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Authors

Lehmann, JO
Fadel, JG
Mogensen, L
[et al.](#)

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Effect of calving interval and parity on milk yield per feeding day in Danish commercial dairy herds

J. O. Lehmann,*¹ J. G. Fadel,† L. Mogensen,* T. Kristensen,* C. Gaillard,‡ and E. Kebreab†

*Department of Agroecology, Aarhus University-Foulum, Blichers Allé 20, DK-8830 Tjele, Denmark

†Department of Animal Science, University of California-Davis, One Shields Avenue, Davis 95616

‡Department of Animal Science, Aarhus University-Foulum, Blichers Allé 20, DK-8830 Tjele, Denmark

ABSTRACT

The idea of managing cows for extended lactations rather than lactations of the traditional length of 1 yr primarily arose from observations of increasing problems with infertility and cows being dried off with high milk yields. However, it is vital for the success of extended lactation practices that cows are able to maintain milk yield per feeding day when the length of the calving interval (CInt) is increased. Milk yield per feeding day is defined as the cumulated lactation milk yield divided by the sum of days between 2 consecutive calvings. The main objective of this study was to investigate the milk production of cows managed for lactations of different lengths, and the primary aim was to investigate the relationship between CInt, parity, and milk yield. Five measurements of milk yield were used: energy-corrected milk (ECM) yield per feeding day, ECM yield per lactating day, cumulative ECM yield during the first 305 d of lactation, as well as ECM yield per day during early and late lactation. The analyses were based on a total of 1,379 completed lactations from cows calving between January 2007 and May 2013 in 4 Danish commercial dairy herds managed for extended lactation for several years. Herd-average CInt length ranged from 414 to 521 d. The herds had Holstein, Jersey, or crosses between Holstein, Jersey, and Red Danish cows with average milk yields ranging from 7,644 to 11,286 kg of ECM per cow per year. A significant effect of the CInt was noted on all 5 measurements of milk yield, and this effect interacted with parity for ECM per feeding day, ECM per lactating day and ECM per day during late lactation. The results showed that cows were at least able to produce equivalent ECM per feeding day with increasing CInt, and that first- and second-parity cows maintained ECM per lactating day. Cows with a CInt between 17 and 19 mo produced 476 kg of ECM more

during the first 305 d compared with cows with a CInt of less than 13 mo. Furthermore, early-lactation ECM yield was greater for all cows and late-lactation ECM yield was less for second-parity and older cows when undergoing an extended compared with a shorter lactation. Increasing CInt increased the dry period length with 3 to 5 d. In conclusion, the group of cows with longer CInt were able to produce at least equivalent amounts of ECM per feeding day when the CInt was up to 17 to 19 mo on these 4 commercial dairy farms.

Key words: extended lactation, dairy cow, milk yield, lactation curve

INTRODUCTION

Dairy production is characterized by cycles of calving, lactation including gestation, and a dry period followed by the next calving. Originally, these cycles were driven solely by annual changes in daylight and feed availability, but, in modern intensive dairy systems, these cycles are mostly driven by decisions of the farmer. Seasonality may still play a major role in modern dairy systems, such as the grassland-based production in New Zealand, where the average calving interval (CInt) is 368 d (LIC and DairyNZ, 2013). In contrast, the average CInt in the confinement systems in Denmark has increased to around 395 d (Danish Cattle, 2014a). The dry period length is likely unchanged, and therefore the extended CInt results in an extended lactation. Both planned and unplanned effects such as reduced fertility may have contributed to this increase in CInt.

Reduced fertility in intensive dairy systems has been linked to the continued genetic selection for increased milk yield through a more severe negative energy balance around the time of calving (Ancker et al., 2006). Managing cows for extended lactation means that cows are likely inseminated after the cows have passed the most severe negative energy balance. Hence, extended lactation may be a way of alleviating this issue as well as reduce the number of cows being dried off with high milk yields (Knight, 2008). Also, extended lactation

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¹Corresponding author: JesperO.Lehmann@agro.au.dk

reduces the required supply of replacement heifers per year.

Furthermore, extended lactation could potentially reduce greenhouse gas (GHG) emission per kilogram of milk produced through a reduction in herd feed use per kilogram of milk produced and, thereby, also improve farm profitability in commercial herds (Knight, 2008; Eckard et al., 2010; Lehmann et al., 2014). However, total meat production will be reduced in a system with extended lactation as a result of fewer calvings and hence fewer culled cows and bull calves for sale. In addition, genetic progress may slow down as a result of longer generation intervals.

The success of using extended lactation as a management system is highly dependent on the ability of a cow to maintain milk yield per feeding day. This yield measure encompasses the whole lactation and the length of the dry period, which is in contrast to traditional figures such as 305-d lactation yield.

Milk yield per feeding day was shown to be maintained during extended lactations in experimental herds in Sweden (Österman and Bertilsson, 2003) and Denmark (Christiansen et al., 2005), as well as commercial herds in Israel (Arbel et al., 2001). On the other hand, Auld et al. (2007) showed a small negative effect and Kolver et al. (2007) showed some gains and some losses in milk yield of cows, which had their lactations extended to up to 2 yr in a pastoral system. Furthermore, 2 studies have indicated a potential negative influence of a previous extended lactation on the dry period length and milk yield of the following lactation (Arbel et al., 2001; Österman and Bertilsson, 2003).

We hypothesized that dairy cows undergoing an extended lactation should be able to produce the same amount of milk per feeding day as cows undergoing lactations of traditional length. Partly because the number of days lactating relative to the number of days dry will be increased, and partly because the potential negative effect of pregnancy on milk yield (Bormann et al., 2002; Roche, 2003) may be delayed when breeding is postponed.

Estimating daily milk production from commercial milk yield recordings is often challenged by data frequency, as farmers typically only conduct monthly or even bimonthly recordings. A lactation curve can be fitted with either empirical (e.g., Wood, 1967; Wilmink, 1987) or mechanistic (e.g., Dijkstra et al., 1997) mathematical functions. The ability of the model to describe the asymptotic phase occurring mid to late lactation is important to estimate daily yield during extended lactations (Macciotta et al., 2011; Steri et al., 2012). Legendre polynomials are useful because they can represent a greater number of lactation curvatures, and

their mathematical properties cause them to have less correlation among parameters (Macciotta et al., 2005).

The main objective of our study was to investigate the milk production of cows undergoing lactations of different lengths on commercial farms in Denmark known to deliberately delay insemination. Furthermore, the aims were to (1) estimate daily milk yield by fitting a Legendre polynomial model to milk yield recordings, (2) investigate the relationship between CInt length, parity, and milk yield, and (3) investigate the influence of previous CInt length on current milk yield.

MATERIALS AND METHODS

Data

The data came from 4 commercial Danish dairy farms known to deliberately delay insemination of selected cows and, hence, manage the herd for extended lactations. The 4 farms (Table 1) varied in herd size, breed, milk production and composition, annual cull rate, CInt length, and milk recording scheme (6 or 11 recordings per year). The farms were selected based on work by van Vliet (2012), who identified 6 farmers practicing extended lactation through contacting dairy cattle advisors. The 4 farms were chosen because they had the longest lactations and were willing to participate in the project.

For completed lactations, the average DIM at first insemination increased consistently as the average CInt length increased for herds 2, 3, and 4 with increasing CInt (Figure 1). This illustrates that the voluntary waiting period increased, but, in these herds, some cows either failed to conceive at first or second insemination or did not express mating behavior. This was particularly pronounced in herd 1, although only 9% of lactations had a CInt greater than 17 mo (Figure 1).

Data consisted of milk yield recordings and dates for inseminations, pregnancy tests, drying off, calving, and culling. Energy-corrected milk yield was calculated using the equation of Sjaunja et al. (1991):

$$\text{ECM} = \text{milk (kg)} \times [0.383 \times \text{fat (\%)} + 0.242 \times \text{protein (\%)} + 0.7832]/3.14.$$

Data were obtained from cows that calved between January 1, 2007, and May 1, 2013, in the 4 herds, and data from 176 lactations with less than a total of 3 milk recordings were removed. Twenty-six lactations (from 15 cows) with no information on date of next calving, drying off date, or culling date and no records during the last 3 mo before May 1, 2013, were removed. Herd 1 purchased 11 cows, of which 5 were purchased after

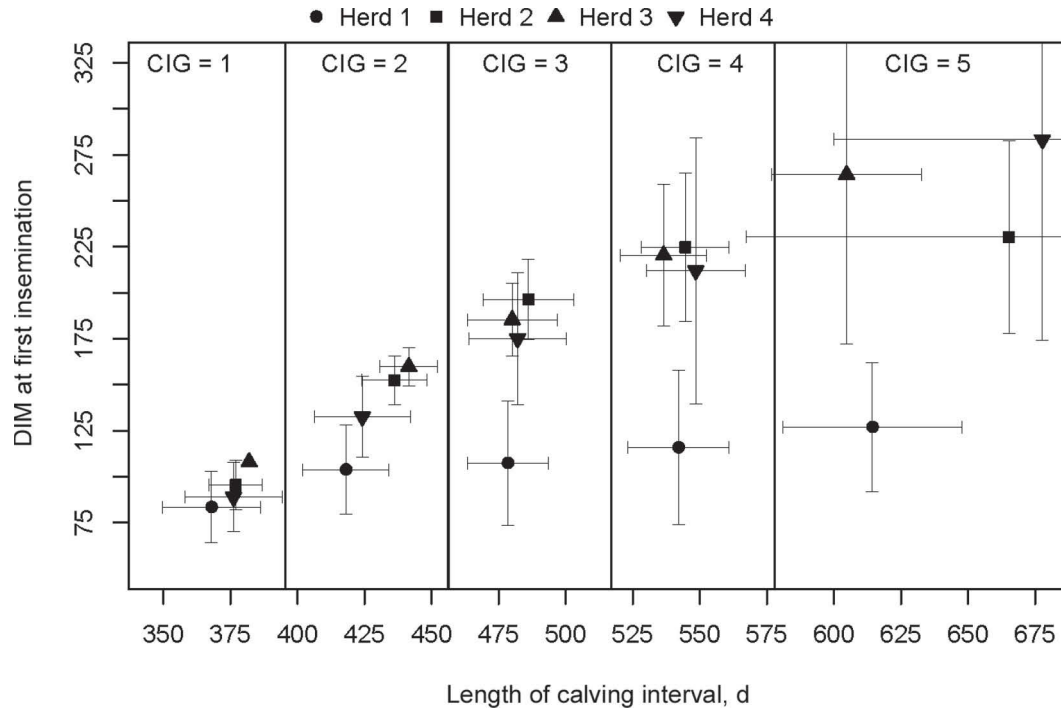


Figure 1. Average DIM at time of first insemination after calving relative to the average length of the calving interval in days based on raw data and grouped by calving interval group (CIG) and herd. Error bars indicate standard deviation. CIG = 1: calving interval (CInt) \leq 13 mo; CIG = 2: 13 mo < CInt \leq 15 mo; CIG = 3: 15 mo < CInt \leq 17 mo; CIG = 4: 17 mo < CInt \leq 19 mo; CIG = 5: 19 mo < CInt.

their first calving, and herd 2 purchased 5 cows, of which 1 was purchased after their first calving. Lactations were removed if the calving had taken place in another herd. A lactation either went from calving until

drying off, from calving until culling, or from calving until data cut-off (May 1, 2013). If a cow had known future calving date and a drying off date had not been reported by the farmer for a given lactation (38%),

Table 1. Characteristics of the 4 Danish dairy farms. Herd averages from 2007 to 2011

Item	Herd			
	1	2	3	4
Annual cows, ¹ no.	146	87	151	108
System	Conventional	Organic ²	Organic ²	Organic ²
Breed	Holstein	Holstein	Crosses ³	Jersey
Average fat, %	3.99	3.86	4.86	6.01
Average protein, %	3.24	3.33	3.69	4.18
Milk yield per annual cow, kg	11,448	10,577	7,119	5,859
ECM per annual cow, ⁴ kg	11,286	10,333	8,020	7,644
Annual cull rate, %	34.1	30.7	35.2	25.3
Milking system	Parlor	Robot	Parlor	Robot
Grazing	No	Yes	Yes	Yes
Average lactating days (SD)	358 (61)	477 (91)	420 (35)	451 (121)
Average CInt, ⁵ d (SD)	414 (63)	521 (92)	468 (35)	497 (119)
Milk recordings per year, no.	11	6	11	6
Completed lactations in data, no.	480	181	434	284

¹One annual cow is an average cow fed for 365 d; therefore, it reflects the average number of cows present in the herd on any day of the year.

²Certified organic according to Danish standards.

³Crosses between Holstein, Jersey, and Red Danish.

⁴Calculated with the equation of Sjaunja et al. (1991).

⁵Calving interval.

then a fixed dry period of 49 d was assigned because the recommended dry period in Denmark is 6 to 7 wk (Danish Cattle, 2014a).

The final data set consisted of 23,394 recordings from 2,580 lactations, of which 1,379 were completed. A lactation was considered completed if a future calving date was known and if this calving took place in the same herd as the preceding one. Each lactation had between 3 and 36 milk yield recordings, which corresponded to 100 to 995 DIM.

Data Analyses

Milk yield was recorded with an interval of either approximately 30 d (2 herds) or approximately 60 d (2 herds) for all cows that were lactating on that given recording day. After calculating ECM, all records were fitted with a Legendre polynomial model to estimate daily and cumulated ECM yield (aim 1). Records from both complete and incomplete lactations were used for the fit to maximize the information about the curvature at the early part of the lactation.

Five variables were used (aim 2) to describe milk yield during a completed lactation: (1) average ECM yield per feeding day (**ECM_Feed**); (2) average ECM yield per lactating day (**ECM_Lac**); (3) cumulative ECM yield during the first 305 d of lactation (**ECM_305**); (4) average ECM yield per day during the first 80 d of the lactation (**ECM_80**); and (5) average ECM yield per day during the last 45 d of the lactation (**ECM_45**). The longer the dry period, the greater the difference expected between **ECM_Feed** and **ECM_Lac**. Two variables, **ECM_80** and **ECM_45**, were used as indicators of early- and late-lactation yield, respectively, where the number of days between them is dependent on **CInt** length. The decrease in yield between **ECM_80** and **ECM_45** illustrates the loss in daily milk production between early and late lactation.

Parities 1 to 9 were present in data, but the number of completed lactations for each parity decreases as the parity number increases. Therefore, parity (**PAR**) was grouped in 3 groups by first, second, and third or greater parities. This meant that a cow may be present multiple times in **PAR** 3. Furthermore, each **CInt** was assigned to 1 of 5 calving interval groups (**CIG**), where **CIG** 1 means $CInt \leq 13$ mo, **CIG** 2 means $13 \text{ mo} < CInt \leq 15$ mo, **CIG** 3 means $15 \text{ mo} < CInt \leq 17$ mo, **CIG** 4 means $17 \text{ mo} < CInt \leq 19$ mo, and **CIG** 5 means $19 \text{ mo} < CInt$. One month was assumed to equal 30.5 d. This created a total of 60 possible combinations of **PAR**, **CIG**, and herd.

Finally, the influence of previous **CIG** on current ECM yield (aim 3) was investigated, as it could be an issue if an extended **CInt** leads to a decrease in milk

yield during the following lactation. Here, the influences of previous **ECM_Feed** on current **ECM_Feed** as well as the influence of previous **ECM_45** on current **ECM_80** were included, as they may be related for each cow, and this would test the strength of their influence.

All data analyses were performed with the R program (R Development Core Team, 2015) and all mixed effects modeling was conducted with the lme4-package (lmer-function) for R (Bates et al., 2014). Least squares means and contrasts were calculated with the least squares means package (lsmeans) for R (Lenth and Hervé, 2015) using the Tukey method. A difference was considered significant if $P < 0.05$.

Aim 1: Estimating Daily ECM Yield

The ECM yield recordings for each lactation were fitted with a fourth-order Legendre polynomial based on equations given by Schaeffer (2004). First, each recorded time point, which in our study was measured as DIM, was standardized to vary between -1 and 1 . Each order of the Legendre polynomial then uses an equation to weight the standardized time point. Hence, a fourth-order Legendre polynomial calculates 4 values for each standardized time point. In addition, Legendre polynomials use 0.7071 as intercept value rather than the traditional 1 used in linear regression, and this is therefore the fifth value used for the regression of ECM yield recordings. For the present model, they were denoted LP0, LP1, LP2, LP3, and LP4, respectively, where LP0 was the intercept value.

This created 5 regression coefficients, and 3 of these were allowed to vary for each random intercept (i.e., random slope effects) to make the regression more flexible and able to reflect differences between different lactations. Parity was used as random intercept to fit 1 unique curve to each available lactation, and the sequence of parities was numbered distinctively for each herd to avoid cross-classification of parity across herds. Hence, the final linear mixed regression model used to estimate daily ECM yields was

$$\begin{aligned}
 Y_{ijkm} = & [\beta_0 + b_{0,j} + b_{0,k(j)} + b_{0,m(k)}] \times LP0 + \beta_1 \\
 & \times LP1_i + [\beta_2 + b_{2,j} + b_{2,k(j)} + b_{2,m(k)}] \times LP2_i + \beta_3 \\
 & \times LP3_i + [\beta_4 + b_{4,j} + b_{4,k(j)} + b_{4,m(k)}] \times LP4_i \\
 & + \text{Herd}_j + \text{Cow}_{k(j)} + \text{Parity}_{m(k)} + e_{ijkm}, \quad [1]
 \end{aligned}$$

where Y_{ijkm} is ECM yield at recording number i ($n = 23,394$) for herd j ($1-4$), cow k ($n = 1,316$) within herd j and parity m ($1-9$) within cow k ; LP0 is the fixed Legendre intercept; LP1_{*i*}, LP2_{*i*}, LP3_{*i*}, and LP4_{*i*} are the 4 Legendre order coefficients calculated based on the

DIM at recording number i ; $\beta_0, \beta_1, \beta_2, \beta_3,$ and β_4 are regression coefficients; $b_{0,j}, b_{2,j},$ and $b_{4,j}$ are random slope effects of herd j ; $b_{0,k(j)}, b_{2,k(j)},$ and $b_{4,k(j)}$ are random slope effects of cow k within herd j and $b_{0,m(k)}, b_{2,m(k)},$ and $b_{4,m(k)}$ are random slope effects of parity m within cow k ; Herd_j is the random intercept of herd j ; $\text{Cow}_{k(j)}$ is the random intercept of cow k within herd j ; $\text{Parity}_{m(k)}$ is the random intercept of parity m within cow k ; and e_{ijkm} is the residual error, which was normally distributed and independent. An attempt to improve the fit by including the remaining Legendre orders as random slope effects did not converge. Goodness of fit of the final model was evaluated with mean squared prediction error (**MSPE**), root MSPE (**RMSPE**) and RMSPE expressed as percentage of observed mean. The MSPE value can be divided in 3 components, where error due to disturbances (Bibby and Toutenburg, 1977) reflects the part of MSPE that cannot be explained by a least squares correction of residuals. The estimated daily ECM yields were then used to calculate ECM_Feed, ECM_Lac, ECM_80, ECM_45, and ECM_305 for each completed lactation.

Aim 2: CInt Length, Parity Group, and ECM Yield

The effect of PAR and CIG on ECM_Feed, ECM_Lac, ECM_80, ECM_45, ECM_305, and dry period length was analyzed with a linear mixed model for all completed lactations ($n = 1,379$, from 810 cows) with PAR within herd as random intercept. This allowed for testing the effect of CIG across the 4 very different farms (Table 1), and the final model was:

$$Y_{ijkm} = \beta_0 + \text{PAR}_i + \text{CIG}_j + \text{PAR}_i \times \text{CIG}_j + \text{herd}_k + \text{par}_{i(k)} + e_{ijkm}, \quad [2]$$

where Y_{ijkm} is the response variable from the completed lactation m ($n = 1,379$) belonging to PAR i (1–3) with CIG j (1–5) in herd k (1–4); β_0 is the common intercept; PAR_i is the effect of PAR i ; CIG_j is the effect of CIG j ; herd_k is the random intercept of herd k ; $\text{par}_{i(k)}$ is the random intercept of PAR i within herd k ; and e_{ijkm} is the residual error, which was normally distributed and independent.

Aim 3: Influence of Previous CIG on Current ECM Yield

The influence of previous CIG on current ECM yield was analyzed separately for cows completing both first and second parity ($n = 286$) and for cows completing both second and third parity ($n = 149$). Each of these 2 data sets were analyzed with 2 different models, where

model [3] analyzed the influence of previous CIG and previous ECM_Feed on current ECM_Feed and model [4] analyzed the influence of previous CIG and previous ECM_45 on current ECM_80. Hence, the second model analyzed the influence of the previous late lactation ECM yield on current early lactation ECM yield.

The final model analyzing the effect of previous ECM_Feed and previous CIG on current ECM_Feed was

$$Y_{ijk} = \beta_0 + \beta_1 \times \text{ECM_PRV}_i + \text{CIG_PRV}_j + \text{HERD}_k + \beta_2 \times \text{HERD}_k \times \text{ECM_PRV}_i + e_{ijk}, \quad [3]$$

where Y_{ijk} is the current average ECM yield per feeding day of cow i ($n = 286$) with a previous CIG j (1–5) from herd k (1–4); ECM_PRV_i is the previous average ECM_Feed of cow i ; CIG_PRV_j is the previous CIG j and HERD_k is the effect of herd k ; β_0 is the common intercept; β_1 and β_2 are regression coefficients; and e_{ijk} is the residual error, which was normally distributed and independent.

In addition, the second initial model analyzing the effect of previous late lactation milk yield and previous CIG on current early lactation milk yield was

$$Y_{ijk} = \beta_0 + \beta_1 \times 45_PRV_i + \text{CIG_PRV}_j + \text{HERD}_k + \beta_2 \times \text{HERD}_k \times 45_PRV_i + e_{ijk}, \quad [4]$$

where Y_{ijk} is the current average ECM yield per day during the first 80 d of cow i ($n = 149$) with a previous CIG j (1–5) from herd k (1–4); CIG_PRV_j is the effect of the previous CIG j ; HERD_k is the effect of herd k ; 45_PRV_i is the previous average ECM_45 of cow i ; β_0 is the common intercept; β_1 and β_2 are regression coefficients; and e_{ijk} is the residual error, which was normally distributed and independent. Herd was included as a fixed effect because of an inadequate amount of observations for a random effect.

RESULTS

Farms, Herds, and Management

The 4 farms (Table 1) had Holstein, Jersey, or crossbred cows with a herd size varying from 87 to 151 annual cows, and milk yield varied from 7,644 to 11,286 kg of ECM per annual cow across herds for cows calving between 2007 and 2011. From 2007 to 2011, herd 1 increased average milk yield per annual cow of 823 kg of ECM, herd 2 increased 583 kg of ECM, herd 3 decreased 33 kg of ECM, and herd 4 decreased 283 kg of ECM (data not shown). Annual cull rate varied

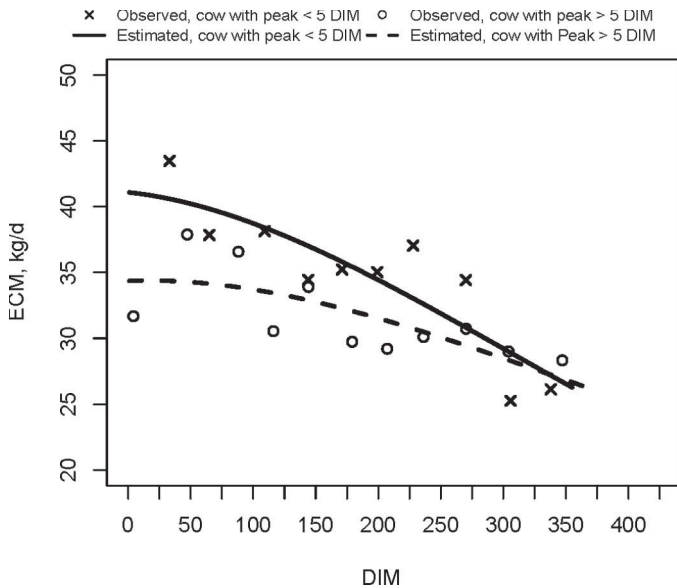


Figure 2. Recorded and estimated ECM yield of 2 randomly selected older cows from herd 1 with a calving interval (CInt) between 13 and 15 mo. Milk was recorded 11 times per year. Cow 1 (solid line) had a CInt of 404 d, whereas cow 2 (dashed line) had a CInt of 420 d. Curves were fitted with a linear mixed model based on a Legendre polynomial (model [1]).

from 25.3 (herd 4) to 35.2% (herd 3), and average CInt length varied from 414 (herd 1) to 521 d (herd 2).

In total, 1,379 completed lactations were available from the 4 herds, and CIG 2 and 3 accounted for 44% in herd 1, 56% in herd 2, 90% in herd 3, and 51% in herd 4. Parity group 1 accounted for 45% of completed lactations, whereas PAR 2 and PAR 3 accounted for 28 and 27%, respectively. Out of the 60 possible combinations of herd, PAR, and CIG, only CIG 1 in PAR 3 for herd 2 and CIG 1 in PAR 1 and 2 for herd 3 did not have any completed lactations.

Inseminations per achieved conception was above 2.5 for CIG 2, 3, 4, and 5 in herd 1, for CIG 5 in herd 2, and for CIG 5 in herd 3 (1 cow in PAR 2), and it was below 2.0 for the majority of CIG. Between CIG 1 and 2 in herd 1, inseminations per conception increased from 1.2 to 2.3, from 1.2 to 2.0, and from 1.3 to 2.2 for PAR 1, 2, and 3, respectively, and these increases were greater than in the 3 other herds. Also, for lactations in herd 1, CIG 3 and greater had at least 3.9 inseminations per conception.

Results of Data Analyses

Estimating Daily ECM Yield. The fourth-order Legendre polynomial model [1] fitted data well with a RMSPE of 2.84 kg of ECM, which corresponded to 10.1% of the observed mean and 98.8% of the MSPE,

came from random error. Residuals were normally distributed with a mean of 0 and a SD of 2.8, and a simple regression of residuals against fitted values gave a slope of 0.04 whereas a simple regression of residuals against DIM gave a slope and intercept of 0; residual variance was 10.5 kg².

Forty-three percent of the completed lactations peaked within the first 5 d after calving across PAR, CIG, and herds. This proportion was lower in all cases for PAR 1 across CIG and herds when compared with PAR 2 and 3. Herd 3 had the highest proportion of peaks occurring before 5 DIM. Lactations that peaked after 5 DIM peaked on average from 63 to 177 DIM across PAR, CIG, and herds, and peaks always occurred later in herd 4 than the other herds (data not shown). Peak milk yield was always earlier for PAR 2 and 3 compared with PAR 1 across CIG and herds.

Figures 2 and 3 show observed values and fitted curves for 2 selected older cows (PAR 3) from herds 1 (11 recordings per year) and 2 (6 recordings per year), respectively. They reflect the nature of on-farm milk recordings, where number of recordings per year and distance between recordings vary, and each figure therefore shows a fitted curve with a peak before and after 5 DIM, respectively.

The average cumulative lactation yield per completed lactation increased with increasing CInt for all combinations of herd and PAR, with the exception of

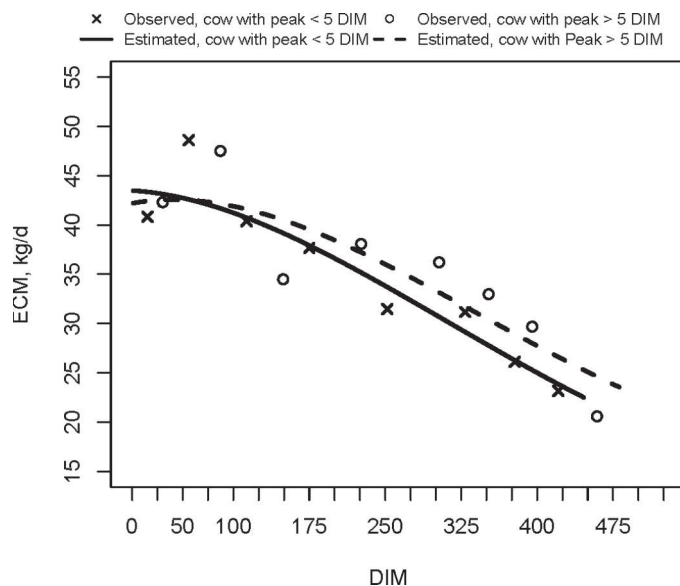


Figure 3. Recorded and estimated ECM yield of 2 randomly selected older cows from herd 2 with a calving interval (CInt) between 15 and 17 mo. Milk was recorded 6 times per year. Cow 1 (solid line) had a CInt of 490 d, whereas cow 2 (dashed line) had a CInt of 513 d. Curves were fitted with a linear mixed model based on a Legendre polynomial (model [1]).

CIG 5 for PAR 3 in herd 1 (Figure 4). Across PAR and CIG, the average lactation milk yield for each herd was 12,326 (SD = 2,700), 14,866 (3,624), 9,820 (1,526), and 10,131 kg of ECM (2,813) for herds 1 to 4, respectively.

CInt Length, Parity Group, and ECM Yield. Model [2] described the 5 milk yield variables well with a RMSPE of up to 16.2% of observed mean, whereas it was 24.6% for the model of dry period lengths (Table 2). These tests showed an interaction effect between PAR and CIG for ECM_Feed ($P = 0.04$), ECM_Lac ($P = 0.01$), and ECM_45 ($P < 0.001$), and they showed an effect of CIG on ECM_305 ($P < 0.01$), ECM_80 ($P < 0.001$), and dry period length ($P < 0.01$). Hence, CIG affected all tested variables. The residual SD of the 6 tests was between 0.5 to 0.7% greater in all cases than the corresponding RMSPE (in kg), and a minimum 99.9% of MSPE for all tests was due to random error (data not shown).

Least squares means showed that ECM_Feed was 1.6 to 2.4 kg greater for CIG 5 compared with CIG 1, 2, and 3 in PAR 1, whereas no difference was noted across CIG for PAR 2 and 3 (Table 3). The ECM_Lac was 2.1 kg less for CIG 5 compared with CIG 1 for PAR 3, whereas it was unchanged for all other combinations of CIG and PAR. The ECM_305 increased with increasing CIG for all PAR, where cows in CIG 5 produced 710 kg more when compared with CIG 1. Furthermore, the simple correlation between ECM_Feed and ECM_Lac was 0.98, and this correlation varied only 0.01 units when tested for each PAR and CIG.

Cows in CIG 5 produced 1.6 kg of ECM_80 more irrespective of PAR when compared with CIG 1, whereas no significant difference was observed in ECM_80 for CIG 1 to 4. No difference in ECM_45 was noted across CIG for PAR 1, whereas it was up to 4.0 and 5.5 kg less for CIG 4 and 5 in PAR 2 and 3, respectively, when

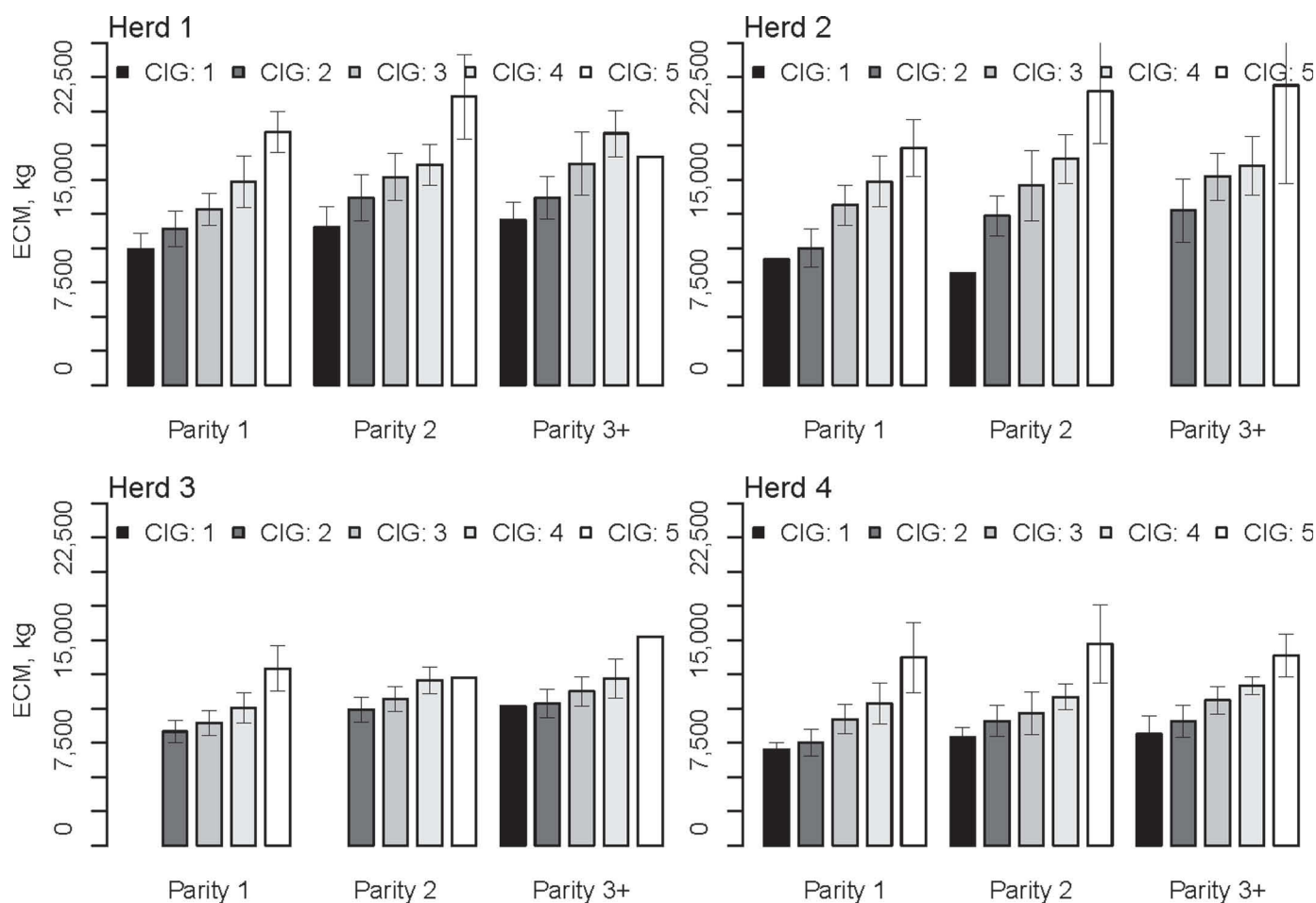


Figure 4. Average cumulative lactation ECM yield (kg) based on fitted values from model [1] (linear mixed model based on a Legendre polynomial) for a completed lactation in each calving interval group (CIG) within parity group within herd. Error bars indicate standard deviation. CIG = 1: calving interval (CInt) ≤ 13 mo; CIG = 2: $13 \text{ mo} < \text{CInt} \leq 15$ mo; CIG = 3: $15 \text{ mo} < \text{CInt} \leq 17$ mo; CIG = 4: $17 \text{ mo} < \text{CInt} \leq 19$ mo; CIG = 5: $19 \text{ mo} < \text{CInt}$.

compared with CIG 1. Finally, the dry period length was 2.9 d greater for lactations in CIG 2 compared with CIG 1, but no difference was seen from CIG 2 to 5.

The difference in daily milk yield between ECM₈₀ and ECM₄₅ consistently increased from CIG 1 to CIG 5 for all 3 parity groups (Table 3), with the largest reduction of 17.3 kg occurring in PAR 3. Dividing these reductions with the number of days between ECM₈₀ and ECM₄₅ gives an indication of milk yield persistency throughout lactation. There was not a consistent trend across CIG, as the slope varied from -0.015 to -0.014 (PAR 1), -0.038 to -0.033 (PAR 2), and -0.039 to -0.035 kg of ECM/d (PAR 3) across CIG. Generally, the largest reductions in PAR 2 and 3 were calculated for CIG 1 and 2.

Influence of Previous CInt Length on Current ECM Yield. A total of 286 cows completed both first and second parity, and 149 cows completed both second and third parity. Furthermore, 69% of the cows completing first parity with CIG 1 to 3 also completed the second parity with CIG 1 to 3, and the same goes for 73% of the cows completing both second and third parity.

Increasing first-parity CIG increased second-parity ECM_{Feed} ($P < 0.01$) and ECM₈₀ ($P < 0.001$), but second-parity CIG did not influence third-parity ECM_{Feed} or ECM₈₀ (Table 4). Therefore, second-parity ECM_{Feed} was 1.3 kg greater, and ECM₈₀ was 4 kg greater when first-parity CIG 4 was compared with 1 (Table 5).

Increasing ECM_{Feed} and ECM₄₅ in previous lactations increased current ECM_{Feed} and ECM₈₀ in all cases. Herd interacted with first-parity lactation milk yield ($P < 0.001$), which meant that the effect of ECM₄₅ on second-parity ECM₈₀ only was different from 0 for herd 1 at $P < 0.05$. Similarly, herd interacted with second-parity ECM_{Feed} ($P = 0.03$), and therefore the effect of this variable on third-parity

ECM_{Feed} was only different from 0 at $P < 0.05$ for herds 1 and 2.

DISCUSSION

Farms, Herds, and Management

The 4 farmers involved in our study were interviewed by van Vliet (2012), and in their study the owner of herd 1 stated that length of the lactation is decided for the individual cow whereas the owners of herds 2 and 3 manage all cows for extended lactation with a few exceptions in herd 2. The owner of herd 4 stated that younger cows are managed for longer lactations than older cows. They all stated that only few cows are dried off earlier because of low milk yields. Furthermore, the 4 farmers agreed that one of their main objectives with managing for extended lactations was to reduce the number of heifers. They noted that it was not economically viable to sell surplus heifers, and that fewer heifers would reduce herd feed use (van Vliet, 2012).

According to Danish 2014 milk recording statistics, the average conventional Holstein herd ($n = 2,695$) had 164 cows with an average production of 9,333 kg of ECM/yr, whereas the average organic Holstein herd ($n = 388$) had 145 cows with an average production of 8,331 kg of ECM/yr (Danish Cattle, 2014b). The average organic Jersey herd ($n = 37$) had 172 cows with a production of 7,838 kg of ECM/yr. Herd sizes and production levels in this study are, therefore, comparable to Danish averages. The 4 herds had an annual cull rate (Table 1) between 25.3 and 35.2%, which is less than the average cull rate of 42.9 and 39.6% for Holstein and Jersey in Denmark, respectively (Lauritsen and Flagsted, 2014). Therefore, these herds have had to maintain their herds with either very few or no imported heifers as fewer replacement heifers are available when cows are managed for longer lactations.

Table 2. *P*-values and root mean squared prediction error (RMSPE) measured in kilograms and percent of observed mean for tests carried out with model [2] – a linear mixed model with herd and parity group (PAR) within herd as random effects

Response ¹	<i>P</i> -value			RMSPE	
	PAR	CIG ²	PAR × CIG	kg	%
ECM _{Feed} , kg/d	<0.001	0.03	0.04	2.70	10.8
ECM _{Lac} , kg/d	<0.001	0.69	0.01	2.84	10.1
ECM ₃₀₅ , kg	<0.001	<0.001	0.43	919.65	10.3
ECM ₈₀ , kg/d	<0.001	<0.01	0.27	3.93	12.5
ECM ₄₅ , kg/d	0.28	<0.001	<0.001	3.69	16.2
Dry period, d	0.17	<0.01	0.71	12.2	24.6

¹ECM_{Feed} = ECM per feeding day; ECM_{Lac} = ECM per lactating day; ECM₃₀₅ = cumulative ECM during the first 305 d; ECM₈₀ = average daily ECM during first 80 d; ECM₄₅ = average ECM during last 45 d before dry off.

²CIG = calving interval group.

Table 3. Effect of calving interval group (CIG) and parity group (PAR; first, second, or third and greater) on 5 measurements of ECM yield and dry period length¹

Responses ²	CIG ³									
	1		2		3		4		5	
	LSM	SE	LSM	SE	LSM	SE	LSM	SE	LSM	SE
Parity group 1										
ECM_Feed, kg/d	22.0 ^b	2.6	22.5 ^b	2.6	22.8 ^b	2.6	23.2 ^{ab}	2.6	24.4 ^a	2.6
ECM_Lac, kg/d	25.2 ^a	3.1	25.3 ^a	3.1	25.4 ^a	3.1	25.6 ^a	3.1	26.3 ^a	3.1
ECM_305 ⁴ , kg	7,834 ^d	1,013	7,949 ^{cd}	1,011	8,109 ^{bc}	1,011	8,310 ^{ab}	1,013	8,544 ^a	1,013
ECM_80, kg/d	26.3 ^b	3.6	26.5 ^b	3.6	26.6 ^b	3.6	27.1 ^{ab}	3.6	28.0 ^a	3.6
ECM_45, kg/d	22.5 ^a	2.3	21.9 ^a	2.3	21.3 ^a	2.3	21.2 ^a	2.3	22.0 ^a	2.3
Dry period, d	45.8 ^b	3.1	48.7 ^a	3.0	49.6 ^a	3.0	51.4 ^a	3.2	48.4 ^a	3.2
Clnt length, ⁵ d	371	19	429	18	481	17	544	17	657	80
Parity group 2										
ECM_Feed, kg/d	25.7 ^a	2.6	26.3 ^a	2.6	26.0 ^a	2.6	26.0 ^a	2.6	27.0 ^a	2.7
ECM_Lac, kg/d	29.4 ^a	3.1	29.6 ^a	3.1	29.1 ^a	3.1	28.8 ^a	3.1	29.4 ^a	3.1
ECM_305 ⁴ , kg	9,336 ^d	1,013	9,451 ^{cd}	1,011	9,611 ^{bc}	1,012	9,812 ^{ab}	1,014	10,046 ^a	1,014
ECM_80, kg/d	34.1 ^b	3.6	34.2 ^b	3.6	34.3 ^b	3.6	34.8 ^{ab}	3.6	35.7 ^a	3.6
ECM_45, kg/d	24.3 ^a	2.3	22.8 ^{ab}	2.3	22.2 ^{bc}	2.3	20.3 ^c	2.4	21.6 ^{bc}	2.4
Dry period, d	45.8 ^b	3.1	48.7 ^a	3.0	49.6 ^a	3.0	51.4 ^a	3.2	48.4 ^a	3.2
Clnt length, ⁵ d	368	18	431	17	481	17	542	19	674	79
Parity group 3										
ECM_Feed, kg/d	27.1 ^a	2.6	26.9 ^a	2.6	27.4 ^a	2.6	27.0 ^a	2.7	26.8 ^a	2.7
ECM_Lac, kg/d	31.4 ^a	3.1	30.5 ^{ab}	3.1	30.8 ^{ab}	3.1	30.1 ^{ab}	3.1	29.3 ^b	3.1
ECM_305 ⁴ , kg	9,756 ^d	1,013	9,870 ^{cd}	1,011	10,030 ^{bc}	1,012	10,232 ^{ab}	1,014	10,465 ^a	1,014
ECM_80, kg/d	35.6 ^b	3.6	35.8 ^b	3.6	35.9 ^b	3.6	36.3 ^{ab}	3.6	37.2 ^a	3.6
ECM_45, kg/d	25.4 ^a	2.3	23.3 ^b	2.3	22.9 ^{bc}	2.3	20.6 ^{cd}	2.4	19.9 ^d	2.4
Dry period, d	45.8 ^b	3.1	48.7 ^a	3.0	49.6 ^a	3.0	51.4 ^a	3.2	48.4 ^a	3.2
Clnt length, ⁵ d	368	18	432	17	481	17	539	17	665	89

^{a-d}Different superscripts within row are significantly different at $P < 0.05$.

¹Estimates are based on model [2], a linear mixed model of PAR and CIG with herd and PAR within herd as random effects.

²ECM_Feed = ECM per feeding day; ECM_Lac = ECM per lactating day; ECM_305 = cumulative ECM during first 305 d; ECM_80 = average daily ECM during first 80 d; ECM_45 = average ECM during last 45 d before dry off.

³CIG = 1: calving interval (Clnt) ≤ 13 mo; CIG = 2: 13 mo < Clnt ≤ 15 mo; CIG = 3: 15 mo < Clnt ≤ 17 mo; CIG = 4: 17 mo < Clnt ≤ 19 mo; CIG = 5: 19 mo < Clnt.

⁴Cows lactating less than 305 d were removed.

⁵Raw mean and standard deviation of Clnt lengths within each combination of CIG and parity group.

Table 4. Carry-over effect between 2 consecutive lactations

Model ¹			P-value ¹			Fit ¹			Variable ²	
Current parity	Previous parity	Herd	Variable	CIG ³	Variable × herd	Adj-R ²	Res SE	Estimate	SE	
First to second parity										
ECM_Feed ⁴	ECM_Feed	<0.001	<0.001	<0.01	0.37	0.82	2.50	0.49 ⁶	0.06	
ECM_80 ⁵	ECM_45	<0.001	<0.001	<0.001	<0.001	0.77	3.96	0.64 ⁷	0.10	
Second to third parity										
ECM_Feed ⁴	ECM_Feed	<0.001	<0.001	0.22	0.03	0.78	2.85	0.60/0.78 ⁸	0.12/0.14	
ECM_80 ⁵	ECM_45	<0.001	0.04	0.50	0.93	0.71	4.63	0.21 ⁶	0.10	

¹P-values and goodness of fit of tests carried out with models [3] and [4], which modeled the effect of previous ECM_Feed and ECM_45 on the current ECM_Feed and ECM_80, respectively. Adj-R² = adjusted R²; Res SE = residual standard error.

²Estimates (least squares) and SE.

³CIG: Calving interval group.

⁴ECM_Feed = ECM per feeding day.

⁵ECM_80 = ECM per day during the first 80 d after calving; ECM_45 = ECM per day during the last 45 d before drying off.

⁶Estimate across all 4 herds.

⁷Estimate for herd 1 as interaction effect caused the estimate to not be different from 0 at $P < 0.05$ for the other herds.

⁸Estimates for herds 1 and 2 as interaction effect caused the estimate to not be different from 0 at $P < 0.05$ for the other herds.

The 4 herds had an average CInt (Table 1), from 19 to 126 d longer than the Danish average of 395 d (Danish Cattle, 2014a), where the SD of the average CInt length was 2 (herd 1), 3 (herd 2), and 4 times (herd 4) greater than the Danish average (Ancker, 2008) and herd 3 had a similar SD. Farmers stated to van Vliet (2012) that they manage their herds for extended lactations, and that this, to some extent, varies from cow to cow. The greater variation in CInt lengths and the increase in CInt length with increasing DIM at first insemination (Figure 1) supports that the farmers were managing their cows for extended lactation. Figure 1 also shows that, particularly for CIG 5, a few cows have difficulties conceiving, but the causes of these of these difficulties are unknown.

One of the arguments for using extended lactation is improved conception rates, as the cow may have passed the most severe part of the negative energy balance at the time of insemination (Knight, 2008). Our results do not support this argument as conception rate was unaffected by CInt and mostly at levels similar to Danish averages (Ancker, 2008). Both Kolver et al. (2007) and Bertilsson et al. (1997) reported higher conception rates with increasing CInt. Christiansen et al. (2005) reported 1.7 inseminations per conception for cows on a 12-mo CInt and 1.5 inseminations for cows on an 18-mo CInt.

Discussion of Data Analyses

Estimating Daily ECM Yield. An RMSPE value of 10.1% of observed mean shows that the Legendre polynomial model [1] was able to produce a reasonable overall fit to data, where 99% of the variation in MSPE came from random error. Also, both the intercept and a slope of the linear regression of residuals against their observed DIM was 0, which shows that model [1] was flexible enough to fit observations across the variation in observed milk yield and over time despite the variation in milk yield levels, parities, lactation lengths, and distance between milk recordings.

However, estimated peak milk yield before 5 DIM occurred in 43% of all lactations, and it may be caused by data frequency. Herd 3 had the highest proportion of early peaks (66%), with 11 milk recordings per year, whereas the proportion ranged from 31 to 35% for the 3 other herds. Others have shown that it is not uncommon for estimated lactations to have a curvature that deviates from the typical shape with its ascending peak and descending phases (Macciotta et al., 2005). In fact, Macciotta et al. (2005) showed that 17 and 36% of lactations continuously decreased from calving until drying off when using the equations of Wood (1967) and Wilmlink (1987), respectively.

They also showed that the proportion of atypical shapes was greater when the first milk recording after calving took place between 30 and 60 DIM compared with before 30 DIM, and that the proportion of atypical shapes was greatest when calving took place during July and August. In contrast to the study by Macciotta et al. (2005), we included lactations longer than 340 d from multiple breeds and testing schemes, which also may affect the proportion of atypical shapes.

CInt Length, Parity Group, and ECM Yield.

The cows were found to produce the same amount of ECM_Feed irrespective of CInt and parity across the 4 commercial herds. Numerically, first-parity cows produced more ECM_Feed with an extended CInt, which was also seen in another Danish experiment with 60 cows (Christiansen et al., 2005), although the results were not significant. Arbel et al. (2001) found the same trend for first-parity cows, where a 60-d delay in time of first insemination resulted in 0.8 kg more ECM_Feed; older cows produced, numerically, 0.2 kg more ECM_Feed.

In agreement with this, Österman and Bertilsson (2003) found a numeric reduction of 0.3 kg ECM_Feed when they compared 12-mo with 18-mo CInt. For first-parity cows, they reported a numeric increase of 1.3 kg of ECM_Feed and a numeric decrease of 1.0 kg of ECM_Feed for older cows. Although cows with a CInt of 18 mo also had a significantly longer dry period (10.9 vs. 15.6 wk), we found an increase of only 3 to 5 d. However, we fixed the dry period at 49 d for 38% of the lactations, but excluding these from the analysis did not change the result.

Christiansen et al. (2005) reported a numerically lower milk yield (26.0 vs. 27.1 kg of ECM) during early lactation (1 to 6 wk after calving) for first-parity cows on an extended lactation. Cows with longer lactations produced 1.4 kg of ECM less per day during the latter part of the lactation (2 to 6 mo after conception), but produced the same amount of milk per feeding day, which may be caused by a dilution of the effect of the dry period on milk yield per feeding day.

Furthermore, Christiansen et al. (2005) found that older cows (second parity and older) produced the same amount of ECM_Feed during the early part of the lactation and produced 4.2 kg of ECM less per day during the latter part (2 to 6 mo after conception). The same trend was observed in our study, where cows produced the equivalent ECM_Feed and yield was lower toward the end of the lactation for extended lactations. This may be beneficial, as cows will then not have to be dried off with as high milk yield.

Influence of Previous CInt Length on Current ECM Yield. Increasing first-parity CIG increased second-parity ECM_Feed and ECM_80. This may be an effect of the cow being closer to fully grown at the start of this lactation, and hence it may not need as much energy for growth. Österman and Bertilsson (2003) found a significantly shorter dry period length during the second 18-mo CInt compared with the first 18-mo CInt, although it was still significantly higher than the second 12-mo CInt. Those authors did not provide a test of the difference, but the second 18-mo CInt produced 0.5 kg more ECM_Feed than the second 12-mo CInt, whereas the difference was -0.3 kg ECM_Feed during the first cycle.

General Discussion

The potential for extended lactation as part of a management concept appears to be applicable for all cows, although the increase in milk yield level from first to second parity may make it economically beneficial to have a short first parity, despite the fact first-parity cows generally have more persistent milk yields than second-parity cows. However, large variation existed among individual cows in milk yield performance during lactation (data not shown), which was also noted by Bertilsson et al. (1997) and Kolver et al. (2007). This indicates a potential for optimization through targeting the planned CInt length to the individual cow. Relating the characteristics of cows to their ability to complete an extended lactation and their production

Table 5. Effect of first-parity calving interval group (CIG) on ECM per feeding day (ECM_Feed) and ECM per day during the first 80 d after calving (ECM_80)¹

	First-parity CIG									
	1		2		3		4		5	
	LSM	SE	LSM	SE	LSM	SE	LSM	SE	LSM	SE
Yield in second parity										
ECM_Feed, kg/d	25.4 ^b	0.4	26.0 ^b	0.3	26.3 ^{ab}	0.3	26.7 ^{ab}	0.5	27.6 ^a	0.5
ECM_80, kg/d	31.5 ^c	0.7	33.5 ^{ab}	0.5	33.2 ^{bc}	0.6	35.5 ^{ab}	0.8	35.9 ^a	0.8

^{a-c}Different superscripts within row are significantly different at $P < 0.05$.

¹Values were calculated based on models [3] and [4]. Model [3] = effect of previous ECM_Feed and CIG on current ECM_Feed; model [4] = effect of previous CIG and average daily ECM during the last 45 d before dry off on current ECM_80.

performance may be an appropriate approach. Another approach may be to investigate if certain genetics are more suitable for extended lactation, where a trait such as milk yield persistency could be of interest.

We found that early-lactation milk yield was greater for cows with a longer CInt compared with cows with a shorter CInt. This measure of milk yield could be used in the future to predict whether or not an individual cow is suitable for extended lactation, as the information would be available around time of first insemination for a lactation of traditional length.

An argument for extended lactation is that it may reduce GHG emission per kilogram of milk produced (Knight, 2008; Eckard et al., 2010; Lehmann et al., 2014). The reduction in the number of calvings per year caused by extended lactation reduces the number of young stock being reared, but it is still possible to maintain the same replacement rate per lactation. It also reduces the proportion of dry cows at any given time if the same dry period length is maintained. Our study showed that cows with extended CInt produced at least the same amount of ECM per feeding day as cows with a traditional CInt length. Therefore, it seems possible to maintain herd output of milk while reducing herd input of feed as a result of fewer animals needing to be fed.

Herd feed use is major contributor for GHG emission at farm gate (Kristensen et al., 2011), but the reduction in GHG emission per kilogram of milk produced caused by the reduced feed use may or may not be counteracted, at a global scale, by a smaller herd output of meat as the number of bull calves and culled cows for sale will be reduced. Assuming that the market needs a constant supply of beef meat, the GHG emission from the production of the alternative beef meat may also need to be taken into account. Thus, several aspects must be taken into account when evaluating the effect of implementing extended lactation on GHG emission and farm profitability. Extended lactation has been shown to both increase (Wall et al., 2012) and reduce GHG emission (Browne et al., 2015).

CONCLUSIONS

Commercial milk yield recordings from 4 herds managed for extended lactations were fitted well with a fourth-order Legendre polynomials. In these herds, it was possible for the cows to maintain an equivalent milk production per feeding day, and first- and second-parity cows maintained equivalent milk production per lactating day within each parity for a CInt of up to 19 mo. However, an increased CInt increased dry period length 3 to 5 d. Late-lactation milk yield decreased for second-parity and older cows with increasing calving

interval. Increasing first-parity CInt increased second-parity milk yield per feeding day and early-lactation milk yield.

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