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Impact of calving interval on milk yield and longevity of primiparous Estonian Holstein cows

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Abstract: Data about 4 474 high-yielding Estonian Holstein dairy cows from 14 herds was analysed for the impact of the first calving interval length (CI_1) on milk yield (MY) and lactation persistency. The results show that cows with CI_1 shorter than 12 months have on average 2 345 kg lower milk yield in the first 1 000 days of productive lifetime than those with CI_1 between 14 and 16 months. This is caused by lower MY in both the first and the second lactation as well as higher probability of being culled before reaching 1 000 days of productive life.

Keywords: dairy; lactation; persistency

High milk yields and shorter productive lives in the herds have questioned short calving intervals as a management objective at dairy farms, especially in the case of primiparous cows. Estonian Holstein dairy herds have some of the highest milk yields in Europe, average milk yield during 305-day lactation was 9 971 kg in 2018, rising by 11% in five years (from 8 978 kg in 2014). On the other hand, productive life (interval from the date of first calving until death or culling from the herd) of the cows has been steadily decreasing, from 1 082 days in 2014 to 1 018 days in 2018 (5.6%), which significantly reduces the economic effect from higher milk yields (Eesti Pol-lumajandusloomade Joudluskontrolli 2015; 2019).

It has been a general practice among dairy farmers that calving intervals should be as short as possible to produce more offspring and achieve higher milk yield per cow per day in milk (Sorensen and Ostergaard 2003). On the other hand, shorter calving intervals also mean that cows spend dry a longer share of their productive life and more calvings also mean more risk for postpartum diseases and disorders. Research is so far inconclusive what strategy results in higher milk output – while most studies agree that longer lactation results in higher total lactation MY for primiparous cows, the results diverge whether it also leads to higher MY per day of CI (MY_{CI}, including lactation and dry period). Some studies (Arbel et al. 2001; Mellado et al. 2016) indicated that for primiparous cows in herds with high milk yield (over 10 000 kg for 305-day lactation), longer calving intervals were associated with higher, not lower MY_{CI}. The others (Stangaferro et al. 2018) have not observed any difference in MY_{CI}.

The purpose of the study was to empirically analyse the relationship between CI and MY in Estonian high-yielding herds. Given the limited resources available for dairy farmers – is minimizing CI_1 a justified management objective in the context of ever higher milk yield per day in milk and shorter productive life, as several studies (Rehn et al. 2000; Arbel et al. 2001) suggest otherwise.

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MATERIAL AND METHODS

Data

The data was collected for Holstein heifers first calved between January 1, 2014 and December 31, 2016 from the database of Estonian Livestock Performance Recording Ltd for 14 Estonian dairy farms. Farms were selected based on the following criteria:

- Data was accessible.
- Data was complete for the required scope and time frame.
- Technological stability (no major changes like transfer to new premises occurred during or immediately before the evaluated time frame).
- No heifers were imported from other herds.
- Health status of the herds was stable, with the culling rate of primiparous cows below 20% annually as the qualifying threshold.
- Cows were milked either 3 times per day in a milking parlour or by a robotic milking system (milking frequency not determined, but expected to be close to 3 times a day on average as well).

The following data blocks were available for the cows:

- Milk tests between January 1, 2014 and December 31, 2018 [milk quantity, fat and protein content, somatic cell count (SCC), urea content].
- Artificial inseminations completed after first calving (no bull matings occurred).
- First calvings (birth date, artificial inseminations and/or mating start and end dates, first calving date).
- Culling date of cows (if culled by December 31, 2018).

Animals with incomplete records on milk tests, inseminations or culling were removed from the dataset. Also, animals with missing records on any number of milk tests due to illness were removed from the dataset.

Only animals of Holstein (Estonian Holstein, EHF) breed were selected from herds where several breeds were present.

The dataset did not include information about precise dry-off dates; therefore, we could not establish an explicit relationship between CI and dry period length. Milk yield was calculated for the whole CI (days) or actual lactation length for cows culled during lactation. In order to take into account differences in fat and protein content, MY was converted to energy corrected milk (ECM) according to the formula proposed by Sjaunja et al. (1990):

$$kgECM = kgYield \times [(38.3 \times F + 24.2 \times P + 783.2)/3\,140] \quad (1)$$

where:

kgECM – 1 kg energy corrected milk;
kgYield – 1 kg natural milk;
F – fat content (g/kg);
P – protein content (g/kg).

Overview of the herd characteristics can be found in Table 1 and Table 2.

Methodology

Lactation milk yield was calculated by the Test Interval Method based on ICAR (International Committee for Animal Recording) guidelines (ICAR 2017):

$$MY_L = I_0M_1 + I_1 \times (M_1 + M_2)/2 + I_2 \times (M_2 + M_3)/2 + I_{n-1} \times (M_{n-1} + M_n)/2 + I_nM_n \quad (2)$$

where:

MY_L – cumulative milk yield in lactation;
M_n – milk weights in kg yielded in 24 h of the recording day;
I_1, I_2, I_{n-1} – intervals, in days, between recording days;
I_0 – interval, in days, between the start of lactation period and the first lactation date;
I_n – interval, in days, between the last recording day and the end of the lactation period.

In this study due to missing information about dry-off dates I_n was set equal to 15 for the cows that reached the next calving (considering that the interval between recording dates is approximately 30 days, therefore dry-off should occur anytime between 1 to 30 days after the last recording date in the lactation – on average after 15 days). For cows culled before the next calving, I_n is the actual interval between the last recording date and the culling date.

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Table 1. Cows that successfully reached the second calving

Farm	No. of cows	Mean MY (ECM) kg/day	Average SCC	Days to first service	Days open	Service interval	Calving interval length (CI), days	Mean AFC	SD AFC
1	447	24.5	262.0	98.0	141.0	50.8	421.0	800	56
2	139	21.9	230.0	92.0	135.0	58.8	414.0	861	134
3	166	27.9	112.0	81.0	110.0	29.0	388.0	726	29
4	252	26.2	176.0	81.0	150.0	40.4	426.0	741	76
5	287	23.6	171.0	65.0	127.0	41.0	401.0	754	67
6	900	26.9	132.0	77.0	108.0	31.0	387.0	786	52
7	349	24.0	122.0	86.0	126.0	35.1	404.0	771	55
8	459	26.2	140.0	67.0	109.0	37.5	389.0	747	59
9	158	25.2	218.0	100.0	151.0	47.8	430.0	778	77
10	315	27.2	162.0	77.0	131.0	36.9	409.0	765	53
11	243	24.1	149.0	72.0	104.0	28.4	384.0	772	67
12	112	24.5	146.0	109.0	142.0	65.5	423.0	786	55
13	324	23.0	99.0	78.0	124.0	36.7	403.0	828	62
14	323	24.2	122.0	64.0	101.0	36.0	380.0	709	54
Total	4 474	25.0	160.1	81.9	125.6	41.1	404.2	773	70

AFC = age at first calving; CI = length of the first calving interval; MY = energy corrected milk (ECM) yield per day of calving interval; SCC = somatic cell count; SD = standard deviation

Table 2. Cows culled before the second calving

Farm	Cows culled before second calving	Percentage of culled cows	Mean DIM at culling	SD	Mean SCC	Mean AFC	SD AFC
1	159	26.1	289	235	793	811	53
2	46	24.7	290	202	417	879	151
3	65	28.1	333	236	168	721	31
4	65	20.4	329	192	256	786	104
5	63	18.0	325	195	267	770	75
6	303	25.2	224	172	388	790	55
7	87	20.0	312	180	237	783	67
8	141	23.5	346	260	274	754	72
9	54	25.5	347	195	508	799	68
10	69	17.9	420	272	221	775	54
11	74	23.3	265	189	370	778	73
12	40	26.3	243	189	441	793	72
13	86	21.0	255	210	543	831	63
14	93	22.4	255	176	312	725	76
Total	1 345	32.3	289	214	394	784	77

AFC = age at first calving in days; DIM = days in milk; SCC = somatic cell count; SD = standard deviation

Milk yield per day of CI (MY_{CI}) was calculated as total milk yield in the lactation divided by CI in days to make cows with different CIs comparable. Cows were grouped into four groups by CI:

- G1: up to 360 days (12 months).
- G2: 360–420 days (12–14 months).
- G3: 420–480 days (14–16 months).
- G4: over 480 days (16 months).

Exact lifetime milk yield (MY_{LIFE}) could not be calculated for all the animals, as part of them still were in the herds as of December 31, 2018.

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Therefore, milk yielded in 1 000 days of productive life (from the date of the first calving of the cow) was established as a proxy for the actual lifetime milk yield. This corresponds to the mean productive life of Estonian Holstein dairy cow that was 1 018 days in 2018 (Eesti Pollumajandusloomade Joudluskontrolli 2019). Differences in MY_{LIFE} were tested by analysis of variance (ANOVA) and pairwise by Tukey's HSD test. As a result, all pairwise differences in means were statistically significant, except for the difference between the longest CI groups (420–480 days and 480+ days, $P = 0.26$). The impact of the age at first calving (AFC) on MY_{CI} and MY_{LIFE} was tested by simple linear regression. The results showed no impact ($R^2 < 1$, $P < 0.01$).

Many different methods have been used to calculate the persistency of lactation MY. As the focus of this study was on primiparous cows whose lactation curve is considerably flatter than that of multiparous cows and the timing of peak milk yield (MY_{peak}) varied in a wide range, the methodology used by Weller et al. (2006) and Togashi and Lin (2004) was adjusted to the characteristics of the given dataset. MY_{peak} was defined as the mean MY of milk tests 1 to 5, as 72% of the animals in the sample had their MY_{peak} in this range. Only animals with uninterrupted data from at least 9 first milk tests in lactation available were included in the lactation persistency analysis (175 animals of the set of 4 474 animals were therefore excluded from milk persistency analysis). Lactation persistency was defined as follows:

$$PERS = (ECM_9 - ECM_{peak})/(DIM_9 - DIM_{peak}) \times 185 \times 100\% \quad (3)$$

where:

PERS – persistency of lactation curve (change in ECM/day from peak to 9th milk test in lactation);

ECM_9 – milk yield at 9th milk test in lactation;

ECM_{peak} – mean ECM yield at milk test 1 to 5 in lactation;

DIM_9 – DIM at 9th milk test;

DIM_{peak} – mean DIM at milk tests 1–5.

As the mean interval between DIM_9 and DIM_{peak} was 185 days, all lactation persistency measurements were adjusted to 185 days as well. R software, v3.6.1 was used for calculations and reports (R Core Team 2019), using the packages tidyverse (Wickham 2019), data.table (Dowle and Srinivasan 2019), kableExtra (Zhu 2019), knitr (Xie 2020) and R Markdown (Allaire et al. 2020).

RESULTS

Both MY_{LIFE} and MY per day of productive life were higher for the cows with the longer first calving interval. Absolute lifetime MY was 2 345 kg ECM or 11% higher in the longest CI group (Group 4) compared with the shortest CI group (Group 1) (Table 3).

Mean MY_{LIFE} was the highest for Group 4, but the pairwise difference between this group and Group 3 was not significant ($P > 0.05$). Therefore, it can be stated that cows with CI_1 longer than 14 months had higher MY_{LIFE} than those with shorter CIs.

This can be explained by a positive relationship between the length of CI and MY in both the first and the second lactation. There was a statistically significant ($P > 0.05$) difference between the shortest CI_1 group (up to 12 months) and all the longer groups (Table 4).

There were no significant differences in MY between the CI_1 groups in their third and fourth lactation.

Key factors that determine lactation MY are MY_{PEAK} and lactation persistency – the maximum

Table 3. Length of the first calving interval and lifetime milk yield

CI_1 group	Mean productive life (days)	SD	Mean MY_{LIFE} (ECM) kg total	SD	Mean MY_{LIFE} (ECM) kg/day	SD	No. of cows
1	860	172	21 302	5 067	25.2	5.5	1 523
2	865	169	22 293	5 137	26.1	5.1	1 701
3	875	154	23 098	5 419	26.1	5.4	740
4	909	126	23 647	5 794	26.2	6.0	510

CI_1 = length of the first calving interval; ECM = energy corrected milk; MY_{LIFE} = lifetime or 1 000-day total milk yield; SD = standard deviation

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Table 4. Relationship between the first calving interval length, age at first calving and milk yield at the first and second lactation

CI_1 group	First lactation					Second lactation				
	Mean MY (ECM) kg/day	SD	Mean AFC	SD	No. of cows	Mean MY (ECM) kg/day	SD	Mean AFC	SD	No. of cows
1	24.8	4.0	763	67	1 523	28.4	4.6	760	63	1 105
2	25.4	3.9	774	67	1 701	29.2	4.6	772	66	1 128
3	25.5	4.0	778	72	740	29.3	4.4	781	74	430
4	25.8	3.9	790	82	510	30.2	4.0	795	92	245

AFC = age at first calving; CI_1 = length of the first calving interval; ECM = energy corrected milk; MY = milk yield per day of calving interval; SD = standard deviation

Table 5. Distribution of peak milk timing by the milk test number

Peak milk test No.	No. of cows	Mean DIM	Mean MY (ECM) kg/day	SD
1	676	23	36.0	5.8
2	772	52	35.7	5.6
3	675	83	35.5	5.6
4	557	112	36.1	5.6
5	414	145	36.6	5.4
6	374	174	36.0	5.6
7	268	206	36.8	5.2
8	231	236	35.7	5.3
9	141	273	37.0	4.9
10 and later	191	328	38.0	5.1

DIM = days in milk; ECM = energy corrected milk; MY = milk yield at milk test; SD = standard deviation

point of the lactation curve and the slope of decline from the peak towards the lactation end. Mean MY_{PEAK} in the sample was recorded at the 4^{th} milk test, at 118 days after calving (DIM), however distribution of MY_{PEAK} timing was quite dispersed (Table 5).

Lactation persistency and MY_{PEAK} were hypothesised to be associated with conception timing. 21.5% of the analysed lactation curves can be considered atypical, where ECM yield at the 9^{th} milk test in lactation was higher than the mean of milk tests 1 to 5.

It is often assumed that lactation MY tends to start declining after a cow conceived again. As CI is determined by open period (between calving and next conception) and pregnancy, the CI can be used as a proxy to measure the impact of open period length as well: CI group boundaries minus 270 days results in open period length group boundaries (differences in the length of pregnancy period were found to be insignificant).

Both lactation persistency and MY_{PEAK} were positively correlated with open period; cows with the shortest open period (CI_1 Group 1) had MY_{PEAK} 2.4 kg ECM or 6.4% lower than those with the longest open period (35.2 kg and 37.6 kg ECM, respectively) (Table 6).

MY_{PEAK} occurred significantly later in lactations with the longer open period (106 DIM vs 148 DIM accordingly). Lactation persistency was accordingly positively correlated with open period length as well (−6.00% for the shortest open period and −1.86% for the longest open period).

All pairwise comparisons between groups were statistically significant ($P > 0.05$).

Table 6. Peak milk yield and lactation persistency

CI_1 group	No. of cows	Mean peak DIM	SD	Mean MY_{PEAK} (ECM) kg/day	SD	Mean MY at milk tests 1–5 (ECM) kg/day	SD	Mean lactation persistency	SD
1	1 360	106.3	72.9	35.2	5.5	30.6	4.2	−5.85	6.00
2	1 690	114.7	76.4	36.1	5.4	31.3	4.2	−4.05	5.21
3	739	129.3	90.2	36.6	5.5	31.3	4.3	−2.69	4.62
4	510	148	108.6	37.6	5.7	31.8	4.3	−1.86	4.98

CI_1 = length of the first calving interval; DIM = days in milk; ECM = energy corrected milk; MY_{PEAK} = milk yield at peak milk test; SD = standard deviation

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Table 7. Number of cows reaching 1 000 days of productive life by the first calving interval

CI_1 group	Total No. of cows	Culled	In herd	% in herd
1	1 523	859	664	43.6
2	1 701	927	774	45.5
3	740	406	334	45.1
4	510	253	257	50.4

CI_1 = length of the first calving interval

Contingency table with the status of cows at 1 000 days of productive life (in herd or culled) and CI_1 group was created to describe a possible relationship between these variables (Table 7). The results showed that the proportion of cows in herd at 1 000 days of productive life was very similar for the three shorter CI_1 groups (43.6%, 45.5% and 45.1%, respectively), while for the cows with the longest CI_1 it was notably higher (50.4%). Statistical significance of the contingency table was tested by a chi-square test, the test results showed a weak relationship between groups (P = 0.067).

A similar contingency table was also created with the status of longevity at 1 000 days of productive life (in herd or culled) and quartiles of age at first calving (AFC); the chi-square test showed a very weak relationship between longevity and quartiles of AFC (P = 0.092).

DISCUSSION

Our results indicate that the strategy of minimizing the length of CI_1 appears to bring about no benefits in terms of either milk yield or longevity of the animals. On the contrary, animals with the CI_1 of at least 14 months have both higher milk yield during the first lactations and longer productive life than those re-calving sooner. Later conception allows them more time to recover body reserves from the first calving (Stangaferro et al. 2018) and thus reduce risks going into the second pregnancy.

The difference in MY_{LIFE} between shorter and longer CI groups is substantial (11%) and should give the farmers a reason to seriously consider re-thinking their strategy.

The results regarding MY and CI interactions agree with studies done in Denmark (Lehmann et al. 2019), Netherlands (Burgers et al. 2019) and Israel (Arbel et al. 2001). In these studies, though, deliberate extension of CIs was used for all or selected animals in all sample herds, which was not the case on the farms in our study.

Case has also been made (Lehmann et al. 2019) for shorter CI_1 because of significantly lower MY of the first-parity cows compared with the second-parity cows, therefore it would make sense to get the cows into their second lactation as fast as possible.

This study supports the notion of higher MY in the second lactation, but also it shows that the positive impact of longer CI_1 on MY in the second lactation compensates a considerable part of the difference.

Also, as about ⅓ of all first-calved cows were already culled during the first lactation (Table 2), it should not be seen as an introduction to higher yielding periods in the future, but rather a major part of the total expected lifetime production in itself. The longer the productive life and lifetime MY of a cow, the lower will be the share of her own raising cost as a heifer per unit of milk she produces (Lehmann et al. 2014).

The impact of herd longevity in comparison with marginal yield improvements on profitability of the farm is particularly high in an environment of falling milk prices and/or rising feed prices (Horn et al. 2012). Herd longevity is a broad animal welfare issue and CI_1 length is just one of its many drivers, however it is important because it is easy to change for the farmers.

There were two issues where the results of this study were inconclusive: impact of age at first calving of the animals and voluntary waiting period before the first insemination after the first calving. No statistically significant relationship was found between age at first calving and MY, CI or longevity, but there may be other aspects that still validate age at first calving as an important measure in herd management, such as probability of a heifer to reach the first calving (our study did not include animals culled before the first calving).

As the timing of the first insemination in herds was highly variable, it is likely that the voluntary waiting period as a fixed guideline had not been determined on the sample farms. Therefore, it is impossible to verify in retrospect if the waiting period length for individual cows was due to purposeful decisions, health problems of the animals or random, depending on the success of heat detection.

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CONCLUSION

A longer first calving interval leads to higher lifetime milk production and lower early culling probability.

Higher lifetime production and longer productive life have a substantial economic benefit potential for dairy farmers from higher milk sales and better utilization of the cost spent on raising the cows. A lower herd culling rate also requires less youngstock to be kept for replacement. Together, these factors could contribute substantially to improving operating margins of dairy farmers without additional cash outlays into operating expenses or investments.

Conflict of interest

The authors declare no conflict of interest.

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