# Relationships Among Changes in Body Condition Score and Reproductive Efficiency in Lactating Dairy Cows

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## Abstract

This manuscripts summarizes research, with emphasis on 3 recent publications, relating body condition score (**BCS**) or changes in BCS with reproductive performance in dairy cows. Cows with lower BCS have greater likelihood of anovulation with reduced reproductive performance due to decreased service rate in cows bred to estrus and reduced pregnancy per AI (**P/AI**) in cows bred to synchronized ovulation. Evaluation of BCS at first AI predicted P/AI in cows bred either to Ovsynch or Double Ovsynch with relative improvements of 30 to 50% in P/AI ( BCS > 2.5 vs BCS < 2.5). Loss of BCS (calving to 21 days postpartum) was associated with a dramatic reduction in P/AI in cows bred to Double Ovsynch. One recent study found that cows with high BCS at 21 days before expected calving were more likely to lose BCS during transition period (21 days before calving to 21 days after calving) and cows that lost BCS had greater health problems and a large reduction in P/AI. Finally, one recent study showed that loss of BCS during the dry period (dry off to calving) was a critical predictor of health and reproductive performance. Excessive BCS at dry off (> 3.25) was the primary predictor of subsequent BCS loss. Thus, dairy herds need to implement evaluation of BCS at dry off, calving, 21 days after calving, and at first AI to diagnose nutritional and management factors associated with BCS change and thereby improve health and reproduction in these dairy herds.

## Introduction

Efficient reproduction is key to profitability and sustainability of dairy operations. The reasons that efficient reproduction improves dairy farm profitability are manifold. First, the shape of the lactation curve, particularly in cows after their first lactation, shows that cows in early lactation are generally more profitable than later lactation cows. Thus, optimization of calving intervals can improve milk production from the herd and improve efficiency of milk production. In most models relating reproduction to profitability, the improvement in milk production is a major factor in improved profitability with improved reproduction.

There are also obvious genetic advantages in herds with efficient reproduction. High quality dams become pregnant to the best AI sires producing exceptional replacement heifers. This advantage will require about 2 years before it will begin to impact herd profitability but the impact can continue for many years. These longer-term advantages generally are of much greater economic impact than the short-term costs of the reproduction program.

Finally, one of the other major advantages of efficient reproduction is the improvement in overall quality of the dairy herd. A dramatic improvement in reproduction in a dairy herd can have a surprisingly rapid impact on the

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management and genetics of a herd, even before the quality replacement heifers produced by the program have entered the milking string. This fairly rapid impact of reproductive management is due to changes in culling practices in a herd. It seems obvious that herds with better reproductive efficiency would cull fewer cows due to poor reproduction; however, it is not as obvious that overall cull rate for the herd may not differ for a herd with good vs poor reproduction, the change is in the type of cow that is culled. If the 21-day pregnancy rate is 15%, then about 27% of cows will not be pregnant by 222 days in milk. Thus, reproductive culls could well represent almost all of the culling on this dairy. In contrast, herds with a 25% 21-day pregnancy rate (an exceptional rate) would have only 10% of cows that are not pregnant at 222 days in milk. Thus, the herd with good reproduction has much greater flexibility to cull "lower value" cows in their herds.

Thus, improvements in milk production, genetics, reproductive costs, and overall quality of the dairy herd can result from improving reproduction. Unfortunately, many dairy farms do not attain optimal reproduction due to many factors related to management, health, and physiology of high-producing dairy cows (Caraviello et al., 2006). The issues involved in reproduction of lactating dairy cows are complex, but increasingly, the interactions between nutrition, the hormonal systems, and altered reproduction in dairy cattle are being elucidated.

Figure 1 provides a generalized summary of 3 general areas in which there is a relationship of nutrition with reduced reproductive performance of lactating dairy cows. Inadequate consumption of nutrients can lead to anovulation and reduced reproductive performance. Inadequate consumption of energy leading to loss of BW and BCS is the primary topic of this manuscript. The middle box shows the effect of high feed consumption on liver blood flow leading to altered reproductive physiology. Finally, excessive levels of carbohydrates, dietary protein, or other feed ingredients can also reduce reproduction (right box). These last 2 areas have been discussed in previous reviews (Sartori et al., 2002, Wiltbank et al., 2006, Santos et al., 2010, Bisinotto et al., 2012, Wiltbank et al., 2014). Thus, the remainder of this manuscript will focus on how BCS and changes in BCS are related to reproductive efficiency in dairy herds.

**Measurement and Uses of BCS**

Evaluation of BCS is a useful management tool to assess body fat stores of Holstein dairy cows (Wildman et al., 1982, Waltner et al., 1993). Body condition score has received considerable attention as a tool to aid in the management of nutritional programs in dairy herds (Waltner et al., 1993, Roche et al., 2009). The BCS of cows at calving, the nadir BCS, and the postpartum BCS loss are associated with differences in milk production, reproduction, and health (Pires et al., 2013). Overconditioned cows with a BCS greater than 4.0 at calving had greater circulating concentrations of non-esterified fatty acids (**NEFA**) in early lactation compared with cows with moderate or low BCS (Pires et al., 2007). Hyperlipidemia, in turn, caused insulin resistance in dairy cows (Hayirli, 2006), consistent with studies linking high BCS to reduced peripheral insulin sensitivity in the lipomobilization state (Ospina et al., 2010b).

The association of energy status during the transition period and reproductive efficiency in dairy cows has been demonstrated in multiple studies. For example, a retrospective analysis of 7 studies of prepartum nutrition found that feeding a high energy diet during the close-up period resulted in increased BCS loss post-partum and increased time to pregnancy

(Cardoso et al., 2013). In addition, 2 studies found that increases in NEFA concentrations during the transition period were predictive of reduced risk of pregnancy by 70 days after the voluntary waiting period (**VWP**) in evaluations of >2000 lactating dairy cows or reduced 21-day pregnancy rate in herd-level evaluations of 60 free-stall herds (Ospina et al., 2010a,b). Recently a study of 156 lactating dairy cows (Garverick et al., 2013) reported that the probability of pregnancy at first timed AI (**TAI**) was decreased as serum NEFA concentrations on day 3 post-partum increased. Other studies also indicate a negative relationship between post-partum NEFA or loss of BCS and fertility (López-Gatius et al., 2003, Chapinal et al., 2012a). In contrast, no effect of increased NEFA or β-hydroxybutyric acid (**BHBA**) concentrations during the transition period was found in a recent large (n = 2,365), multi-region study (Chapinal et al., 2012b). Unfortunately, none of these studies provided detailed information on reproductive management protocols, except for Garverick et al. (2013).

One critical issue is the relationship of lower BCS and increased anovulation in dairy cattle. Early studies demonstrated that the day of energy balance nadir was related to timing of first ovulation ($r^2 = 0.72$) with first ovulation occurring, on average, 10 days after the energy balance nadir (Butler and Smith, 1989). In a large collaborative study (> 5,000 cows evaluated) done by 3 different reproductive physiologists (Milo Wiltbank, Paul Fricke, and Jose Santos) and two geneticists (George Shook and Rebecca Bamber), it was found that anovulation had a fairly high heritability for a reproductive trait ($h^2 = 0.171$) in dairy cattle (Bamber et al., 2009). In addition to the genetic findings in this study, the study reported the percentage of cows with anovulation at ~60 days after calving, which as would be expected, was greater in cows with lower BCS (Figure 2). For example, cows with very low BCS (< 2.00) had over 40% anovulation, whereas cows with 2.75 or greater BCS had 20.9% anovulation. However, less than 5% of cows had very low BCS (< 2.00) and only 25.8% had low BCS (< 2.50), demonstrating that in US dairy herds most cows have reasonable BCS by time of expected AI (~60 DIM) and most cows are cycling. Nevertheless, herds that have severe loss of BCS and consistently low BCS during the early post-partum period would be expected to have a high percentage of anovular cows. High percentage of anovular cows can dramatically reduce reproductive performance in lactating dairy cows (Gumen et al., 2003, Santos et al., 2016a, Santos et al., 2016b). One other complication is that when pregnancy is established in anovular cows, these cows are more likely to undergo pregnancy loss compared to cyclic cows (Santos et al., 2004, Sterry et al., 2006, Santos et al., 2009b). Thus, lower BCS (< 2.75) increases percentage of cows that are anovular and anovular cows reduce reproductive efficiency either by reducing percentage of cows that receive AI due to lack of expression of estrus and ovulation, decreased fertility after induction of ovulation and timed AI, and increased pregnancy loss in cows that become pregnant.

## Effect of BCS at Time of AI on Fertility

A study summarizing early research (before 2003) from 11 studies with a total of 7,733 cows (López-Gatius et al., 2003) categorized cows by as low, intermediate, and high BCS (BCS < 2.5; between 2.5 and 3.5; and > 3.5, respectively). Cows calving with a low BCS (BCS < 2.5) had a decreased relative risk of pregnancy at first AI (relative risk = 0.91) compared to cows calving with an intermediate BCS (2.5 < BCS < 3.5).The relative risk of pregnancy at first AI, however, did not differ between cows calving with an intermediate BCS and cows calving with a high BCS. Detection of estrus was the primary reproductive management tool used in these early studies; therefore, cows that were not cycling would not receive AI. Current programs use GnRH and prostaglandin (**PGF**) to synchronize ovulation, allowing all anovular cows to be bred by timed AI, thereby increasing service rate in these cows, but fertility remains suboptimal.

An early study from our laboratory evaluated the effect of BCS near AI on fertility in cows that were bred to Ovsynch. The cows with low BCS (< 2.5) had lower P/AI compared to cows with normal (> 2.75) BCS (28.1%, 32/114 vs. 43.7%, 125/286; $P < 0.05$) at the pregnancy diagnosis near 60 days after AI (Souza et al., 2007). To calculate the relative improvement in fertility, differences between BCS classes are calculated (43.7 – 28.1 = 15.6), then the difference is divided by the percentage pregnant in the low BCS (15.6/28.1 = 55.5%). So there are greater than 50% more pregnancies after an Ovsynch and timed AI program in cows with good BCS as compared to low BCS. This observed effect of BCS on P/AI is somewhat greater than calculated relative reductions in P/AI in other studies that compared fertility in cows with lower vs. higher BCS: 33.1% (Ribeiro et al., 2011), 38.6% (Ribeiro et al., 2012), 15.2% (Santos et al., 2009a), 25.3% (Escalante et al., 2012), and 45.7% (Moreira et al., 2000). Thus, lower BCS can dramatically reduce fertility, even when Ovsynch is used to induce ovulation and allow timed AI.

In a more recent study (Carvalho et al., 2014), we evaluated the effect of lower BCS at the time of AI in cows that are bred with the Double Ovsynch protocol. Compared to a Presynch-Ovsynch protocol, a Double-Ovsynch protocol dramatically decreases the proportion of cows initiating the Ovsynch protocol in a low P4 environment (Souza et al., 2008, Herlihy et al., 2012, Ayres et al., 2013). This is important for interpreting our research because it is well-described that cows with low P4 at the beginning of the Ovsynch protocol have decreased P/AI compared with cows with high P4 concentrations (Silva et al., 2007, Denicol et al., 2012, Giordano et al., 2012a, Giordano et al., 2012b, Giordano et al., 2013). In our study using Double-Ovsynch for all breedings (Carvalho et al., 2014), there was a decrease of 8.8% in P/AI in cows with low BCS compared to high BCS (40.4% vs. 49.2%; $P = 0.03$) which calculates to a relative increase in P/AI of 21.8% (8.8/40.4). We continue to update data from this research (Carvalho, P.D., unpublished). From a total of 30 to 40 lactating cows bred with Double Ovsynch at first AI, only 24.7% (n = 752) had lower BCS (< 2.50). These cows had lower P/AI (40%) compared to cows with better BCS (> 2.50; 52.6%, 1203/2288) or a relative increase of 31.5% in P/AI (Figure 3). Thus, timed AI programs allow all cows to be bred, but cows with BCS less than 2.75 have much lower fertility than cows with better BCS, even when a program like Double Ovsynch is utilized that is expected to induce ovulation in anovular cows.

### Effect of Change in BCS After Calving on Fertility

A frequently-discussed hypothesis that was first introduced by Britt (1992), postulated that energy status during the early post-partum period could alter follicular/oocyte quality resulting in negative effects on subsequent fertility in lactating dairy cows. This early study compared cows that lost BCS (n = 30) to cows with little BCS change (n = 46) during the early postpartum period (Britt, 1992). The P/AI was lower in cows with high BCS loss than in cows with little BCS loss either at first AI (62% vs 25%) or at all AIs (61% vs 42%). Interestingly, the cows that had the high BCS loss had much greater BCS at calving than cows with little BCS loss (3.15 vs 2.78). Thus, this early study introduced the concept that loss in BCS score after calving reduced fertility.

The summary of early research mentioned above (López-Gatius et al., 2003) also categorized change in BCS from calving until AI (7,733 cows from 11 studies) as: increased (gain in score), slightly decreased (0 to 0.5 point loss), moderately decreased (0.6 to 1 point loss), or severely decreased (>1 point loss). The effect of BCS change decreased risk of pregnancy (relative risk = 0.9) but only for cows categorized as suffering a severe BCS loss (> 1 BCS point) between parturition and first AI compared with cows categorized as undergoing increased or slight BCS loss. The relative risk of pregnancy did not differ between cows with a slight vs. moderate loss in BCS between parturition and first AI. Cows with severe loss in BCS between parturition and first AI also remained open for 10 days longer compared with cows undergoing a slight BCS loss. There was no difference in days open for cows with moderate or slight BCS loss. A more recent study (Santos et al., 2009a) also reported that cows losing more BCS between calving and first AI had lower P/AI and were more likely to undergo pregnancy loss than cows with little BCS loss. Moreover, cows that lost more BCS were also more likely to be anovular by 65 days in milk (**DIM**; Santos et al., 2009a). By contrast, Ruegg and Milton (1995) reported no association between BCS or BCS change from parturition to first AI and days to first estrus, days to first postpartum insemination, or number of inseminations required for cows to become pregnant.

We recently published a study in which we evaluated BCS of lactating dairy cows (n = 1,887) at time of calving and 21 days after calving. Cows were categorized by BCS change and then received timed AI after a Double Ovsynch protocol. Overall, only 7.3% of cows lost 0.5 or more BCS points (139/1,887). There was no difference between cows that lost 0.5 or more BCS points compared to those that lost 0.25 BCS points in P/AI at 40 days (27.3% vs. 24.6%; $P > 0.15$) or at 70 days (24.6% vs. 22.3%, $P > 0.15$) after TAI, or in pregnancy loss between first and second pregnancy examination (7.9% vs. 9.4%, $P > 0.15$). Therefore, we combined these cows into a single group for all subsequent analyses (i.e., cows that lost BCS between calving and 21 DIM). Overall, the proportion of cows that lost, maintained, and gained BCS between calving and 21 DIM was 41.8%, 35.8% and 22.4%, respectively (Table 1). At the 40 days pregnancy examination (Table 1), P/AI differed ($P < 0.001$) dramatically among BCS change categories and was greater for cows that gained BCS (83.5%; 353/423), intermediate for cows that maintained BCS (38.2%; 258/675), and least for cows that lost BCS (25.1%; 198/789). Similarly, at the 70 days pregnancy diagnosis (Table 1), there was a dramatic effect of BCS change on P/AI ($P < 0.001$) but no effect on pregnancy loss ($P = 0.34$). There was an effect of parity (primiparous vs. multiparous) on BCS at parturition (2.82 vs. 2.98; $P < 0.001$) and at 21 DIM (2.76 vs. 2.90; $P < 0.001$) and on P/AI at 40 days (50.1% vs. 35.4%; $P < 0.001$) and 70 days (47.0% vs. 32.6%; $P < 0.001$) after TAI but no effect ($P = 0.41$) on pregnancy loss. However, both primiparous and multiparous cows had a similar effect of BCS on P/AI (Carvalho et al., 2014).

The median calving to pregnancy interval differed (Log-Rank test, $P < 0.001$) between BCS groups and was 84, 113, and 128 days for cows with gaining, maintaining, and losing BCS between calving and 21 days postpartum, respectively. Cows gaining BCS between calving and 21 days postpartum were 3.0, and 2.5 times more likely to be pregnant by 300 DIM compared with cows losing and maintaining BCS (HR = 3.0, $P < 0.001$; and HR = 2.5, $P < 0.001$, respectively). Cows maintaining BCS between calving and 21 days postpartum were 1.2 times more likely to conceive by 300 DIM compared with cows losing BCS (HR = 1.2, $P = 0.01$).

A commonly accepted idea regarding postpartum energy balance in dairy cows is that all or nearly all cows lose BCS or weight during the postpartum period and that cows only differ in the degree to which they lose BCS or weight. We were surprised at the relatively small degree of loss of BCS or BW observed in this experiment. Only 41.8% (789/1887) of cows lost BCS during the first 21 days postpartum and this was similar for the 2 farms that were utilized in this study. Further, the observation that only 7.3% of cows lost 0.5 or more BCS (139/1,887) during the first 21 days after calving seems somewhat at variance with previous reports of BCS losses of 1 or more units during the early postpartum period (López-Gatius et al., 2003, Gumen et al., 2005, Santos et al., 2009b). Even more surprising was the observation that 33.5% (358/1070) of cows on Farm 2 gained BCS during the first 21 days after calving and that almost 60% of cows on either farm maintained or gained BCS during this early post-partum period.

Recently (Carvalho et al., 2014), we have done weekly BW evaluation from calving until AI in lactating dairy cows (n = 72). As shown in Figure 4, Quartile 1 cows gained about 2.5% of BW from the first to third week after calving, Quartile 2 cows maintained BCS, Quartile 3 cows lost ~4% of BW by 6 weeks post-partum (~0.25 BCS), and only Quartile 4 lost ~7.5% of BW in the early post-partum period, equivalent to about 0.5 BCS unit. Thus, the BW changes in this study were consistent with our large study indicating that there are many cows that do not lose BCS or BW during the early post-partum period and that losses in BCS under current management conditions may be less than previously reported.

Table 2 shows the effect of quartile of BW loss on embryo characteristics. First, there was no effect of parity on any of the embryo characteristics so all parities were combined for the analysis. Superovulatory response did not differ ($P > 0.15$) among quartiles (Table 2). Similarly, total unfertilized structures, total structures recovered, and recovery rate did not differ (not shown) and total fertilized structures and percentage fertilization also did not differ ($P > 0.15$) among quartiles. Total degenerated embryos were greatest for Q4 cows, lowest for Q1 and Q2, and intermediate for Q3. Percentage of degenerated embryos was similar among Q1, Q2, and Q3 cows and was greatest for Q4 cows (Table 2). Similarly, the percentage of fertilized structures that were classified as degenerate embryos was greatest for Q4 and least for Q1, Q2, and Q3 ($P = 0.04$). Conversely, percentage of fertilized structures classified as quality 1 and 2 ($P = 0.05$) or quality 1, 2, and 3 ($P = 0.04$) was lower for Q4 than for other quartiles (Table 2).

Thus, the most fascinating results in our study were the dramatic differences in P/AI that were observed in cows due to BCS change during the early post-partum period. In our study, cows with an increase in BCS had increased P/AI (at 70 days pregnancy diagnosis) by an astonishing 42.3% (78.3% - 36.0%) compared to cows maintaining BCS and 55.5% (78.3% - 22.8%) compared to cows losing BCS during the first 3 weeks post-partum. This difference could also be observed in the dramatic improvement in time to pregnancy in the cows that gained BCS during the early post-partum period. The BCS at parturition was slightly greater for cows that subsequently lost BCS (2.93) compared to cows that maintained (2.89) or gained (2.85) BCS; however, this minor difference seems unlikely to explain the extraordinary fertility differences. In addition, the parity differences between BCS categories seem unlikely to explain the results since primiparous and multiparous had similar differences in fertility based on change in BCS. Overall, our results agree with the Britt (1992) hypothesis, which postulates that negative energy balance during the early postpartum period is associated with decreased P/AI at first AI. In addition, it seems clear that loss of BW during the early postpartum period was associated with reduced quality of embryos after superovulation. This suggests that effects of postpartum BCS/BW loss directly impact the early embryo, perhaps by direct effects on the oocyte during this period.

**Effect of Changes in BCS During Dry Period on Fertility**

In subsequent research, it has become clear that the loss of BCS during the early postpartum period is reflective of changes that are already occurring in BCS during the dry period. A recent study from our group (Barletta et al., 2017), categorized cows by whether they gained, maintained, or lost BW during the entire transition period (-21 days before calving to +21 days after calving). The percentages of cows that gained, maintained, or lost BCS from -21 to 21 DIM were 28, 22, and 50%, respectively. At Day -21, the cows in the group that lost BCS had the greatest BCS (2.97), following by Maintained (2.70), and the Gained group (2.57) had the lowest BCS ($P < 0.01$; Table 3). The Lost group had greater percentage of cows with BCS > 3 on Day -21 ($P < 0.01$) than the other groups. However, all cows had similar BCS on Days -7 (2.71; $P = 0.99$) and Day 7 (2.71; $P = 0.91$). At Day 21 postpartum, BCS was greater for cows that gained (2.90), intermediate for cows that maintained (2.70) and lower for cows that lost (2.54) BCS ($P < 0.01$; Table 3). Almost all cows that were over 3.0 BCS at Day -21, lost BCS during the transition period (Barletta et al., 2017). Thus, BCS at the start of the transition period is the primary driver of BCS loss during the transition period.

There are dramatic changes in health and reproduction in cows that lose BCS during the transition period (Barletta et al., 2017). As shown in Table 4, days to first ovulation was much longer in cows that lost BCS (47.1 days), shorter in cows that maintained BCS (37.9 days), and cows that gained BCS had the earliest days to first ovulation (33.9 days). The P/AI either at the first pregnancy diagnosis (32 days) or second pregnancy diagnosis (70 days) varied substantially by BCS loss group (Table 4). For example, cows that gained BCS had almost 3-fold greater P/AI (45.5% P/AI at 70 days) compared to cows that lost BCS (15.7%). Cows that lost BCS were also more likely to have 2 or more health problems during the early postpartum period (62.9%) than cows that gained BCS (39.4%), which may partially underlie the observed reproduction problems. There were no differences in milk yield among the groups. It appears that many of the health and reproduction problems have already been determined before the transition period due to elevated BCS in some cows.

A recent study is also consistent with this idea (Chebel et al., 2018). This study evaluated records from 2 dairy farms in California (n = 16,104 lactations in 9,950 cows) and classified cows by BCS at dry off and parturition as having excessive BCS loss (- 0.75 or more; 9.9% of lactations), moderate loss (-0.5 to -0.25; 39.9%), no change in BCS (0; 29.9%), or gained BCS during dry period (> 0.25; 20.2%). The factor that explained the greatest percentage of the variation in the statistical model for BCS loss during the dry period was BCS at dry-off (94.7%) with only ~5% of variation explained by all other variables in the model (temperature-humidity index, calf sex, parity, days dry, number of calves, etc.). In this study, cows were bred by detection of estrus during a Presynch program (2 prostaglandin treatments 14 days apart) followed by timed AI using various Ovsynch modifications in cows that were not detected in estrus. Evaluation of P/AI at first AI shows that BCS loss during the dry period had a substantial effect (P < 0.001) on reproductive performance. For example, cows that gained BCS had greater P/AI (41.9% P/AI at 67 days pregnancy diagnosis) compared to cows with excessive BCS loss (20.8%; Odds ratio = 0.36), moderate BCS loss (28.3%; OR = 0.55), or no change in BCS (33.1%; OR = 0.68). The authors concluded that "loss of BCS during the dry period was a predisposing factor associated with health disorders and reduced productive and reproductive performance in Holstein cows."

## Conclusions

It seems clear that evaluation of BCS could be a critical method for evaluating current management strategies on a dairy and as a predictor of future health and reproductive problems. For the research reviewed in this manuscript, BCS should be evaluated at dry off, near calving, at 21 days after calving, and at the time of first AI. The actual BCS at first AI is a clear predictor of expected outcome from the AI, even when excellent programs are utilized to induce cyclicity in cows, such as Double Ovsynch. It is also impressive that cows that are gaining BCS have dramatically better P/AI compared to cows losing BCS, based on measurements of BCS change: 1) during the period from calving to 21 days, 2) during entire transition period (-21 to + 21 days), or 3) only during the dry period (at dry off to calving). The key determinant of BCS loss seems to be that cows with excessive BCS have the least likelihood of gaining BCS and have the greatest BCS loss, on average. Excessive BCS at dry off seems to be any cows that is > 3.25 (Chebel et al., 2018), whereas at calving, it seems to be any > 3.0 (Carvalho et al., 2014; Barletta et al., 2017). Evaluation of BCS at these key times will allow clear analysis of current management practices by producers, veterinarians, and nutritional professionals and rational development of strategies to correct problems, such as excessive BCS at dry off, resulting in dramatic improvements in health and reproduction in their dairy herds.

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**Table 1.** Effect of BCS change from calving to 21 days in milk (DIM) on pregnancies /AI (P/AI) for cows classified as losing, maintaining, or gaining BCS.

| Measure | Lost BCS | Maintained BCS | Gained BCS | *P* Value BCS Change |
|---|---|---|---|---|
| % of cows | 41.8 (789/1887) | 35.8 (675/1887) | 22.4 (423/1887) | |
| P/AI (40 days) | 25.1 (198/789)$^{c}$ | 38.2 (258/675)$^{b}$ | 83.5 (353/423)$^{a}$ | <0.001 |
| P/AI (70 days) | 22.8 (180/789)$^{c}$ | 36.0 (243/675)$^{b}$ | 78.3 (331/423)$^{a}$ | <0.001 |
| Pregnancy loss | 9.1 (18/198) | 5.8 (15/258) | 6.2 (22/353) | 0.34 |
| BCS at calving | $2.93 \pm 0.01^{a}$ | $2.89 \pm 0.02^{b}$ | $2.85 \pm 0.02^{b}$ | 0.005 |
| BCS at 21 DIM | $2.64 \pm 0.01^{c}$ | $2.89 \pm 0.02^{b}$ | $3.10 \pm 0.02^{a}$ | <0.001 |

$^{abc}$Values within a row with different superscript letters differ at $P < 0.05$.

**Table 2.** Changes in embryo quality based on quartile of body weight loss (Carvalho et al., 2014; Figure 4).

| | Quartile (Q) | | | | |
|---|---|---|---|---|---|
| | Fourth Q Lost + | Third Q Lost | Second Q Maintain | First Q Gain | *P*-value |
| Corpus leteum (#) | $18.4 \pm 2.6$ | $18.4 \pm 1.7$ | $19.0 \pm 1.7$ | $16.0 \pm 2.0$ | 0.67 |
| Fertilized (%) | $76.9 \pm 7.1$ | $77.0 \pm 6.6$ | $77.6 \pm 7.6$ | $78.4 \pm 7.1$ | 0.99 |
| Quality 1 & 2 (%) | $38.0 \pm 8.7$ | $61.3 \pm 8.2$ | $60.6 \pm 9.4$ | $63.4 \pm 8.6$ | 0.14 |
| Degenerate (%) | $35.2 \pm 8.5^{a}$ | $12.6 \pm 4.6^{b}$ | $14.5 \pm 6.3^{b}$ | $9.6 \pm 3.7^{b}$ | 0.02 |
| Quality 1 & 2 of Fertilized (%) | $48.4 \pm 9.5^{a}$ | $78.3 \pm 6.6^{b}$ | $72.6 \pm 9.5^{b}$ | $77.7 \pm 7.4^{b}$ | 0.05 |
| Degenerate of Fertilized (%) | $46.9 \pm 9.6^{a}$ | $17.4 \pm 6.4^{b}$ | $24.8 \pm 9.3^{ab}$ | $16.2 \pm 7.0^{b}$ | 0.04 |

$^{ab}$Values within a row with different superscript letters differ at $P < 0.05$.

**Table 3.** Body condition score (BCS; least squares means ± SEM) on days -21, -7, 7, and 21, in relation to calving, for cows that lost, maintained, or gained BCS during the transition period (Barletta et al., 2017).

| Item | Change in BCS[1] | | | *P*-value |
|---|---|---|---|---|
| | Gained | Maintained | Lost | |
| n | 69 | 54 | 122 | - |
| BCS at -21 DIM | 2.57 ± 0.03[c] | 2.70 ± 0.04[b] | 2.97 ± 0.03[a] | < 0.01 |
| BCS at -7 DIM | 2.72 ± 0.04 | 2.71 ± 0.06 | 2.71 ± 0.04 | 0.99 |
| BCS at 7 DIM | 2.72 ± 0.04 | 2.71 ± 0.06 | 2.69 ± 0.04 | 0.91 |
| BCS at 21 DIM | 2.90 ± 0.04[a] | 2.70 ± 0.04[b] | 2.54 ± 0.03[c] | < 0.01 |

[abc]Values within a row with different superscript letters differ at P < 0.05.
[1]Cows had their BCS evaluated during the transition period (-21 to 21 DIM) using a 5-point scale with 0.25 increments.

**Table 4.** Effect of changes in body condition score (BCS) during the transition period (-21 to 21) on diameter of the ovulatory follicle, pregnancies per AI (P/AI), pregnancy loss, days postpartum at first ovulation, and percentage of cyclic cows at 50 DIM for cows that lost, maintained, or gained BCS (Barletta et al., 2017) .

| Item | Change in BCS[1] | | | *P*-value |
|---|---|---|---|---|
| | Gained | Maintained | Lost | |
| Cows, % (no./no.) | 28 (69/245) | 22 (54/245) | 50 (122/245) | |
| Cyclic cows at 50 DIM, % | 100[a] (69/69) | 94.4[b] (51/54) | 81.1[c] (99/122) | 0.015 |
| First ovulation, days | 33.9 ± 0.5[c] | 37.9 ± 0.7[b] | 47.1 ± 1.0[a] | < 0.01 |
| Ovulatory Follicle, mm | 18.5 ± 0.5 | 19.0 ± 0.8 | 18.4 ± 0.4 | 0.76 |
| P/AI 32 days, % (no./no.) | 53.0 (35/66)[a] | 26.9 (14/52)[b] | 18.3 (21/115)[b] | < 0.01 |
| P/AI 70 days, % (no./no.) | 45.5 (30/66)[a] | 25.0 (13/52)[b] | 15.7 (18/155)[b] | < 0.01 |
| Pregnancy loss, % (no./no.) | 14.3 (5/35) | 7.1 (1/14) | 14.3 (3/21) | 0.79 |

[abc]Values within a row with different superscript letters differ at P < 0.05.

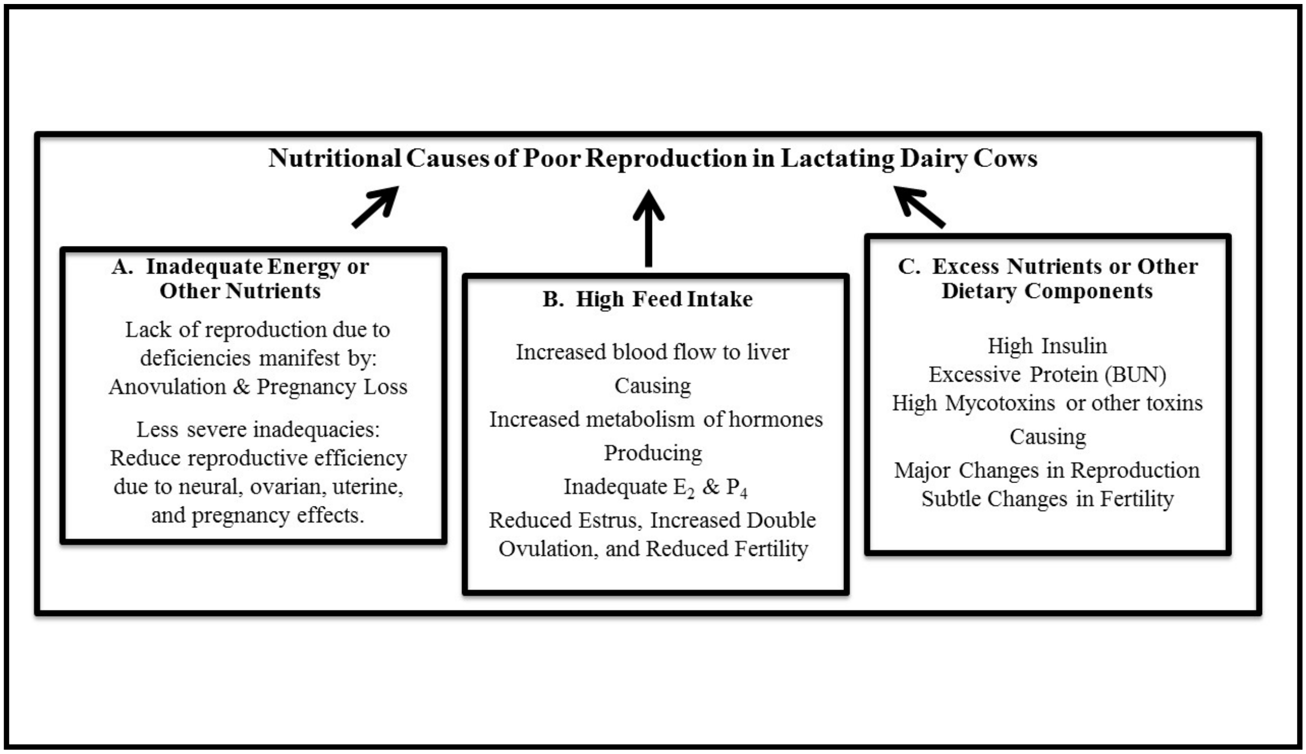


**Figure 1.** Summary of 3 different ways in which nutrition can produce reduced reproductive efficiency in lactating dairy cows. A. Inadequate intake of energy or other nutrients can lead to deficiencies which may be manifest as anovulation or pregnancy loss or as decreases in fertility and other measures of reproductive efficiency. B. High feed intake leads to high liver blood flow due to the high blood in the digestive tract that flows through the hepatic portal vein to the liver. This pathway leads to high metabolism of steroid hormones such as estradiol (E2) and progesterone (P4), causing reduced circulating E2 and P4 which causes large changes in reproductive physiology in lactating dairy cows. C. Excess consumption of certain nutrients, such as high carbohydrate diets leading to increased insulin or excessive protein leading to high blood urea nitrogen (BUN) can cause decreases in reproductive efficiency in certain situations. Consumption of feeds that contain certain toxins, such as high phytoestrogens, can produce dramatic changes in reproductive physiology, including reduced fertility.

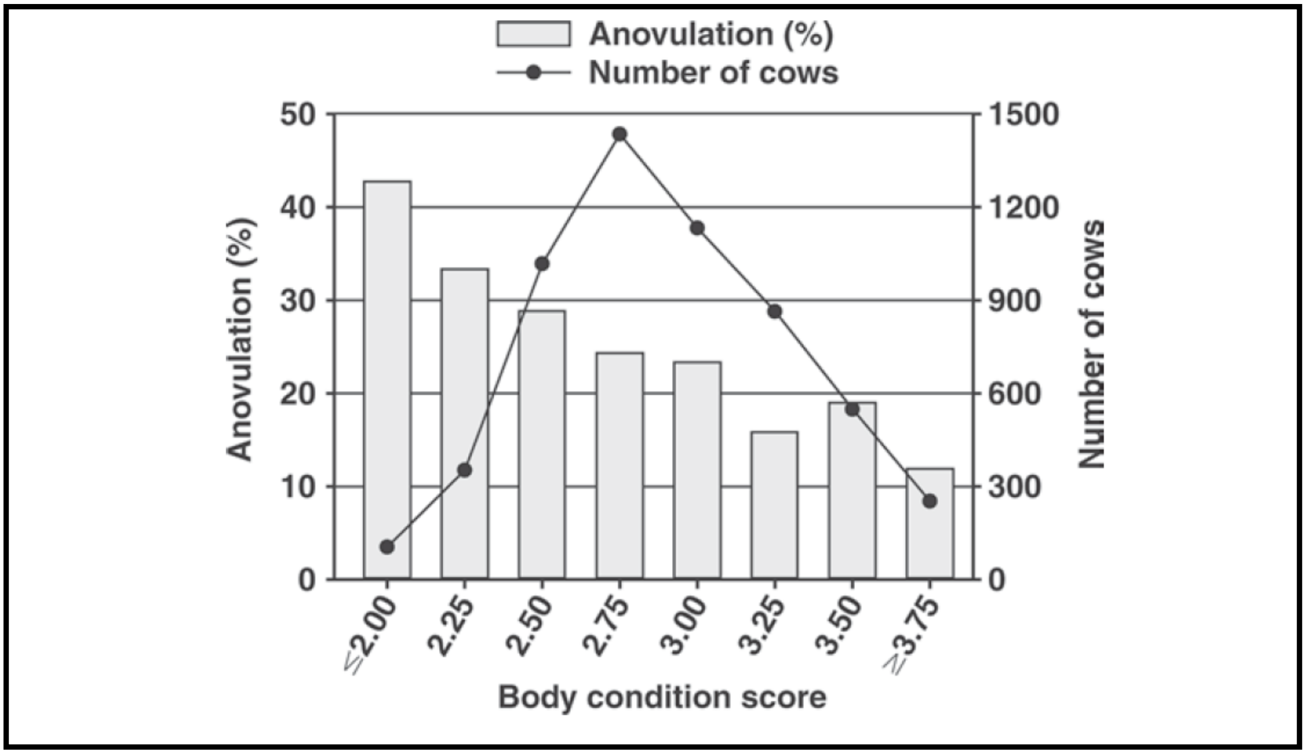


**Figure 2.** Relationship between BCS and percentage of cows that are anovular (Bamber et al., 2009). The low BCS cows (< 2.5) were a low percentage of the total cows (25.8%) but had a greater percentage of cows that were anovular (30.9%) compared to cows with greater BCS (74.2% of cows; 20.9% anovular).

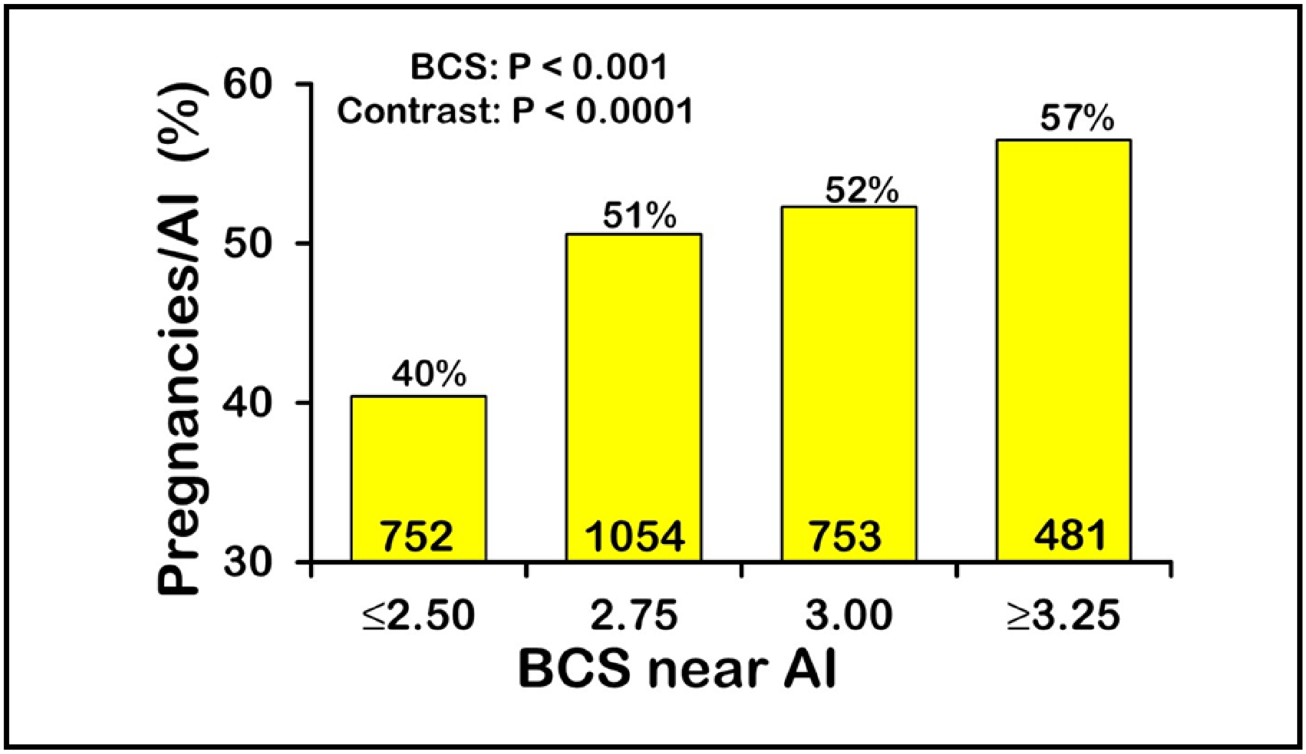


**Figure 3.** Effect of BCS at the time of AI on pregnancies per AI after Double Ovsynch and timed AI (Carvalho, P.D., unpublished). The contrast compared cows with low BCS (< 2.50) to cows with greater BCS (> 2.75).

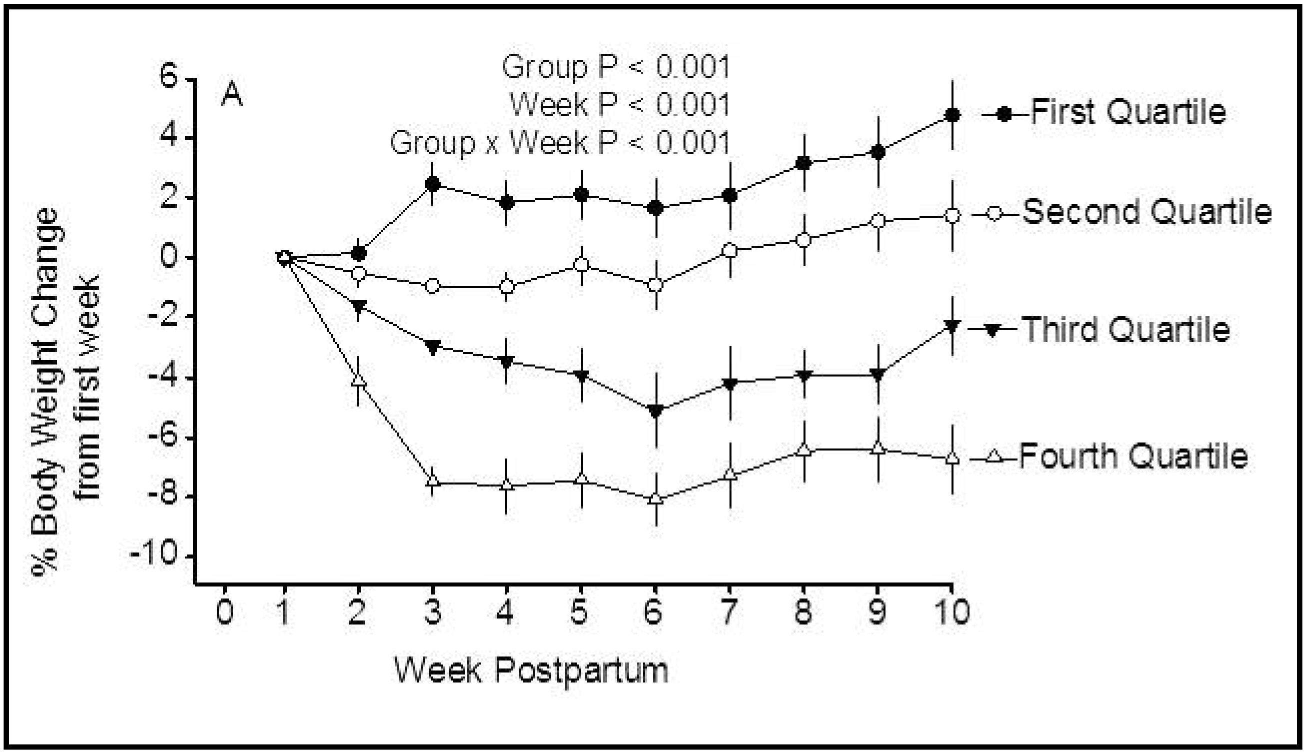


**Figure 4.** Percentage body weight change based on weight during first week postpartum (Carvalho et al., 2014). Cows were ranked according with % of body weight change from first to third week postpartum and divided into quartiles. Cows in the first quartile gained body weight, whereas cows in the second quartile maintained a relatively constant body weight. The third and fourth quartiles lost body weight with the third quartile losing ~4% of body weight and the fourth quartile losing ~8% of body weight. At the end of this time period cows in all four quartiles were superovulated and embryos (n = 560) were evaluated for fertilization and quality (Table 2).