

INFLUENCE OF NUTRITION AND WEIGHT LOSS ON REPRODUCTION
AND EARLY EMBRYONIC DEATH IN CATTLE

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Introduction

Maintaining acceptable levels of reproductive performance in cattle is a challenging problem, particularly when cows are producing high yields of milk or when nutrient intake is below the demand for extended periods of time. In such situations, the associated negative energy balance may result in prolonged postpartum anestrus, lower levels of progesterone secretion by corpora lutea (CL) and lower rates of conception. Fertility in high-producing cattle also may be affected by excessive intake of protein, inadequate intake of fibrous feeds or other nutritional imbalances. There is some evidence that such factors affect embryonic survival. This paper will review some of the current thinking in these areas and provide insights into potential biological mechanisms through which fertility is influenced by these factors. The paper will focus primarily on the postpartum dairy cow.

Metabolism in the High-Producing Cow

Genetic selection for specific production traits such as lactation, growth or fattening changes the balance among metabolic hormones that regulate the flow of nutrients to various physiological processes. The directed flow of nutrients to a specific process such as growth or lactation is controlled through homeorhetic mechanisms, which contrast to homeostatic mechanisms that maintain a physiological equilibrium (1). An example of how selection for milk yield changed blood levels of somatotropin (growth hormone), a potent stimulator of lactation, insulin, a hormone that favors fattening, and other hormones is shown in Table 1 (2). In that selection experiment, Holstein cows were mated to semen stockpiled from 20 bulls that were in AI service in 1964 and whose merit was near breed average (Controls), or to AI bulls that had the highest transmitting abilities for milk during subsequent years (Selected). The data in Table 1 reveal that five generations of selection changed the ratio of somatotropin to insulin. Thus genetic selection changed the homeorhetic signals in Selected cows to favor higher milk production (increased somatotropin) and to decrease fat deposition (decreased insulin) during lactation.

Table 1. Hormones in lactating Selected and Control Holstein cows. Control cows were sired by bulls in use in AI at the time the selection experiment was started. Selected cows were sired by the best bulls available through AI over the years of selection. From Bonczek et al. (2).

Trait	Control Generation = 5.3	Selected Generation = 4.8
Milk, lbs (305 d)	16,284	21,732
kg (305 d)	7,401	9,878
Insulin, μ U/ml	22.5	18.8
Somatotropin, ng/ml	3.7	4.5
Prolactin, ng/ml	41.9	39.1
Thyroxine, ng/ml	47.7	44.1

Metabolic hormones control the flux of nutrients to organs and uptake of these nutrients by tissues, including reproductive tissues. It is important to recognize that there is a difference between nutrient availability (concentration in the blood) and its uptake by different types of cells. Metabolic hormones act through tissue-specific receptors to regulate the ability of cells to acquire nutrients from the available supply. For example, incorporation of glucose into lipid within adipocytes (lipogenesis) is decreased by administration of somatotropin to lactating cattle whereas breakdown of lipids (lipolysis) to form fatty acids and glycerol (a potential precursor for glucose) is increased by somatotropin. Thus various tissues compete for nutrients because of their responses to the action of various hormones. Tissue response is affected by the number of receptors for the hormone on the cell membrane or within a cell of the specific tissue and by the amount of hormone presented to the tissue. The amount of hormone presented to the tissue is influenced by blood flow to the tissue and by concentration of the hormone in blood. The reproductive system competes with other physiological systems for nutrients because the same metabolic hormones that control processes such as growth and lactation also control the function of reproductive target tissues within the hypothalamus, ovary and uterus.

Postpartum Anestrus and Subsequent Fertility

Fertility in the postpartum cow is influenced by the number of estrous cycles that occur between parturition and first insemination. Thus, Thatcher and Wilcox (3) reported that cows that had experienced two or three heats before insemination had nonreturn rates of 44 to 47% compared to 34% for cows that had not shown heat before the breeding period beginning at 60 days postpartum. Therefore, when bred at the same time postpartum, cows that

have experienced two or more estrous cycles before being inseminated are more fertile than those inseminated at first or second cycle. Research conducted by Butler and colleagues (4,5) showed that commencement of postpartum estrous cycles is closely linked to the time when the postpartum nadir in negative energy balance occurs (Figure 1). Thus, when negative energy balance reaches its lowest point soon after calving and then begins returning toward a positive balance, cows cycle sooner and breed back quicker than when the negative energy nadir occurs later.

A principal factor that affects postpartum energy balance is feed intake. For example, Villa-Godoy et al. (6) reported that variation in energy balance in postpartum Holstein cows was influenced most strongly by dry matter intake ($r = .73$) and less by milk yield ($r = -.25$). Thus differences among cows in the severity of negative energy balance is more related to how much they eat than it is with how much milk they produce.

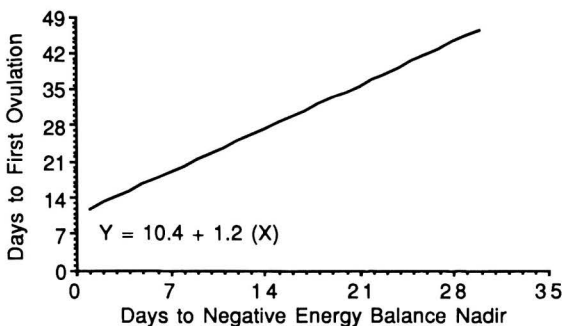


Figure 1. Days from parturition to first ovulation among cows that reached the nadir in negative energy at different postpartum intervals. Redrawn from Canfield and Butler (5).

Postpartum Energy Balance and Progesterone Secretion

Folman and colleagues (7) were the first to point out that postpartum nutrition affected progesterone during the breeding period in high-producing dairy cows. They fed 14 Holstein cows either high-energy rations (6 kg of hay plus free access to concentrates) or rations that included the same amount of hay but restricted amounts of concentrates. Cows were milked three times daily and inseminated at first estrus beyond 56 days postpartum. Cows that conceived at first service had higher levels of progesterone during the luteal phase before first breeding than cows that failed to conceive. Moreover, among cows requiring more than one service, cows fed the higher energy diet had greater luteal-phase progesterone concentrations than cows fed the lower energy diet. Cows fed the higher energy diets required fewer services per conception. The investigators also noted that weight change (an estimate of energy balance) during the estrous cycle preceding first service influenced progesterone secretion during the luteal phase preceding first service; cows that gained weight had higher levels of progesterone than cows that lost weight.

Subsequently, we (8) studied the relationship between progesterone secretion prior to first service and fertility in 212 Holstein and Jersey cows. In both breeds there was a positive relationship between the level of progesterone in blood during 12 days before first service and conception rate at first service. Thus, for Holstein cows, each 1 ng/mL increase or decrease in average progesterone during the last half of the estrous cycle preceding first service was associated with a 12.4% difference in conception rate; for Jerseys a 1 ng/mL change in average progesterone was associated with a 7.4% change in conception rate. For Jerseys, there also was a positive relationship between weight change during 28 days before first AI and progesterone during 12 days before first AI. A 1 kg change in weight during this 4-week period was associated with a .03 ng/ml change in average progesterone. Thus a cow that lost 20 kg during the 28 days before first AI would have an average progesterone 1.2 ng/ml lower than one that gained 20 kg, and this would result in a 9% difference in first service conception rate.

Villa-Godoy et al. (6) were the first to emphasize that energy balance in the immediate postpartum period exerted a profound latent effect on progesterone secretion during the breeding period in high-producing Holstein cows. They showed that cows that experienced the greatest decline in energy balance during 9 days postpartum had the lowest levels of progesterone secretion during the postpartum second and third estrous cycles, 40 to 70 days after parturition. Moreover, cows that differed in postpartum energy balance did not differ in daily milk yield during the first 100 days postpartum (mean = 32.4 kg, 4.0% FCM). Their data support the concept that early postpartum feed intake, not milk yield, is the main factor that influences progesterone secretion during the breeding period. This conclusion is made because feed intake was the variable most closely linked to energy balance.

Postpartum Energy Balance and Fertility

In the last several years, changes in body condition score (BCS) have been used to judge the energy balance state of the postpartum cow. On a 5-point scale, a 1 point change in BCS is equivalent to a 25 to 60 kg change in live weight, unadjusted for changes in gut fill (9). Both labile protein and fat are depleted when body condition changes,

and a decrease in condition is associated with negative energy balance. Butler and Smith (10) showed that overconditioning (BCS above 4.0 at 1 to 2 weeks prior to calving) per se did not affect overall reproductive performance, but their data showed a tendency for overconditioned cows to have lower conception rates at first service. In contrast, they showed that severity of body condition loss postpartum strongly influenced first service conception rate (Table 2). Thus, cows that experienced a body condition loss of <.5 points during the first 5 weeks postpartum had a first service conception rate of 65% compared with conception rates of 53% and 17% for cows that lost .5 to 1.0 or >1.0 points of body condition. Similarly Francos et al (11) reported that cows which lost 1 point in BCS between parturition and 50 to 80 days postpartum had conception rates at first service 21% lower than cows that had no change in BCS during the same period. Clearly then, a change in body condition of approximately 1 point or more after calving affects fertility during the breeding period. Weaver (12) pointed out that BCS at calving may be related to severity of BCS loss after calving because fatter cows (those with higher BCS) may have lower feed intakes than cows with lower scores. He suggested that a BCS near 3.5 at calving was optimal for milk yield, health and fertility. Ultimately, however, cows that lose higher amounts of body condition soon after parturition have cumulative pregnancy rates that are similar to cows that lose little condition (Table 2), so the infertility associated with body tissue loss is temporary.

Table 2. Changes in body condition score and reproductive traits of Holstein cows. From (10).

Trait	Loss in body condition score during the first 5 weeks postpartum		
	<.5	.5 to 1.0	>1.0
No. cows	17	64	12
Days to 1st ovulation	27±2	31±2	42±5
Days to first observed estrus	48±6	41±3	62±7
Days to first service	68±4	67±2	79±5
First service conception rate, %	65	53	17
Services per conception	1.8±.4	2.3±.2	2.3±.4
Pregnancy rate, %	94	95	100

Feeding fat to postpartum cows may change the relationship between energy balance and fertility through ways that are not clearly understood. For example, Sklan et al (13) fed high-producing Holstein cows calcium soaps of fatty acids (CSFA) for 4 months postpartum at the rate of 2.6% of dry matter intake. Cows fed CSFA lost more weight during the early postpartum period and their fertility at first service was slightly lower than controls (39.2 vs 41.6%); however, for services 2-4, cows fed CSFA had higher conception rates (42.6 vs 25.0%). These data indicate that CSFA may somehow restore fertility sooner in cows losing substantial weight postpartum. Similarly, Ferguson et al (14) showed that feeding fat to high-producing postpartum cows improved first-service conception rate, although the magnitude of the difference in conception rate between cows fed diets with or without fat supplementation varied considerably among four herds.

The effects of dietary fat on fertility may be through progesterone secretion because cows fed CSFA or other fats had higher progesterone levels after breeding than controls (13,14). Lucy et al (15) treated Holstein cows with prostaglandin F₂α to induce luteolysis and fitted them an intravaginal progesterone releasing devices to deliver a constant amount of progesterone. One half of the cows were fed control diets and one-half were fed diets containing CSFA. Cows fed CSFA had larger diameter dominant follicles than control, indicating that CSFA may affect CL function (progesterone secretion) by altering development of the prevulatory follicle.

Temporal Relationship Between Weight Loss and Fertility

In an effort to understand how losses in body condition could affect fertility several weeks later, a theoretical model was developed (16) based on the rates of follicular growth estimated by Lussier and colleagues (17). In their study, growth of earliest antral follicles to the ovulatory stage required approximately two estrous cycles. By extrapolation, then, one can estimate that 60 days or more are required for the growth of inactive primordial follicles to the ovulatory stage. This theoretical model is illustrated in Figure 2.

One can visualize from Figure 2 that the first two ovulatory follicles after parturition begin development when energy balance is positive, during the previous dry period. In contrast, the third, fourth and possibly the fifth follicles begin their development when energy balance is most negative. It was our expectation that follicles which begin to grow when energy balance is most negative might be exposed to adverse metabolic conditions that would render them less functional. This would lead to production of poorer quality oocytes and secretion of less progesterone after ovulation. Thus a follicle exposed to undesirable conditions during its earliest stages of development may somehow become imprinted so that it reflects that adversity as lower fertility.

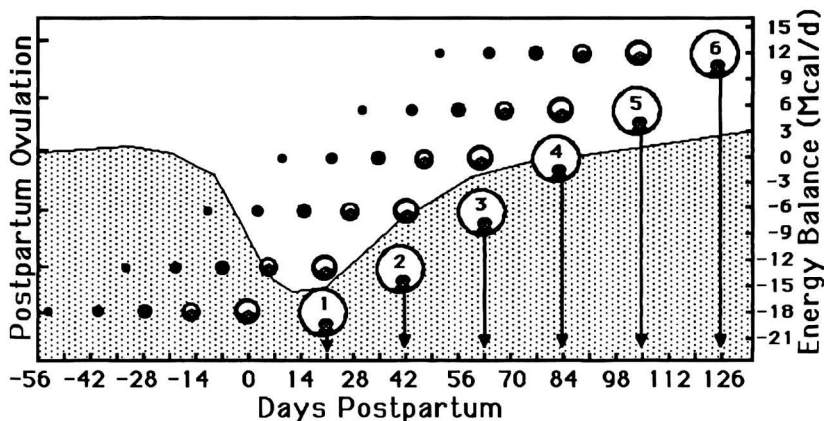


Figure 2. An illustration of the predicted time-course of development of the first six follicles destined to ovulate at various times during the postpartum period. For simplicity, only ovulatory follicles are depicted. The shaded area depicts the predicted energy balance at various times.

If the theoretical model was correct, it predicted that the first two CL would differ little in progesterone secretion between cows that differed in postpartum losses of body condition, whereas the third, fourth and fifth CL would differ because cows that lost more body condition should have CL that produce less progesterone. To determine whether this model was supported by experimental evidence, data from one of our earlier studies (8) were reanalyzed to determine the temporal relationship between loss in condition, development of preantral follicles and the secretion of progesterone from these follicles. Blood samples collected twice weekly were available from 76 Holstein cows that differed in postpartum losses in body condition (High = below average loss; Low = above average loss). The results are depicted in Figure 3. One can see that the results support the theoretical model, because CL function, as manifested by progesterone secretion during peak luteal function (days 6-13 of cycle 1; days 10-17 of cycles 2-5) was not different during the first two cycles, but cows that lost more condition produced less progesterone during cycle 3-5. The fertility of these cows that had differed in amounts of body condition loss also differed (Table 3).

Nutrition and Early Embryonic Losses

Early embryonic death contributes to lower reproductive performance in cattle by delaying repeat service. Once the embryonic signal for recognition of pregnancy has been elicited, several days or weeks are required for the cow's endocrine system to recognize that the embryo is dead and for therefore for the CL of pregnancy to regress. Northey and French (18) flushed embryos from the uterus of cows on days 13 to 19 of pregnancy and noted that estrous cycles were extended from approximately 20-22 days for cows flushed on days 13-15 to 25-27 days when embryos were flushed from the uterus on days 17-19. These results illustrate that signals produced by preattachment embryos prolong CL function, and a similar situation occurs after attachment. For example, Kastelic and Ginther (19) injected colchicine into embryos on day 42 of pregnancy and determined by real-time ultrasound that the embryos died 1.2 days later; however, an additional 20.8 days elapsed between the time of embryonic death and subsequent ovulation. This long delay was associated with continued secretion of progesterone by the CL, indicating that luteolysis did not occur until 3 weeks after the embryo died. In contrast, when luteolysis was induced by treatment of cows with prostaglandin F_{2α} on day 42 of pregnancy, embryos died within 2.6 days and ovulation occurred 2.7 days later.

The observation that estrous cycles are prolonged in cows experiencing early embryonic death has led several groups to use milk or blood progesterone assays to estimate embryonic death rates in cattle. An example of the distribution of cycle lengths for cows expected of experiencing embryonic death is show in Figure 4. In this study (A. Abma and J. H. Britt, unpublished), data from 329 estrous cycles among 96 Holstein cows were used to estimate percentage of mated cows that may have experienced embryonic death because cycles were extended beyond 27 days (range 27 to 52 days). It was estimated that this population of cows exhibited a 9.3% incidence of embryonic death based on prolonged progesterone secretion and extended estrous cycles. This proportion is similar to the 7.2% estimated for Holstein cows by Kummerfield et al (20) and the 7.7% reported by Lamming et al. (21) for Holstein or British Friesian cows. Using these same procedures, we (A. Abma and J. H. Britt, unpublished) estimated that the early embryonic death rate in Jersey cows was 3.1%, consistent with the higher fertility in Jerseys (8).

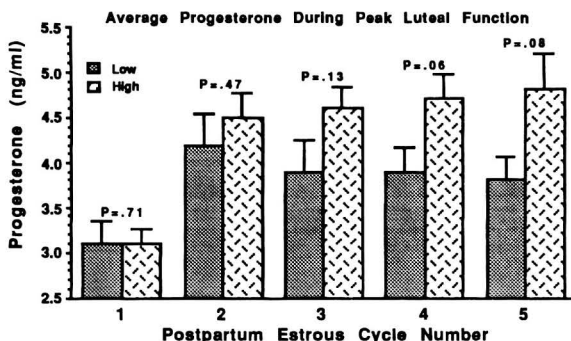


Figure 3. Progesterone secretion during peak luteal function of postpartum cycles of cows sorted solely on basis of body condition score during weeks 1 to 5 after calving. The 'P' values for each cycle represent the probability that progesterone concentrations differed between the two body condition groups for that cycle.

In preparing this paper, I could find no evidence of effects of changes in body condition on embryonic death. Re-analyses of data shown in Table 2 did not show that change in body condition influenced apparent embryonic death. There are data however that implicate excess intake of dietary protein in embryonic development. For example, Blanchard et al (22) fed cows diets that differed in rumen degradable intake protein (73% vs 64%) and then subjected the cows to superovulatory treatments to evaluate quality of embryos recovered on day 7 of pregnancy. Cows fed the diets with higher degradability (73%) had lower fertilization rates (55 vs 79%) and produced fewer transferable embryos.

Table 3. Results of retrospective analysis of data from high-producing Holstein cows sorted solely on basis of change in body condition scores between weeks 1 and 5 postpartum.

Trait	High Cows	Low Cows
No. cows ^a	46	30
Body condition score change ^b		
Weeks 1 to 5	+0.06	-.58*
Days postpartum to first AI	84.9	82.9
Conception rate (%)		
First service	62*	25*
All services	61*	42*

^aBody condition scores are on a 1 (thin) to 5 (fat) scale; High=little loss in score ; Low=greater loss in score.
* P < .05

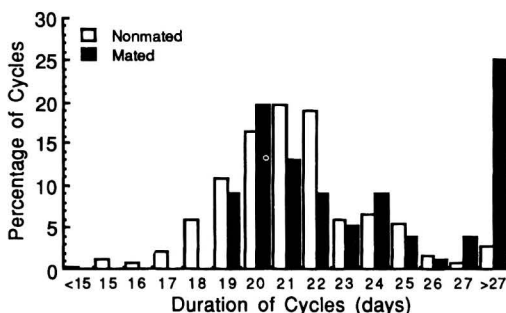


Figure 4. Distribution of 329 estrous cycles of nonmated and mated Holstein cows. The first postpartum estrous cycle was omitted for each cow. Cycle lengths were based on progesterone profiles from blood samples collected twice weekly from 96 cows.

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Summary

Cows that experience moderate to severe losses in body weight after calving, as manifested by decreases in body condition scores, are less fertile during the normal breeding period than cows that experience less loss in body condition. The lower fertility is associated with lower secretion of progesterone from corpora lutea, potentially because of ovulation of less functional follicles. The follicles may be impaired in their early development by the effects negative energy balance and its associated changes in metabolic hormones. Feeding fat may alleviate some of the effects of loss in condition, although the best strategy seems to be to have cows in moderate condition at calving to maximize postpartum dry matter intake. There is little evidence that body weight loss affects embryonic death; however, feeding excess rumen degradable protein might lower fertilization rates and cause more embryos to degenerate during early development.