pryce et al., 2001).

These conflicting genetic and phenotypic results emphasise the importance of distinguishing between genetic fatness and phenotypic fatness when trying to control energy balance through manipulating BCS. Therefore, BCS at calving must be assessed relative to the cow's genetic target.

Body condition score in later lactation and the dry period

Negative energy balance can be reduced partially by increasing the plane of nutrition during early lactation. Much greater benefits can be achieved, however, by controlling BCS during mid- to late-lactation and the dry period. In mid- to late-lactation, BCS usually increases (e.g. Mao et al., 2004), but is sometimes maintained at target levels (e.g. Yan et al., 2006), and might decrease if feed supply is restricted (e.g. Pryce and Harris, 2006). It is not clear whether BCS usually increases in later lactation because BCS targets vary with stage of lactation, the feedback signal is down-regulated, or different constraints assume priority. Declining milk yield, coupled with relatively high intake of dry matter, would lead to increases in insulin status. Increasing insulin would encourage deposition of body fat, but feedback from leptin and its associated factors would have a delayed effect on dry matter intake (Chilliard et al., 2001).

During the dry period, BCS is more likely to increase than during lactation because plasma insulin is considerably higher in dry cows (Grum et al., 1996). For this reason, producers who wish to increase BCS of cows that are thin at drying off often feed dry cows above their requirements for maintenance and pregnancy. On the other hand, cows with a high BCS at drying off are often fed on a low plane of nutrition so that body fat is mobilised in late gestation. Such practices should be avoided. There is no benefit from higher BCS at calving, which will increase negative energy balance and disease susceptibility. Cows that lose BCS during the dry period are more prone to dystocia (Gearhart et al., 1990; Keady et al., 2005) and are more likely to be culled in their subsequent lactation (Gearhart et al., 1990). The best strategy is to monitor BCS in late lactation and ensure that the cow is dried off with a BCS that is desired at calving.

Body condition score targets for production and fertility

The relationship between BCS at calving and change in BCS during the first 10-12 weeks of lactation is similar to that seen 20 years ago (Figure 2). BCS at calving predicted to give no change in early lactation has decreased from 2.49 in older studies to 2.10 in recent studies. A loss of 0.5 BCS units is considered acceptable and provides a safety margin to allow for variation among cows within a herd. It is recommended, therefore, that BCS should be in the range of 2.5 to 3.0 at calving to minimise negative energy balance.

Conclusions

Changes in BCS during early lactation highlight the role of body fat in controlling feed intake and energy balance. The strong relationship between BCS at calving and change in BCS provides evidence that cows have a target BCS in early lactation. Cows that are fatter than their target BCS mobilise body fat; cows that are thinner than their target BCS gain body fat. The rate at which a cow changes BCS towards its target is affected by diet composition as well as the cow's current BCS; low energy and high protein diets increase BCS loss in cows that are above target BCS; low energy diets reduce BCS gain in cows that are below target BCS.

Cows of high genetic merit are likely to experience deeper and more prolonged negative energy balance in early lactation. Negative energy balance is undesirable because it reduces reproductive performance and increases susceptibility to diseases. Therefore, short-term financial gains in extra milk production from cows that are fat at calving will be offset by longer-term financial losses through premature culling. Changes in BCS during the dry period are undesirable, so BCS should be monitored and adjusted in late lactation to ensure that cows are dried off with a BCS appropriate for calving.

To reduce the impact of negative energy balance on cow health and performance, BCS at calving should be no more than 0.5 BCS units above a cow's target BCS. Cows of low genetic merit for milk yield (target BCS 2.5-3.0) should calve with BCS of 3.0 or less; cows of high genetic merit for milk yield (target BCS 2.0-2.25) should calve with BCS of 2.75 or less. The most important message for producers is that increasing BCS at calving exacerbates negative energy balance problems instead of overcoming them.

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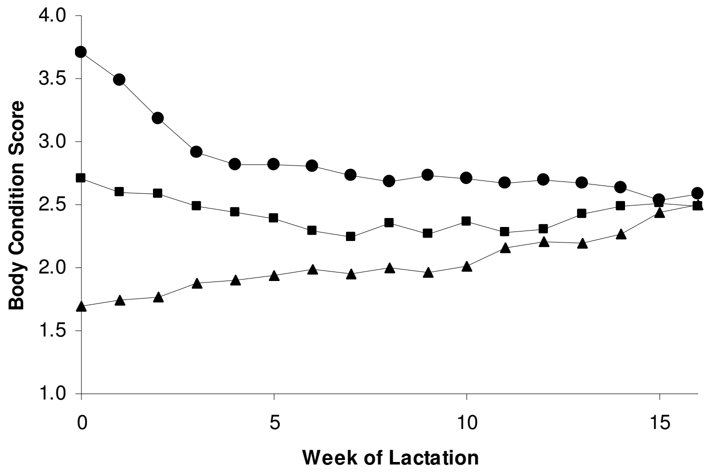
Figure 1. Changes in BCS (a), milk yield (b) and dry matter intake (c) for cows calving at BCS (1-4 scale) >3.5 (•), 2.5 – 3.0 (■), or <2.0 (▲). Data are combined means of Experiments 1 and 2 from Garnsworthy and Topps (1982).

(a)



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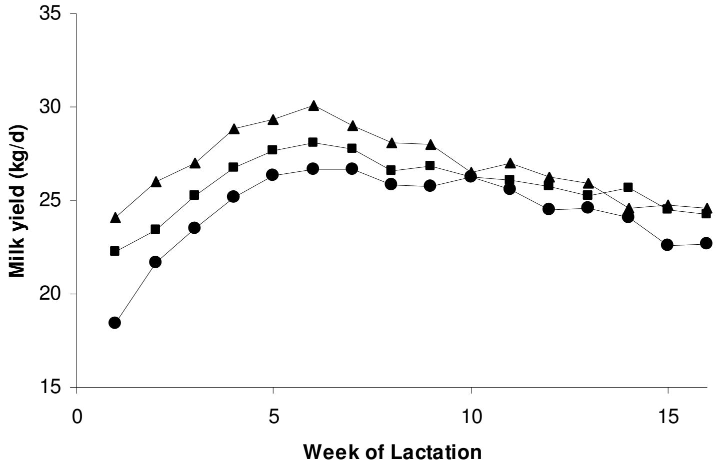

(c)

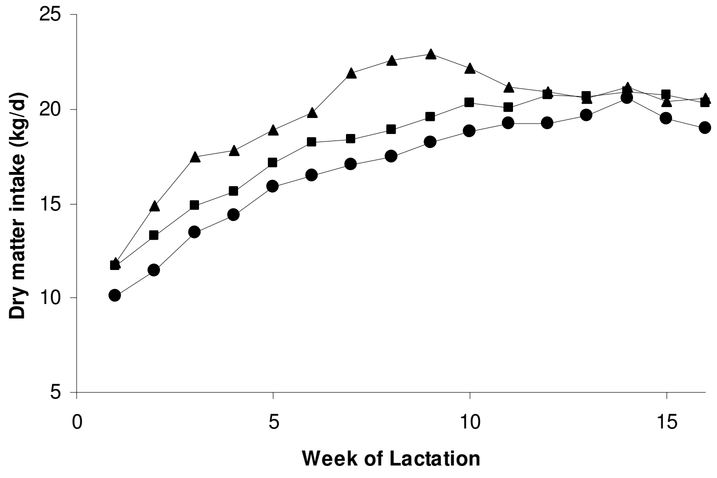

Figure 2. Relationship between BCS at calving and change in BCS over the first 10 – 12 weeks of lactation for studies published 1980 – 1993 (◆) compared with studies published 2000 – 2006 (•). Vertical dotted lines show BCS at calving that result in zero change in BCS, which has decreased from 2.49 in earlier studies to 2.10 in recent studies. From Garnsworthy (2006). Data are group means (converted to a 1 – 5 scale) from Bernabucci et al. (2005), Bourchier et al. (1987), Garnsworthy and Huggett (1992), Garnsworthy and Jones (1987; 1993), Garnsworthy and Topps (1982), Garnsworthy, Webb, et al. (2006: unpublished), Grainger et al. (1982), Horan (2005), Jones and Garnsworthy (1988; 1989), Lactera et al. (2005), Land and Leaver (1980; 1981), MacMillan et al. (1982), Meikle et al. (2004), Reist et al. (2003), Roche et al. (2006), Stockdale (2000; 2004; 2005), Treacher et al. (1986), Yan et al. (2006).

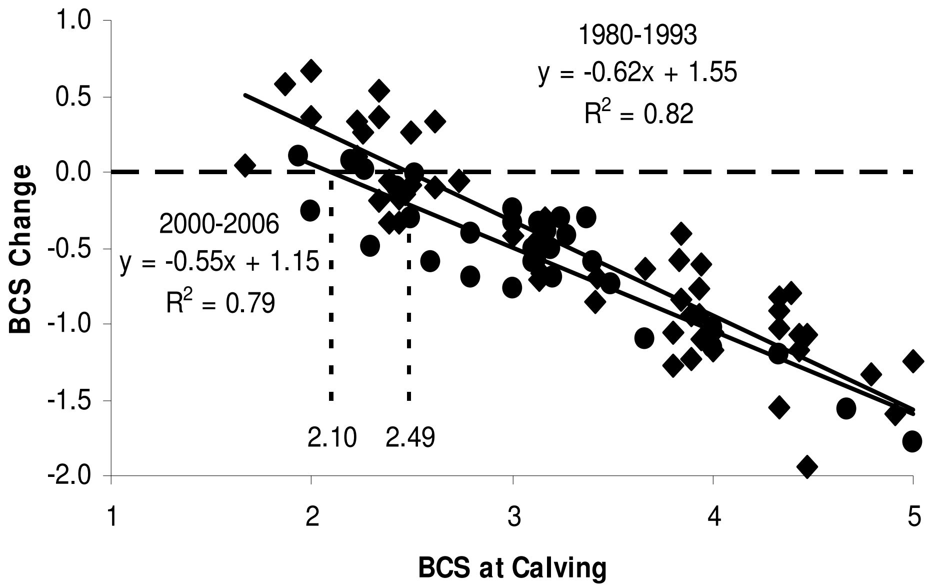

Figure 3. Changes in BCS for cows of high (solid lines) or low (dashed lines) genetic merit, with high (•) or low (▲) BCS at calving. Data are from Holmes (1988) and have been converted to a 1 – 5 BCS scale.

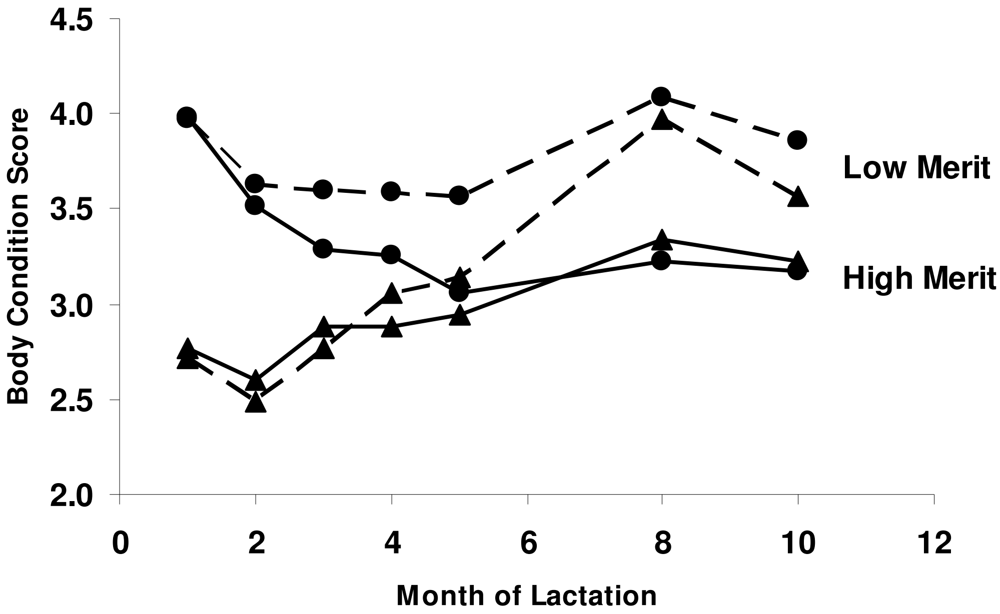

Figure 4. Changes in BCS throughout lactation for daughters of three bulls. Curves are derived from cubic regression coefficients of daughter BCS values. Data are from Jones et al. (1999), converted to a 1 – 5 scale.