OPTIMIZATION OF TRANSITION PERIOD ENERGY STATUS FOR IMPROVED HEALTH AND REPRODUCTION

Ric R. Grummer

Dept of Dairy Science, University of Wisconsin, Madison, USA
rgrummer@wisc.edu

1. INTRODUCTION

Numerous metabolic changes occur as the dairy cow approaches parturition. To a large extent, these alterations are a reflection of the hormonal changes that occur to facilitate parturition and lactogenesis. Dairy cattle may experience negative energy balance beginning a few days prior to calving. This occurs because of the reduction in dry matter (DM) intake (DMI) and to a limited extent, the increasing nutrient demand by the growing fetus. Once copious milk production begins after calving, the severity of negative energy balance continues to increase. Energy balance (EB) can also affect the hormonal status and metabolism of dairy cows. For years, energy status of cows has been related to incidences of metabolic disorders and infectious diseases as well as reproductive performance of dairy cows. This paper will primarily focus on research that our laboratory has conducted on the energy status of the transition dairy cow, physiological changes in the dairy cow during the final weeks prior to calving, and potential strategies for minimizing the extent of negative energy balance during the transition period.

2. ENERGY BALANCE DURING THE TRANSITION PERIOD

Energy balance is the difference between the energy consumed (Ec) by the animal and the energy required (Er) by the animal and can be defined on a daily basis. Energy is required for one or more of the following functions: maintenance (Em), growth (Eg), production (Ep), and fetal growth (Ef). For example, if a mature cow (no longer growing) is in the dry period, EB = Ec - Er or = Ec - (Em + Ef). The NRC (2001) does not consider energy requirements for mammary growth, but the requirement could be as high as 3 Mcal NEl/day. If EB is negative, the cow utilizes fat stores as an energy source and loses tissue weight. If EB is positive, the cow stores excess energy as fat and gains tissue weight.

Energy requirements for maintenance of a mature cow and a heifer as well as the additional requirements for conceptus growth during the final 60 days of gestation are shown in Figure 1. It is often stated that transition cows must be fed additional concentrate during the final three weeks prior to calving to meet the energy demands of a growing fetus. However, the data in Figure 1 reveals that the additional energy requirements imposed by increasing fetal growth is really quite trivial. Decreases in DMI are more likely to pose a nutritional challenge to a cow approaching parturition.

Figure 2 shows a typical energy balance curve as cows progress through the transition period and early lactation (from trial described in Rastani *et al.* 2005a). Cows in this trial were fed a far-off low-energy diet (1.50 Mcal NEl/kg) for the first four weeks of the dry period, a moderate-energy transition diet (1.69 Mcal/kg DM) for the final four weeks prior to calving and a high-energy lactation diet postcalving (1.75 Mcal/kg DM). Interestingly, cows on this experiment barely entered into negative energy balance before calving. Even if lower energy, higher fiber diets are fed, the duration and extent of negative energy balance will be quite trivial. However, there is definitely a change in energy balance during the final week prior to parturition. The most severe negative energy balance occurs postpartum and is usually encountered within 1-2 week after calving.

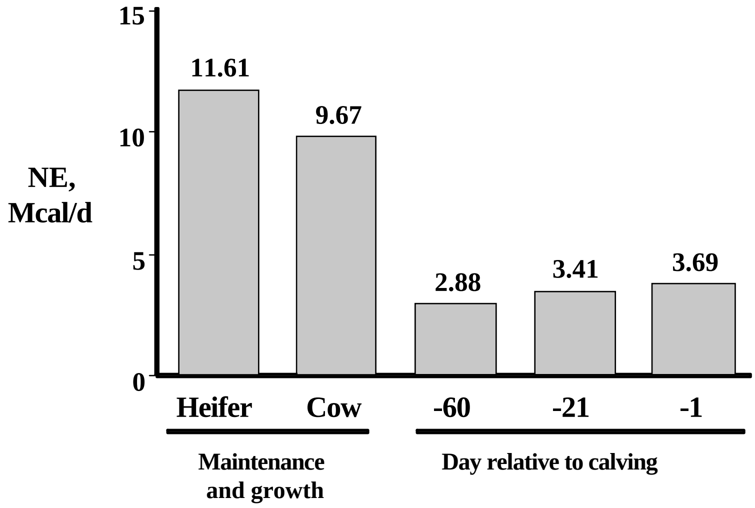

Figure 1. **Energy requirements of heifers and cows for maintenance and for pregnancy at specified times relative to calving**

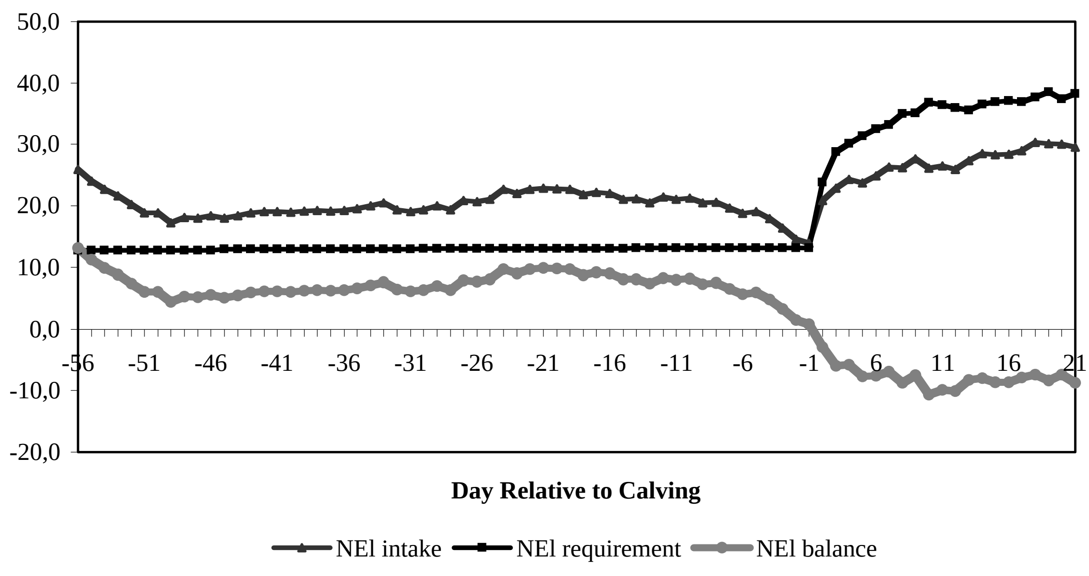

Figure 2. **Energy intake, requirements, and balance of cows fed a far-off low-energy diet (1.50 Mcal NEl/kg) for the first four weeks of the dry period, a moderate-energy transition**

diet (1.69 Mcal/kg DM) for the final four weeks prior to calving and a high-energy lactation diet postcalving (1.75 Mcal/kg DM)

To get a better idea of extent and duration of negative energy balance cows typically experience after calving, we collected data from twenty studies published in peer reviewed journal articles since 1988 (Grummer & Rastani, 2003). A total of 52 dietary treatments were implemented in these studies. Trials varied in duration, but for 49 of the 52 treatments, positive EB was reached by the end of the study. In 90% of the cases (44 out of 49), cows had reached positive EB by 63 days postpartum. The mean number of days in milk until EB was reached was 45 (standard deviation = 21 days). Because there was large variability in the length of time to reach positive EB, we examined the relationship between peak milk yield or days to peak milk yield. The correlation between peak milk yield ($r = 0.24$, $P = 0.16$) or days to peak milk yield ($r = 0.23$, $P = 0.17$) and time to reach positive EB was extremely low indicating that some other factor besides energy output was responsible for variability in the length of time it takes to reach positive EB. The data did not allow us to examine the relationship between energy intake or DMI and time to reach positive EB. However, we were able to examine the relationship between energy density of the diet and days to positive EB. The data indicated that there was a stronger relationship between days to positive EB and energy density of the diet ($r = 0.57$, $P < 0.0001$) than peak milk yield. This data provides evidence that NEI may be a more important factor affecting return to positive EB than milk yield because NEI is a function of DMI and energy density of the diet.

We also examined individual cow data from a recent research trial (Grummer & Rastani, 2003). First, we calculated weekly means for daily NEI, FCM yield, and EB for 24 primi- and 49 multiparous cows from 2 through 21 weeks postpartum to examine the relationships between these parameters (Table I). Average 4% FCM yield was 29.2 kg/day for primiparous cows and 38.4 kg/day for multiparous cows for the first 21 weeks postpartum. It is clear from data in Table I that EB is more closely related to NEI than energy output as measured by FCM. Next we examined time required to reach positive EB for each of the cows in the study. Average time to reach positive EB was the same for multiparous and primiparous cows, 5 ± 2 weeks. Positive EB had been reached by 7 weeks postpartum for 92% of the primiparous cows and 73% of the multiparous cows (79% of all cows).

Table I. **Correlation coefficients between energy balance and FCM or NE_L intake from weekly means of 49 multi- and 24 primiparous cows from 2-21 wk postpartum**

Item	**FCM**		**NE_L Intake**	
	r	**P**	**r**	**P**
All Cows	-0.26	< 0.0001	0.58	< 0.0001
Primiparous	-0.15	0.001	0.75	< 0.0001
Multiparous	-0.33	< 0.0001	0.69	< 0.0001

We can conclude several things from our research:

- under most circumstances, cows only experience a slight duration of negative energy balance prior to calving; the most dramatic decline occurs early postpartum,
- return to positive energy balance occurs relatively quickly for most cows if they are fed diets that are nutritionally adequate (as is the case in these research studies),
- energy balance is more likely to be related to NEI intake than milk yield.

3. THE RELATIONSHIP BETWEEN ENERGY BALANCE AND REPRODUCTIVE PERFORMANCE

A survey of New York DHI records from 1950 to 1986 indicated that conception rates of mature lactating cows have declined from 66 to 51% as average milk yield has increased nearly 3000 kg/lactation (Smith, 1986). However, there has been no change in conception rates for heifers during the same time period. This suggests that a shift in genetic makeup of cows is not responsible for poor conception rates.

Energy balance was measured in very few of the studies that have been conducted to examine the relationship between nutrition and reproduction. Usually, body condition score is monitored and is used as an indicator of energy balance. Magnitude of body weight or condition loss in early lactation has been positively related to services per conception and conception rates in some (King, 1968; Hollen & Branton, 1971; Butler & Smith, 1989; Britt, 1992) but not all studies (Gardner, 1968; Stevenson & Britt, 1979; Carstairs *et al.* 1980; Sklan *et al.* 1989). Ninety-three Holstein cows that had finished a nutrition-reproduction trial were regrouped based on condition loss following completion of the study. Cows that experienced greater than 1 unit condition score loss during the first 5 weeks postpartum (n = 12) had greater days to first ovulation, days to first observed estrus, days to first service, and had a lower conception rate than cows experiencing less condition loss (n = 81; Butler & Smith, 1989, Table II). After completion of a trial at North Carolina, seventy-six Holstein cows were divided into a high (+.06 condition units; n = 46) or low (-.58 condition units, n = 30) group depending on condition loss during the first 5 weeks postpartum, the period of greatest fat mobilization (Britt, 1992). Milk production by cows in the two groups were not significantly different. Cows in the low group exhibited more days to first ovulation and lower first service and all services conception. Cows did not differ in plasma progesterone concentration during the first two estrous cycles but cows in the high group had significantly greater plasma progesterone concentrations during the third, fourth, and fifth cycles. This data supports the theory that conditions, which exist during initiation of follicular development, may be as critical to ovarian function as those conditions at the time of ovulation. Caution must be used in interpreting retrospective analysis of data. Dividing cows based on condition score loss may in effect be dividing cows into distinct genetic groups which may differ in many ways that could influence reproductive performance. Consequently, it may not be body condition per se that was affecting reproduction.

Table II. **Effects of body condition score loss on reproductive performance** (Butler & Smith, 1989)

	Body Condition Score Loss		
	< .5	**.5-1.0**	**> 1.0**
Number of Cows	17	64	12
Days to 1st Ovulation*	27	31	42
Days to 1st Estrus**	48	41	62
Days to 1st Service*	68	67	79
1st Service Conc. Rate*	65	53	17
Services/conception	1.8	2.3	2.3

*< .5 and .5-1.0 are different than > 1.0 (P < .05)
**.5-1.0 is different than > 1.0 (P < .05)

Butler & Canfield (1989) monitored early lactation dairy cows and cows that were dried off immediately after calving to study the relationship between negative energy balance and time to first ovulation. They clearly demonstrated a positive relationship (R^2 = .72) between the days to negative energy balance nadir (most extreme negative energy balance) and days to first ovulation. Delay in first postpartum ovulation is associated with reduced conception rates and increased interval from calving to conception (Darwash *et al.* 1997). Lucy *et al.* (1992) reported that cows having first ovulation before day 42 required fewer services per conception than cows having first ovulation after day 42. Early resumption of normal ovulatory cycles seems to be important for greater reproductive efficiency; an increased number of estrous cycles before the onset of breeding is related to fewer services per conception (Thatcher & Wilcox, 1973; Lucy *et al.* 1992; Darwash *et al.* 1997).

4. RELATIONSHIP BETWEEN ENERGY STATUS AND LIPID RELATED METABOLIC DISORDERS

Analysis of liver biopsies obtained from dairy cattle every other day during the periparturient period indicates that the most rapid rate of hepatic triacylglycerol (TAG) infiltration in the liver is during parturition (Vazquez-Anon, 1994). This coincides with the most rapid and extensive rise in plasma NEFA concentration during the same period. This “spontaneous” development of fatty liver occurs to a variable extent in all dairy cattle. Data from our herd indicates that approximately 50% of cattle develop moderate to severe fatty liver during this time (Grummer, 1993). Additional elevation of hepatic TAG commonly occurs after calving and is dependent on the severity of negative energy balance associated with copious milk production and the occurrence of metabolic disorders and diseases. Elevated NEFA at calving is partially caused by a reduction in energy intake as feed intake is decreased near the time of calving. Bertics *et al.* (1992) demonstrated that increasing energy intake by force feeding cows to maintain feed intake through calving reduced but did not eliminate the elevation in NEFA and liver TAG at calving. Consequently, hormonal changes associated with parturition and lactogenesis most certainly contribute to the surge in plasma NEFA at calving.

Force feeding cows through calving caused a reduction in fatty liver (Bertics *et al.* 1992), consequently, it was commonly recommended that feed intake should be maximized prior to calving to enhance energy status of cows and prevent fatty liver. However, numerous studies have indicated that prepartum feed intake was not always strongly related to liver TAG immediately after calving and the original interpretation of the data from Bertics *et al.* (1992) was too simplistic. For example, feed intake was lower when cows consumed high fiber diets, yet liver TAG was not higher (Rabelo 2002, Rabelo *et al.* 2005). Likewise, heifers consume less feed than mature cows (even when expressed as a percentage of body weight), yet they have lower hepatic TAG at calving (Rabelo 2003, Rabelo *et al.* 2005). Cows fed high fiber diets and heifers demonstrate a relatively flat intake curve prior to calving, i.e., less intake depression as calving approaches. Therefore, were the benefits of force feeding observed by Bertics *et al.* (1992) due to maximizing feed intake, or were they due to the avoidance of feed intake depression? We pooled data from three of our studies to try and answer this question. Plasma NEFA or hepatic TAG at calving were more closely associated with the magnitude of intake depression than to the absolute level of feed intake prior to depression (measured between 21 and 14 days prior to expected calving; Figure 3 and 4; Grummer *et al.* 2004). Further studies are needed to verify that change in feed intake (or energy balance) is a more important metabolic signal for the development of fatty liver than the absolute level of feed intake (or energy intake). If this is true, certain management factors (diet composition, diet changes, grouping changes, cow comfort) that contribute to a decline in feed intake prior to calving may contribute to the development of fatty liver.

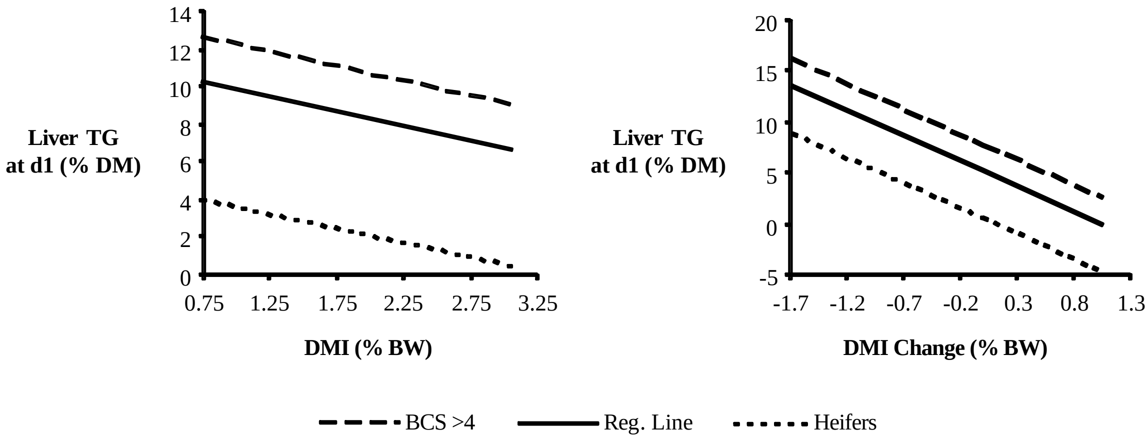

Figure 3. **The relationship between prefresh dry matter intake (DMI) during days -21 to -14 prior to calving or DMI change during the final 21 days prior to calving on liver triglyceride (TG) at 1 day after calving**

The solid line represents the regression generated using data from all animals. The long dashed line represents cows with a body condition score (BCS) > 4 and the short dashed line represents heifers. There were no interactions with BCS or parity, thus the slopes of all three lines within a graph are similar (slope = -1.53 for DMI, -4.96 for DMI change).

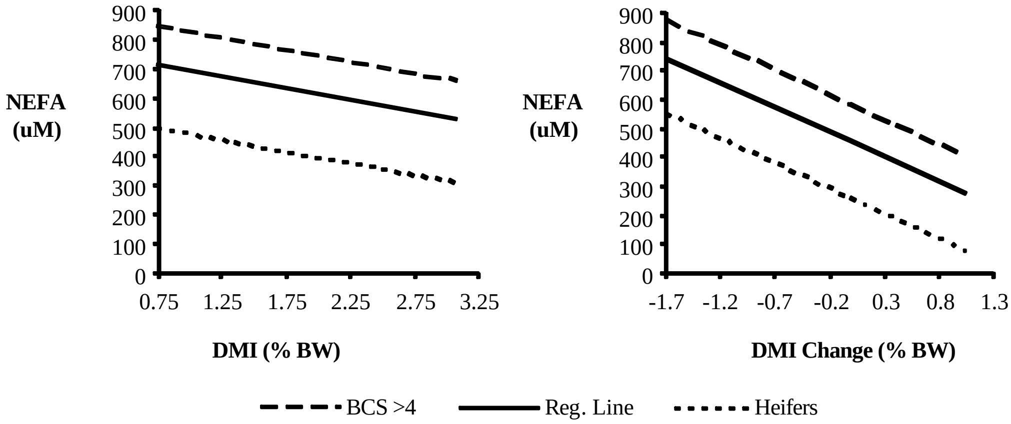

Figure 4. **Effects of prefresh dry matter intake (DMI) during days -21 to -14 prior to calving or DMI change during the final 21 days prior to calving on plasma NEFA concentrations at 1 day after calving**

The solid line represents the regression generated using data from all animals. The long dashed line represents cows with a body condition score (BCS) > 4 and the short dashed line represents heifers. There were no interactions with BCS or parity, thus the slopes of all three lines within a graph are similar (slope = -79 for DMI, -172 for DMI change).

5. STRATEGIES TO REDUCE THE FLUCTUATIONS IN ENERGY INTAKE DURING THE TRANSITION PERIOD

Numerous dietary strategies have been examined for transition cows, but feed restriction by limiting feed offered or by increasing the fiber content of the diet is the only reliable way to minimize large reductions in energy intake near the time of calving.

(Limiting the amount of feed offered is not practical for group fed animals.) We suspect management has a much greater influence than nutrition on magnitude of feed intake changes during the transition period, although little research has been conducted in this area. It only makes sense that managing cows to minimize stress would also minimize the depression in feed intake during the periparturient period.

Our laboratory was interested in feeding a single diet the entire gestation-lactation cycle to eliminate diet changes and the stress of diet and pen changes around parturition. Our hypothesis was that this would help foster continuous high energy intake throughout the transition period and reduce metabolic disorders. The only way we felt we could accomplish this goal was to shorten the dry period to lessen the likelihood of over-conditioning cows. We designed an experiment (Rastani *et al.* 2005a) with three treatments. Multiparous cows were fed the same lactation diet from -90 to -57 days prior to expected calving (here on referred to as day prepartum). Cows were assigned to treatments at -56 days prepartum. The 3 treatments were:

- 56 days dry; cows fed a low-energy far off diet from -56 to -29 days prepartum and a moderate-energy transition diet from -28 days to parturition,
- 28 days dry; cows fed lactation diet throughout the dry period,
- 0 days dry; cows fed lactation diet until calving.

After calving, all animals were fed the same lactation diet. The only difference between the pre- and postpartum lactation diets was the addition of buffer after parturition.

Actual days dry for the 56, 28 and 0 day treatments were 54, 29 and 5. Some cows on the 0 day treatment spontaneously dried up. Continuation of milking resulted in higher DMI prior to calving (Figure 5). However, even cows on the 0 day treatment experienced a decline in feed intake as calving approached. Differences in feed intake between treatments continued but to a lesser magnitude after calving. There was no significant difference in 4% fat-corrected milk (FCM) production between 56 and 28 day treatments; cows on 0 day produced about 5 kg FCM less per day than those on 28 day. Cows on the 28 day treatment produced milk with a higher fat test, consequently there were differences in milk yield between cows on the 56 and 28 day treatments (data not shown). Energy balance is shown in Figure 6. Most striking is that cows that were continuously milked did not enter into negative energy balance.

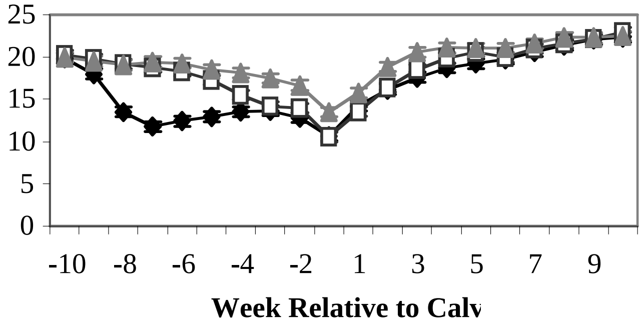

Figure 5. **Dry matter intake of cows experiencing a 56, 28, or 0 day dry period**

Cows on the 28 and 0 day dry period treatment were fed high-energy lactation type diets the entire trial. Cows on the 56 day dry period received a low energy far-off dry cow diet for the first 4 weeks of the dry period and a moderate energy diet for the final four weeks of the dry period.

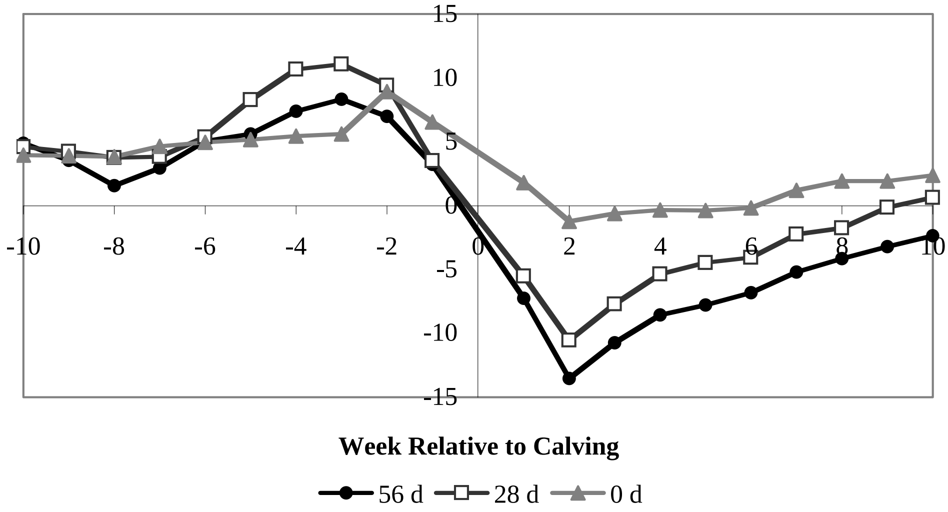

Figure 6. **Energy balance of cows experiencing a 56, 28, or 0 day dry period**

Cows on the 28 and 0 day dry period treatment were fed high-energy lactation type diets the entire trial. Cows on the 56 day dry period received a low energy far-off dry cow diet for the first 4 weeks of the dry period and a moderate energy diet for the final four weeks of the dry period.

Body condition score and body weight loss postpartum increased as days dry increased. This reflected a more favorable energy balance as days dry decreased. As one might expect, shortening the dry period resulted in a reduction in plasma NEFA, β-hydroxybutyrate, and liver TAG (Figure 7). However, the differences were only significant between cows on the 0 and 28 day treatments (liver TG and plasma NEFA only). Insufficient animal numbers dictated that we could not do a statistical analysis of data on incidences of metabolic disorders.

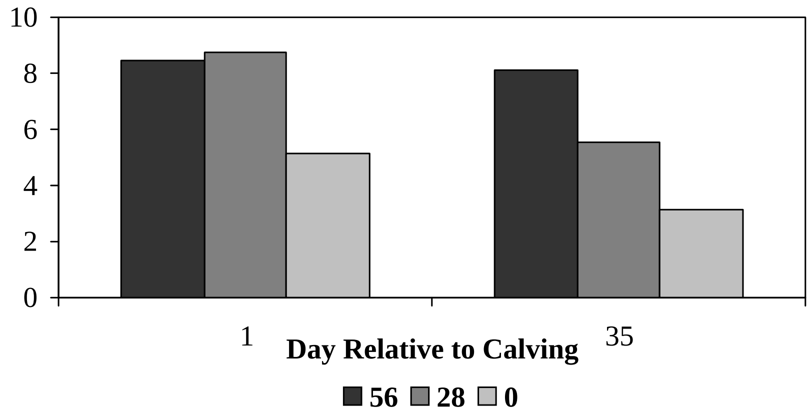

Figure 7. **Liver triacylglycerol (TAG) cows experiencing a 56, 28, or 0 day dry period. Cows on the 28 and 0 day dry period treatment were fed high-energy lactation type diets the entire trial**

Cows on the 56 day dry period received a low energy far-off dry cow diet for the first 4 weeks of the dry period and a moderate energy diet for the final four weeks of the dry period.

Ovarian dynamics were monitored by ultrasound three times per week (Gumen *et al.* 2005). Clearly, reducing the dry period resulted in a more rapid resumption of ovarian activity (Table III). Although this trial ended at 70 day postpartum, reproductive performance of cows was monitored beyond 70 d. Cows that were on the 0 day dry treatment had fewer days to first AI, higher first service conception rate, fewer services per conception, and fewer days open. We suspect that these benefits were due to differences in energy balance. However, because there were limited cows numbers in this trial and cows were not on experiment beyond 70 d, these results must be interpreted with caution.

Table III. **Ovarian dynamics and reproductive performance of cows fed and managed for 56, 28, and 0 d dry periods**

	56 d	**28 d**	**0 d**
Follicle diameter (mm) at first ultrasound	6.3^{b}	8.2^{ab}	9.5^{a}
Days to first 10 mm follicle	10.5^{b}	8.9^{a}	8.0^{a}
Days to first postpartum ovulation	31.9^{b}	23.8^{b}	13.2^{a}
Days to first AI	75.0	68.0	69.4
First service conception rate, %	20^{b}	26^{ab}	55^{a}
Services per conception	3.0^{b}	2.4^{ab}	1.7^{a}
Days open	145^{b}	121^{ab}	94^{a}

^{a,b} differ at $P < 0.05$

Next, we decided to conduct a trial on a large commercial dairy herd so that we could have sufficient cow numbers to examine the effects of dry period length on metabolic disorders and reproduction. (The drawback of doing this type of trial is the inability to monitor feed intake and energy balance.) Cows (n = 772) were assigned to either a 55 (control, C) or 34 day dry period (S). Dry cows on C were fed a low-energy diet until 34 day before their expected calving date and then all cows (C and S) were fed a moderate-energy transition diet until calving. Cows on C produced more milk than cows on S (43.8 vs. 41.8 kg/day). There was no treatment by time or treatment by parity interaction for milk yield. Fat (C = 3.35 vs. S = 3.48) and protein percent (C = 2.69 vs. S = 2.82) was affected by treatment. The incidences of mastitis, displaced abomasum, ketosis, metritis and retained placenta did not differ between treatments. There appears to be no beneficial effect of shortening the dry period from 55 to 34 day on health. Perhaps in this trial, the short dry period was not extreme enough to observe health benefits from reducing dry period length. To monitor ovarian activity, beginning two weeks postpartum, weekly blood samples were collected and analyzed for progesterone. Cows received AI based on removed tail-chalk after 45 DIM followed by Ovsynch and timed AI (37% of first AIs) after 80 DIM if not previously inseminated. Based on survival analysis, S cows had fewer days to first ovulation (median = 35 vs 43 days) as determined by serum progesterone > 1.0 ng/ml and showed a tendency to have fewer days to first service (median days = 67 vs. 72). However, first service conception rate did not differ between treatments (29.8 vs. 32.0%). The proportion of cows pregnant at 150 DIM was greater for S (51.8%) than for C (43.9%) cows. Survival analysis indicated a treatment effect for days open (median = 166 vs. 130 for C vs. S cows). Thus, decreasing the duration of the dry period from 55 to 34 day improved reproductive efficiency based on fewer days open and more cows pregnant at 150 DIM.

We have recently examined the effects of milking frequency during continuous milking for the final four weeks of pregnancy on post-calving milk production (Rastani *et al.* 2005b). At 28 days prior to expected calving, cows were assigned to 0x (28 day dry period), 1x or 4x/day milking until parturition. Before or after the treatment period, all cows were milked 2x/day. Cows responded differently to treatment depending on parity. Postpartum milk production for cows following their second gestation was greater for cows milked 0x/d (40.2 kg/day) compared with cows milked 1x and 4x/day (33.9 and 30.2 kg/day, respectively). Postpartum milk production for cows following their third or greater parity was greater for 0x/d (43.9 kg/day) compared with 1x/day (32.9 kg/day) but there was only a tendency for greater milk production compared to 4x/d (40.3 kg/day). Energy balance of cows that are continuously milked remain remarkable consistent and did not become negative during the transition period (Figure 8). This agreed with our earlier study (Rastani *et al.*

2005a, Figure 6). If management strategies can be devised to continuously milk cows without a substantial loss in milk production (e.g. by increasing milking frequency prepartum), the benefit of avoiding negative energy balance may be enormous. This may lead to a reduction in postpartum disorders and an improvement in reproductive function of dairy cows since it would eliminate the dramatic fluctuations in metabolism that cows currently endure.

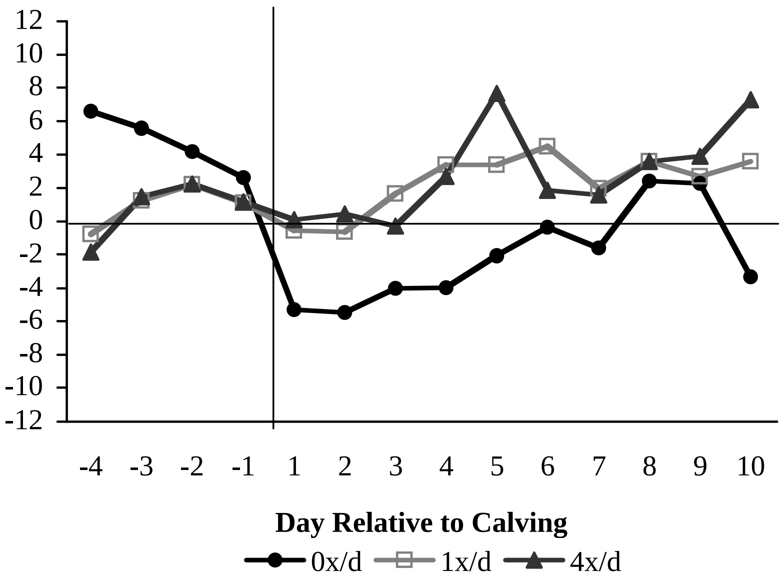

Figure 8. **Energy balance of cows that were milked 0x, 1x, or 4x/day for the last 28 days of pregnancy**

6. SUMMARY AND CONCLUSION

Energy balance may become negative before calving, but under most traditional feeding schemes, the extent and duration is quite small and short. Magnitude of change in energy balance may be a more important predictor of susceptibility to metabolic disorders than absolute energy balance prior to and at calving. After calving, negative energy balance decreases rapidly, but on average it should not last more than 5-7 weeks in a well-fed herd. Negative energy balance is more closely related to energy intake than level of milk production. Large reductions and prolonged duration of negative energy balance are detrimental to reproductive performance of dairy cows. A high priority of research should be to identify management strategies to minimize the extent and duration of negative energy balance so that we can achieve better health and reproduction of dairy cows. Our research has demonstrated that elimination of the dry period will eliminate negative energy balance in dairy cows. This is not solely a function of lower milk production. (Negative energy balance has been observed in dairy cattle for decades and it can be traced back to times when the genetic potential for milk production was much lower.) Elimination of negative energy balance in continuously milked cows is primarily due to greater energy intake. Identifying means to continuously milk cows without a subsequent loss in milk production should be a high priority of researchers. However, one cannot focus only on lost milk production because that must be weighed against the potential positives of better health and reproduction of the cow. However, at this point, the potential positives need further characterization.

7. KEY WORDS

Energy balance, milk production, reproductive performances of dairy cows.

8. RESUME

Chez la vache avant le vêlage, le bilan énergétique peut devenir négatif, mais dans la plupart des schémas traditionnels d'alimentation, ce phénomène reste limité en intensité et en durée. Le degré de variation du bilan énergétique semble être un indicateur plus pertinent de la susceptibilité aux affections métaboliques, que la valeur absolue du bilan énergétique avant et autour du vêlage. Après le vêlage, le bilan énergétique décroît rapidement, mais, en moyenne, cela ne devrait pas durer plus de 5-7 semaines dans un élevage avec une alimentation correcte. Le bilan énergétique négatif est plus étroitement corrélé à l'apport en énergie qu'au niveau de production de lait. Une diminution importante et prolongée du bilan énergétique apparaît préjudiciable aux performances de reproduction des vaches laitières. Une des priorités de la recherche serait d'identifier des stratégies de gestion visant à minimiser l'intensité et la durée du déficit énergétique et ainsi à améliorer l'état sanitaire et les capacités de reproduction des vaches laitières. Nos recherches ont montré que l'élimination de la période de tarissement supprime la négativité du bilan énergétique chez les vaches laitières. Cela n'est pas simplement dû à une baisse de la production de lait chez les vaches en lactation continue (un bilan énergétique négatif est observé depuis des décennies en élevage laitier, à des périodes où le potentiel génétique pour la production de lait était moins important) mais aussi et principalement à un meilleur apport en énergie. Identifier les moyens permettant une lactation continue sans perte conséquente de production de lait devrait donc être une priorité pour les chercheurs. Cependant, la diminution de production laitière ne peut être le seul paramètre à prendre en compte car il doit être discuté par rapport aux gains potentiels sur la santé et les capacités de reproduction de l'animal. En l'état actuel, les paramètres identifiant ces gains doivent être mieux définis et caractérisés.

9. MOTS CLES

Bilan énergétique, production laitière, capacités de reproduction des vaches laitières.

10. REFERENCES

Bertics SJ, Grummer RR *et al.* Effect of prepartum dry matter intake and liver triglyceride concentration and early postpartum lactation. J Dairy Sci, 1992; 75:1914.

Britt JH. Reproductive efficiency in dairy cattle as related to nutrition and environment. Proc Adv Nutr Sem for Feed Prof, University of Wisconsin, 1992:30.

Butler WR, Smith RD. Interrelationships between energy balance and postpartum reproductive function in dairy cattle. J Dairy Sci, 1989; 72:767.

Butler WR, Canfield RW. Interrelationships between energy balance and postpartum reproduction. Proc Cornell Nutr Conf Feed Manufact, Cornell University, 1989.

Carstairs JA, Morrow DA *et al.* Interrelationships between energy balance and postpartum reproductive function in dairy cattle. J Dairy Sci, 1980; 72:767.

Darwash AO, Lamming GE *et al.* The phenotypic association between the interval to postpartum ovulation and traditional measures of fertility in dairy cattle. Anim Sci, 1997; 65:9-16.

Gardner RW. Interactions of energy levels offered to Holstein cows prepartum and postpartum. II. Reproductive performance. J Dairy Sci, 1968; 52:1985.

Grummer RR. Etiology of lipid related metabolic disorders in periparturient dairy cattle. J Dairy Sci, 1983; 76:3882.

Grummer RR, Rastani RR. When should lactating dairy cows reach positive balance? Prof Anim Scient, 2003:19:197-203.

Grummer RR, Mashek DG *et al.* Dry matter intake and energy balance in the transition period. Managing the Transition Cow to Optimize Health and Productivity. Vet Clin North Ame. NB Cook & KV Nordlund, Eds. WB Saunders Co, 2004:447-470.

Gumen A, Rastani RR *et al.* Reduced dry periods and varying prepartum diets alter postpartum ovulation and reproductive measures. J Dairy Sci, 2005; 88:2401-2411.

Hollen BF, Branton C. Effects of early postpartum weight changes on reproductive performance of dairy cattle. J Dairy Sci, 1971; 54:787.
King JO. The relationship between conception rate and changes in body weight, yield, and SNF content of milk in dairy cows. Vet Rec, 1968; 83:492.

Lucy MC, Staples CR *et al.* Influence of diet composition, dry matter intake, milk production and energy balance on time of postpartum ovulation and fertility in dairy cows. Anim Prod, 1992; 54:323-331.

Rabelo E, Rexende RL *et al.* Effects of pre- and postfresh transition diets varying in dietary energy density on metabolic status of periparturient dairy cows. J Dairy Sci, 2005; 88:4375-4383.

Rabelo E, Rezende RL *et al.* Effects of transition diets varying in dietary energy density on lactation performance and ruminal parameters of dairy cows. J Dairy Sci, 2003; 86:916-925

Rastani RR, Silva del Rio N *et al.* Effects of milking frequency prepartum on postpartum milk production, milk composition, and dry matter intake in dairy cows. J Dairy Sci, 2005b; 88:286.

Rastani RR, Grummer RR *et al.* Reducing dry period length to simplify feeding transition cows, milk production, energy balance, and metabolic profiles. J Dairy Sci, 2005a; 88:1004-1014.

Sklan D, Bogin E *et al.* Feeding calcium soaps of fatty acids to lactating cows: effect of production, body condition, and blood lipids. J Dairy Res, 1989; 56:675.

Smith TR. Dairy Herd Profile Summary and Analysis. Cornell Univ Anim Sci Mimeo Ser, 1986; 90:27.

Stevenson JA, Britt JH. Relationships among luteinizing hormone, estradiol, progesterone, glucocorticoids, milk yield, body weight and postpartum ovarian activity in Holstein cows. J Anim Sci, 1979; 48:570.

Thatcher WW, Wilcox CJ. Postpartum estrus as an indicator of reproductive status in the dairy cow. J Dairy Sci, 1973; 56:608-610.

Vazquez-Anon M, Bertics S *et al.* Peripartum liver triglyceride and plasma metabolites in dairy cows. J Dairy Sci, 1994; 77:1521.