Energy Balance of Dairy Cattle in Relation to Milk Production Variables and Fertility

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ABSTRACT

Variables derived from milk yield records were investigated to find an easy to measure and readily available indicator of the energy balance status of a lactating cow. Weekly energy balances during the first 180 d in milk (DIM) were calculated from weekly yield, live weight, and energy intake records for 470 first lactation heifers. The energy balance curve for each cow was estimated using a random regression model. From each curve, three measures were calculated to describe the energy balance status: 1) total energy deficit in early lactation, 2) interval for return to positive energy balance, and 3) lowest value (nadir) for energy balance. Mean energy deficit per lactation was 776.8 MJ of NEL/d, interval for return to positive energy balance was 41.47 d, and nadir was $-33.72$ MJ of NE L/d. Regression analysis to relate these variables to interval to start of luteal activity (measured using progesterone profiles) showed that a low nadir of energy balance was related to delayed resumption of luteal activity. In general, a 10 MJ of NEL/d lower nadir of energy balance corresponded to a delay of ovulation of 1.25 d. A relatively strong decrease in fat percentage during early lactation was significantly correlated with lower nadir of energy balance, larger energy deficit, and later return to positive energy balance. The maximal correlation was between nadir of energy balance and a decrease of milk fat percentage. This correlation remained above 0.60 throughout the first 26 DIM but dropped to 0.14 at 180 DIM. Large decreases in milk fat percentage were related to high initial fat percentages at the start of lactation and slightly lower fat percentages later during lactation. Hence, we concluded that a decrease in fat percentage during early lactation might serve as an indicator of energy balance.

**Key words:** energy balance, milk fat percentage decrease, fertility, random regression

**Abbreviation key:** SLA = start of luteal activity, EB = energy balance, EFP = estimated fat percentage, \( \Delta \text{EFP} \) = change in estimated fat percentage, IPEB = interval postpartum to return of positive energy balance, TED = total energy deficit during early lactation.

INTRODUCTION

In general, dairy cows experience a negative energy balance (EB) in early lactation, because feed intake can not support the required energy for milk yield and maintenance. However, there are large differences between animals in the magnitude of the negative EB. These differences are important because of the association with fertility (3, 5, 6, 7, 8, 12, 25, 28). Hence, a variable reflecting the EB status of cows would be useful for decision-making (e.g., feeding and insemination decisions) or for the identification of potential problems. However, individual food intakes are required to obtain EB, and these are not measured on dairy farms.

An indicator of EB status is BCS (15, 23). Loss of BCS is correlated with fat mobilization (21, 31) and, therefore, BCS might be used as indicator of EB during early lactation. Routine scoring and recording of BCS is not a common practice on most dairy farms in The Netherlands; however, milk yield and milk composition data are available on more than 80% of the herds in The Netherlands. Use of these data to identify between-cow variation in EB might be an inexpensive alternative to measuring feed intake or BCS, because the energy status is expected to affect milk yield and milk composition. Some results (17) suggest that the fat to protein ratio is negatively related to EB. Also, persistency of milk (i.e., a lower peak yield) is expected to improve EB. A change in fat to protein ratio and the milk fat percentage during early lactation had a negative effect on conception at first insemination (22). Therefore, the hypothesis that milk yield and composition variables can help to monitor the EB status of cows seems justified.

Because duration and magnitude of EB are potentially of importance for fertility, several measures of EB were considered in this study. One variable examined was the total energy deficit during early lactation (TED), which is the sum of daily negative EB over a fixed period. Other EB measures used were the lowest
value (i.e., nadir) of daily EB during early lactation, postpartum interval to nadir, and the postpartum interval of return to positive energy balance (IPEB) (5, 8).

The objective of this study was to investigate whether a change in milk composition variables during lactation could be used as an indicator of EB during lactation and subsequent fertility. First, we determined which milk composition variable was most closely linked to different measures of EB and at what moment during lactation this milk composition variable was most indicative of EB. Second, the relationship between start of luteal activity (SLA) and measures of EB and the predictor of EB was investigated.

**MATERIAL AND METHODS**

Data in this study were collected from primiparous cows at the experimental dairy farm ’t Gen of the Institute for Animal Science and Health (Lelystad, The Netherlands) that calved between September 1991 and September 1997. Some cows in this herd (~50%) participated in the ‘Delta’ sib-testing program of Holland Genetics (Arnhem, The Netherlands), and the other cows originated from the farm. The latter cows were, on average, about half a standard deviation below the Delta cows in the Dutch production index (INET: reflecting milk, fat, and protein yield impact on future net profit). All cows could access food ad libitum (complete ration of artificially dried grass, corn silage, and concentrates, 6:5:10).

Milk yield was measured, and milk was sampled for determination of fat and protein percentages at a fixed day in the week (Friday) at a weekly interval. Feed intake was measured daily with automated feed intake units. Both energy intake and requirements were averaged by week postpartum. Energy requirements were calculated according to Dutch standards; the VEM system was used, which is based on energetic validation of net energy (9). In this system, energy requirements are dependent upon maintenance, growth, and milk yield. van der Hoving and Alderman (27) gave a detailed description of this system in comparison with other European systems.

Originally, 13,677 weekly means of EB, weight, and milk yield and fat and protein percentages of 638 lactations were available for analysis. Data were collected from October 1991 to February 1998. Records started prior to 30 DIM for all lactations, but lactation length varied from 78 to 182 DIM. To exclude effects of lactation length, lactations were restricted to those with one or more records later than 120 DIM (failure to conceive was not an important reason for culling in this period). Furthermore, to exclude measurement and data errors, data were restricted to those within three standard deviations of the mean. After these restrictions, 11,275 records from 470 lactations that ranged from 3 to 182 DIM remained. Table 1 summarizes the number of records removed from original data.

### Table 1. Record loss due to different exclusion criteria.

<table>
<thead>
<tr>
<th>Reason for exclusion</th>
<th>Cows</th>
<th>Records removed</th>
<th>Records left</th>
</tr>
</thead>
<tbody>
<tr>
<td>Last DIM within lactation ≤ 120</td>
<td>470</td>
<td>2263</td>
<td>11,413</td>
</tr>
<tr>
<td>Kilograms of milk &gt; mean ± 3 SD</td>
<td>470</td>
<td>43</td>
<td>11,370</td>
</tr>
<tr>
<td>Percentage of fat &gt; mean ± 3 SD</td>
<td>470</td>
<td>74</td>
<td>11,296</td>
</tr>
<tr>
<td>Percentage of protein &gt; mean ± 3 SD</td>
<td>470</td>
<td>21</td>
<td>11,275</td>
</tr>
</tbody>
</table>

**EB Measures**

A random regression model was used (24) to determine the EB curve for each cow and to correct for fixed effects. The function used was developed by Ali and Schaeffer (1) and adapted by de Vries et al. (12) for EB description in early lactation as follows:

\[
EB_{ijt} = Y_{Mi} + a_1 u + a_2 v + a_3 v^2 + a_{j1} + a_{j2} u + a_{j3} v + a_{j4} v^2
\]  

where \(EB_{ijt}\) = energy balance on DIM \(t\) of cow \(j\) measured in yr-mo \(i\); \(Y_{Mi}\) = effect of yr-mo \(i\) (January...December, 1991...1998); \(u = (DIM_t/305); v = ln (305/DIM_t); a_1, a_2, a_3 = fixed effects; and \(a_{j1}, a_{j2}, a_{j3}, a_{j4} = random\) effects of cow \(j\). Fixed and random effects were estimated using ASREML software (16).

Using Equation [1] an EB curve was obtained for each cow, which was used to calculate three variables linked to EB. These were the interval from calving to return to positive EB postpartum, the nadir of EB (lowest EB value reached in the first 180 DIM), and TED. The TED was calculated as follows:

\[
TED_i = -1 \sum_{t}^{180} EB(t)_i
\]  

where TED\(_i\) = TED of cow \(i\) during lactation, and IPEB\(_i\) = IPEB of cow \(i\). The EB\(_t\) describes EB in MJ of NEL/d of cow \(i\) on DIM \(t\), as estimated by Equation [1] for this lactation. Finally, TED\(_{wk}\) for the interval from calving to wk\(_l\) were calculated for each cow as the energy deficit over a fixed interval from calving (i.e., until wk\(_l\) = 6, 8, 11, or 15 respectively) using Equation [2] with IPEB\(_i\) substituted by the number of days in the last week of the interval.
Milk Yield Variables

Preliminary analyses were performed to screen for the milk yield variable most useful for the prediction of EB. Different milk yield variables were considered; changes were calculated for milk yield, percentage of fat, percentage of protein, fat yield, protein yield, and fat-protein ratio from wk 2 to wk 6, 8, 11, and 15. The first two intervals were chosen because mean nadir of fat percentage occurred in wk 8. To observe relations at the time that most cows had returned to positive EB, intervals from wk 2 to 11 and from wk 2 to 15 were added. Selection of the most useful yield variable was based on correlations with TED, nadir, IPEB, and TEDwk.

For the milk yield trait with the highest correlation to EB in the preliminary analysis, further analysis was performed using a random regression model. Reasons for this additional analysis were that a random regression model 1) allowed adjustment for seasonal effects across cows, 2) accounted for missing values, and 3) gave a lactation curve describing yield during the first 180 d of lactation for all animals, taking into account all records from calving to 180 DIM. It was expected that changes in yield were, therefore, better estimated compared with the preliminary analysis, but, more importantly, the lactation curves allowed calculation of changes in milk yield at each DIM. This finding was important to be able to estimate the correlation between EB and change in milk yield at different DIM.

The variable selected as having the highest correlation with EB measures was fat percentage change (see results). Thus, a random regression analysis similar to the analysis of EB was performed for fat percentage. Because fat percentage had a different pattern during lactation than EB, the best fitting curve describing percentage of fat was determined first. Several curves (1, 20, 29, 30) as well as polynomials were tested for goodness of fit on fat percentage during lactation. The curve selected was similar to the function developed by Wilmink (29), but the fixed value in this curve of −0.05 was re-estimated to be 0.0615, as suggested by Jamrozik et al. (20). The model used was as follows:

\[ FP_{jt} = YM_i + a_1 u + a_2 v + a_{j1} + a_{j2} u + a_{j3} v \]  

where \( FP_{jt} \) = fat percentage of cow j for DIM t measured in yr-mo i (January...December, 1991...1998); \( YM_i \) = effect of yr-mo i (January...December, 1991...1998); u = DIM t; v = \( \exp(-0.0615t) \); \( a_1, a_2 = \) fixed effects; and \( a_{j1}, a_{j2}, a_{j3} = \) random effects of cow j.

Random regression analysis made it feasible to estimate fat percentages (EFP) as well as changes in fat percentage (\( \Delta \text{EFP} \)) for all cows for each DIM. The latter were calculated from the derivative of the EFP curve for all cows. Correlations between \( \Delta \text{EFP} \) (at different DIM) and TED, nadir, and IPEB were estimated to investigate the association with EB.

Start of Luteal Activity

For some of the cows included in the study, progesterone values in the milk were available on Monday and Friday of each week. Progesterone profiles for these cows (n = 275) were used to determine number of days to first luteal activity. The SLA was the first DIM that progesterone was over 3 ng/ml (10, 11). This measure was regressed on TED, IPEB, nadir of EB, and \( \Delta \text{EFP} \). As distributions are skewed for these traits, logarithmic transformations of SLA and IPEB were also used in the regression analysis (11).

RESULTS

Weekly means for milk yield, percentages of fat and protein, and EB are given in Figure 1. The curve for EB estimated by Equation [1] agrees closely with observed EB at different lactation stages. All parameters used to describe the mean curve and estimates for the fixed effects were significantly different from zero (Table 2). On average, cows returned to positive EB at 41.5 DIM, and in the preceding period, these cows had on average a TED of 776.8 MJ of NEL. Differences in energy deficiency between cows were substantial; in total, 82 cows (i.e., 17.5% of the cows) did not experience negative EB during the first 180 DIM.
Table 2. Estimate for the fixed regression coefficients and the other fixed effects in the random regression models describing energy balance and percentage of fat from calving to 180 DIM.

<table>
<thead>
<tr>
<th></th>
<th>Energy balance</th>
<th>Fat percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>r</td>
<td>F</td>
</tr>
<tr>
<td>month</td>
<td></td>
<td></td>
</tr>
<tr>
<td>year</td>
<td></td>
<td></td>
</tr>
<tr>
<td>month × year</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(DIM/305)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ln2 (305/DIM)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>exp(−0.0615 × DIM)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DIM</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1$^r$ = Regression coefficient and F = type III F.

Identification of Milk Yield Variables Most Related to EB

Correlations of IPEB, TED, TEDwk, and nadir with changes in all milk yield variables from wk 2 to 6, 8, 11, or 15, as derived from the preliminary analysis, are given in Table 3. Although change in fat yield (ΔFY)

Table 3. Correlations between changes in several milk variables from wk 2 of lactation to wk 6, 8, 11, or 15 with interval to return to positive energy balance (IPEB), total energy deficit in early lactation (TED), nadir of energy balance, and energy deficits calculated over the same interval as the interval that the change in milk yield variables is calculated (TEDwk).

<table>
<thead>
<tr>
<th></th>
<th>IPEB</th>
<th>TED</th>
<th>Nadir of EB</th>
<th>TEDwk</th>
</tr>
</thead>
<tbody>
<tr>
<td>△ kg of milk</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>wk 2 to 6</td>
<td>0.194</td>
<td>0.175</td>
<td>−0.154</td>
<td>0.180</td>
</tr>
<tr>
<td>wk 2 to 8</td>
<td>0.139</td>
<td>0.124</td>
<td>−0.056</td>
<td>0.107</td>
</tr>
<tr>
<td>wk 2 to 11</td>
<td>0.056</td>
<td>0.036</td>
<td>0.014</td>
<td>0.032</td>
</tr>
<tr>
<td>wk 2 to 15</td>
<td>−0.025</td>
<td>−0.070</td>
<td>0.113</td>
<td>−0.032</td>
</tr>
<tr>
<td>△ Fat percentage</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>wk 2 to 6</td>
<td>−0.370</td>
<td>−0.385</td>
<td>0.439</td>
<td>−0.414</td>
</tr>
<tr>
<td>wk 2 to 8</td>
<td>−0.415</td>
<td>−0.432</td>
<td>0.470</td>
<td>−0.432</td>
</tr>
<tr>
<td>wk 2 to 11</td>
<td>−0.467</td>
<td>−0.484</td>
<td>0.519</td>
<td>−0.494</td>
</tr>
<tr>
<td>wk 2 to 15</td>
<td>−0.464</td>
<td>−0.484</td>
<td>0.508</td>
<td>−0.473</td>
</tr>
<tr>
<td>△ Protein percentage</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>wk 2 to 6</td>
<td>−0.170</td>
<td>−0.162</td>
<td>0.144</td>
<td>−0.159</td>
</tr>
<tr>
<td>wk 2 to 8</td>
<td>−0.152</td>
<td>−0.128</td>
<td>0.101</td>
<td>−0.136</td>
</tr>
<tr>
<td>wk 2 to 11</td>
<td>−0.093</td>
<td>−0.077</td>
<td>0.045</td>
<td>−0.071</td>
</tr>
<tr>
<td>wk 2 to 15</td>
<td>−0.009</td>
<td>0.006</td>
<td>−0.048</td>
<td>−0.004</td>
</tr>
<tr>
<td>△ Fat/protein ratio</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>wk 2 to 6</td>
<td>−0.274</td>
<td>−0.293</td>
<td>0.353</td>
<td>−0.323</td>
</tr>
<tr>
<td>wk 2 to 8</td>
<td>−0.341</td>
<td>−0.370</td>
<td>0.418</td>
<td>−0.365</td>
</tr>
<tr>
<td>wk 2 to 11</td>
<td>−0.442</td>
<td>−0.481</td>
<td>0.518</td>
<td>−0.482</td>
</tr>
<tr>
<td>wk 2 to 15</td>
<td>−0.472</td>
<td>−0.505</td>
<td>0.546</td>
<td>−0.491</td>
</tr>
<tr>
<td>△ Fat, g</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>wk 2 to 6</td>
<td>−0.228</td>
<td>−0.263</td>
<td>0.332</td>
<td>−0.288</td>
</tr>
<tr>
<td>wk 2 to 8</td>
<td>−0.326</td>
<td>−0.377</td>
<td>0.446</td>
<td>−0.370</td>
</tr>
<tr>
<td>wk 2 to 11</td>
<td>−0.444</td>
<td>−0.500</td>
<td>0.557</td>
<td>−0.493</td>
</tr>
<tr>
<td>wk 2 to 15</td>
<td>−0.445</td>
<td>−0.518</td>
<td>0.568</td>
<td>−0.469</td>
</tr>
<tr>
<td>△ Protein, g</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>wk 2 to 6</td>
<td>0.042</td>
<td>0.024</td>
<td>−0.014</td>
<td>0.029</td>
</tr>
<tr>
<td>wk 2 to 8</td>
<td>0.005</td>
<td>−0.016</td>
<td>0.044</td>
<td>−0.019</td>
</tr>
<tr>
<td>wk 2 to 11</td>
<td>−0.022</td>
<td>−0.028</td>
<td>0.059</td>
<td>−0.030</td>
</tr>
<tr>
<td>wk 2 to 15</td>
<td>−0.028</td>
<td>−0.067</td>
<td>0.090</td>
<td>−0.030</td>
</tr>
</tbody>
</table>

had the highest correlation with TED (−0.518) and nadir (0.568), the change in fat percentage (ΔFP) showed a consistently high correlation throughout lactation with nadir of EB (0.439 to 0.508 vs. 0.332 to 0.568 for ΔFP and ΔFY, respectively). A more consistent correlation was observed between TEDwk and ΔFP compared with the correlations between TEDwk and ΔFY (i.e.,
−0.414 to −0.494 for ∆FP vs. −0.288 to −0.493 for ∆FY). Hence, these results suggest the use of ∆FP as a better indicator of EB rather than ∆FY. Another alternative might have been to use the change in fat to protein ratio, as correlations with TED, nadir, and IPEB were similar to the correlation with change in fat percentage. However, because the change in protein percentage was correlated only weakly with EB measures (up to −0.170), most (if not all) information in this ratio was likely derived from ∆FP.

As correlations were used to select ∆FP, a linear relationship with measures of EB was assumed. Although not formally tested, visual assessment of the graphs displaying the relationship between change in milk yield variables and EB measures seemed to justify this assumption of linearity because there were no signs of a nonlinear relationship or a bimodal distribution.

**Detailed Analysis of the Relationship Between Fat Percentage and EB**

The mean lactation curve for fat percentage was estimated (Figure 1). Correlations of TED, IPEB, and nadir of EB to ∆EFP at different DIM ranged from −0.567 to 0.170, −0.517 to −0.141, and 0.611 to 0.140, respectively (Figure 2). Correlations between EB measures and ∆EFP were consistently high during the first 25 DIM but decreased after this period. The time during lactation that ∆EFP gave the best prediction of EB differed slightly per EB measure; the highest correlations between ∆EFP and nadir, IPEB, or TED were observed at DIM 1, 7, and 13, respectively (Figure 2). The correlation between nadir of EB and ∆EFP on first DIM was the highest correlation observed: 0.611. This relationship is shown in Figure 3.

To clarify if differences in ∆EFP are caused by a relatively high fat percentage at the start of lactation or a relatively low fat percentage in a later lactation stage, cows were divided into quarters by nadir of EB (Table 4). This comparison showed that cows with lower nadir of EB started lactation with a much higher fat percentage than average, but this higher EFP could not be sustained in later lactation. At 58 DIM, cows in a more negative EB had a slightly lower EFP.

**Start of Luteal Activity**

For the 275 lactations with progesterone data available, luteal activity started at 29.7 DIM on average. However, distribution of this SLA was skewed: mode of SLA was around 18 DIM, whereas SLA ranged from 10 to 97 DIM. Regression coefficients of SLA and lnSLA on all EB measures were significantly different from zero: a larger TED, later IPEB, and lower nadir of EB were all related to a larger SLA (Table 5). For example, a 10 MJ of NE\textsubscript{L}/d lower nadir of EB increased SLA by 1.25 d. However, a loglinear relationship gave a slightly better fit, suggesting that this regression coefficient increased from 1.0 to 1.6 d with increasing negative EB. This finding is illustrated in Figure 4. The regression coefficients of SLA and lnSLA on ∆EFP were, however, not significantly different from zero. This finding might have been due to some animals with high values for SLA, because when outliers for SLA (32 values of SLA over 50 DIM) were removed from the data, the relationship between ∆EFP and SLA and lnSLA proved significantly different from zero as well (Table 5).
Table 4. Mean values of estimated fat percentage (EFP) at 1 DIM, nadir of EFP at 58 DIM, and individual nadir of EFP for cows divided into quartiles for nadir of energy balance (EB).

<table>
<thead>
<tr>
<th>Quartile of EB</th>
<th>EB nadir</th>
<th>1 DIM</th>
<th>58 DIM</th>
<th>Nadir</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lowest quartile (n = 117)</td>
<td>−72.11</td>
<td>5.65*</td>
<td>3.77†</td>
<td>3.72</td>
</tr>
<tr>
<td>25–50% quartile (n = 118)</td>
<td>−40.65</td>
<td>5.22*</td>
<td>3.80†</td>
<td>3.77</td>
</tr>
<tr>
<td>50–75% quartile (n = 118)</td>
<td>−20.22</td>
<td>4.89*</td>
<td>3.84†</td>
<td>3.81</td>
</tr>
<tr>
<td>Highest quartile (n = 117)</td>
<td>−1.96</td>
<td>4.66*</td>
<td>3.92†</td>
<td>3.86</td>
</tr>
</tbody>
</table>

*Means within column differ at $P \leq 0.0001$.  
†Means within column differ at $P \leq 0.005$.  

DISCUSSION

The aim of this study was to find a milk yield variable that could be used as an indicator of EB during early lactation. For this purpose, several measures of EB were calculated for first lactation cows, and these measures for EB were correlated to different milk yield variables. As discussed previously, $\Delta$FP during early lactation was chosen as variable for the prediction of EB measures. Other variables such as change in fat to protein ratio and $\Delta$FY could also be used as predictors of EB. However, $\Delta$FP seems to be the component common to all of these potential milk production variables. The advantage of the use of change in fat percentage, compared with absolute fat percentage, is that cows that have high fat percentages throughout the lactation (e.g., because of their genetic merit) are not necessarily identified as being in a negative EB. The dynamics of fat percentage during lactation is used to identify variation among animals in EB.

A biological or physiological explanation for the relationship between fat percentage and EB is related to mobilization of fat reserves. Cows in a negative EB mobilize more body fat reserves and produce glycerol for energy resources, which leads to increased NEFA concentrations in blood. These NEFA are taken up by the liver and can be oxidized for additional energy supply or esterified into triglycerides, which can lead to either ketosis or fatty liver disorder. However, a fraction of triglycerides are transformed to very low density lipoproteins, which can be taken up by the udder (2, 4, 26). Because deposition of very low density lipoproteins is at maximum in early lactation (18), a higher fat percentage in early lactation can be caused by a decreased milk yield because of a lack of glucose during maximum milk fat production. Hence, change in milk fat percentage can indicate subclinical ketosis during early lactation in dairy cattle. These findings agree with a previous report (14) of elevated fat contents in test-day milk yields for ketonemic cows and a recent study (13), which found that milk fat percentage provided a better predictor of $\beta$-hydroxybutyric acid than did the milk fat to protein ratio or milk protein percentage. These results support that $\Delta$FP might be useful for identification of potential problem cows or to identify EB as a potential source of problems.

Although measures of EB were derived from records collected at one experimental herd, these values were considered representative for EB differences for cows within other herds. Weekly EB patterns were similar to those found in another herd (12), and TED, nadir, and IPEB agreed closely between these studies. The $\Delta$FP could be useful to identify across-herd differences for EB, especially because plasma NEFA concentration of cows differed strongly between commercial dairy herds (19). However, the indicator for EB suggested in this study is based on variation between cows from a

Table 5. Effects of interval to return to positive energy balance (IPEB), lnIPEB, total energy deficit in early lactation (TED), nadir of energy balance (EB), and change in estimated fat percentage on first DIM ($\Delta$EFP on 1st DIM) on postpartum interval to start of luteal activity (SLA) and lnSLA.1

<table>
<thead>
<tr>
<th>Effect on SLA (d)</th>
<th>P</th>
<th>R²</th>
<th>Effect on lnSLA (d)</th>
<th>P</th>
<th>R²</th>
</tr>
</thead>
<tbody>
<tr>
<td>IPEB</td>
<td>0.125</td>
<td>0.002</td>
<td>0.035</td>
<td>0.0044</td>
<td>0.000</td>
</tr>
<tr>
<td>lnIPEB</td>
<td>3.795</td>
<td>0.173</td>
<td>0.008</td>
<td>0.159</td>
<td>0.040</td>
</tr>
<tr>
<td>TED</td>
<td>0.004</td>
<td>0.003</td>
<td>0.032</td>
<td>0.0001</td>
<td>0.000</td>
</tr>
<tr>
<td>Nadir of EB</td>
<td>−0.125</td>
<td>0.001</td>
<td>0.042</td>
<td>−0.0043</td>
<td>0.000</td>
</tr>
<tr>
<td>$\Delta$EFP on 1st DIM (n = 275)</td>
<td>−12.086</td>
<td>0.612</td>
<td>0.001</td>
<td>−0.779</td>
<td>0.249</td>
</tr>
<tr>
<td>$\Delta$EFP on 1st DIM (n = 243)</td>
<td>−30.349</td>
<td>0.030</td>
<td>0.020</td>
<td>−1.349</td>
<td>0.011</td>
</tr>
</tbody>
</table>

1Two data sets were used, one including all data with SLA (n = 275) and one excluding outlying measures for progesterone (SLA > 50 DIM; n = 243).
within-herd analysis. However, it might be hypothesized that this indicator is robust across herds because it had a proper biological explanation and the within-lactation deviation is used. Hence, some of the between herd differences in absolute fat percentages might be accounted for, and changes in fat yield during lactation (adjusted for season) might be relatively unaffected by herd differences other than EB. If this hypothesis is proven to be correct, then fat percentage can also be used to identify EB-related herd problems.

It is also pertinent to consider whether present results are applicable to multiparous cows because first lactation cows have a lower mean EB in comparison with later lactation cows (8). This question cannot be answered without having data available from multiparous cows, although de Vries et al. (12) reported that lower nadir of EB delayed the first observed estrus for first-parity and multiparity cows. Thus, it is expected that the observed correlation between ∆FP and SLA also holds in later lactations, albeit the magnitude of ∆FP and the subsequent effect on EB is likely to differ between lactations.

Start of Luteal Activity

Mean SLA in this study (29.7) was close to the 27.0 and 27.3 d reported by Darwash et al. (10, 11) but is 9 to 10 d higher than the number of days to first ovulation from Beam and Butler (3) and Canfield et al. (8). These differences might be partially due to sampling progesterone only twice a week, but a more likely explanation is that these are caused by some animals that did not show any luteal activity before d 50. That the regression coefficients of SLA on all EB measures are significantly different from zero confirms earlier evidence of effects of EB on SLA (3). In a previous study (12) and in this study, nadir of EB was the variable that had the highest correlation with SLA or with the postpartum interval to detected estrus. Therefore, an association between the ∆FP and SLA was also expected. However, the regression coefficient was significantly different from zero only after exclusion of 32 outlying values for SLA. The delayed luteal activity in these 32 animals was likely caused by other factors than EB. A relationship between predicted transmitting ability for fat percentage and SLA was indicated by others (11) and indicated a genetic component to the relationship between higher fat percentages during lactation and delayed ovulation. Further investigation of the (genetic) relationship between postpartum change in fat percentage and fertility variables is needed on a larger data set.

CONCLUSIONS

A low nadir of EB is correlated with a delay in the postpartum start of luteal activity. Cows experiencing stronger negative EB postpartum start lactation with elevated fat percentages, which decrease to values that are slightly lower than average fat percentages later in lactation. Therefore the decrease in fat percentage in the first weeks postpartum can be used as an indicator of energy deficits during early lactation and of EB-related problems of a cow such as delayed resumption of ovarian activity. Data in this study are relevant of primiparous cows and effects in multiparous cows need further study.

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REFERENCES


