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Associations between milk production level, calving interval length, lactation curve parameters and economic results in Holstein cows

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Abstract

The objective of work was to evaluate effects of milk production level (MY1≥9500 kg, n=23; MY2 = 8000-9499, n=28; and MY3≤7999 kg, n=29) and calving interval length (CI1≥440 days, n=22; CI2 = 400-439 days, n=33; and CI3≤399 days, n=25) on the lactation curve parameters calculated using MilkBot® Model and economic profitability of Holstein dairy cow breeding. Data were obtained from 80 Holstein cows on 1st to 4th parity calved between January and August 2012 on the dairy farm of the Czech University of Life Sciences Prague in Czech Republic. Lactation curve parameters differed more in relation with milk production level compared to calving interval length. Lactation curve in cows with the highest MY was characterized with significantly higher overall magnitude (scale parameter) of milk production (P<0.01), higher peak yield (P<0.01) which occurred later (P<0.05) and higher persistence (P<0.05). Due to combination of higher persistence and total yield, average milk yield per day of calving interval was significantly (P<0.05) higher in cows with middle CI than in short CI. Optimal calving interval length should be assessed in relation with lactation persistence and milk production level. The highest individual profitability was reached by cows in MY1 and CI2 group.

Key words: dairy cows, reproduction results, lactation curve, persistence, costs, income, profitability

Introduction

The number of cows that yielded milk significantly longer than 305 days of lactation has markedly increased in recent years (Duchacek et al., 2012). The expected benefits of extended lactations include a reduced number of days dry within the cows lifetime, reduced costs per cow associated with mating, calving and animal health through reduced metabolic stress, exposure to fewer periods of high risk and increased longevity (Borman et al., 2004). However, fertility in dairy cattle has an important effect on herd economics as well. Therefore, short calving interval gives more offspring and a higher milk yield per day from cows in milk, but also a higher risk of periparturient diseases occurrence per cow-year, so it has been questioned whether short calving interval is still economically optimal (Sorensen and Ostergaard, 2003). On the other hand, reproduction results continuously declined for last 30-40 years (Beran et al., 2013). The main reason of poor fertility is assume to be negative energy balance (NEB) (Duchacek et al., 2014), evoking body reserves mobilization to meet the increased nutrient demand for milk yield (Beran et al., 2012). Several studies showed an association between the energy balance and lactation curve shape, which correspond with calving to conception interval length (Konjačić et al., 2010; Andersen et al., 2011).

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Milk production level and lactation persistency are factors determining the optimal calving interval length as the ability of cow to maintain production following peak yield (Wood, 1967). Delayed open period can lead to increased lactation persistency as well as increased milk yield in the subsequent lactation (Arbel et al., 2001). High yielding cows maintain milk yields in mid to late lactation, and this can tend to boost the overall milk yield (Yamazaky et al., 2011).

Lactation persistency directly corresponds with feed costs, therefore it has a significant economic importance. Persistent lactations increase the fraction of feed energy provided by roughage compared to more expensive concentrates (Dekkers et al., 1998). Atashi et al. (2013) documented higher persistency and lower peak yield improves cows´ robustness to the stress of lactation and metabolic disorders, as a consequence of shallower energy imbalance, followed by less body reserves mobilization to meet the nutrient demand for lower milk production.

Therefore, reduction of milk yield in early lactation (Togashi and Lin, 2003) followed by lactation persistency increase after lactation peak could help to maintain the health of dairy cows during lactation without decreasing total milk yield (Yamazaky et al., 2011).

The objective of this work was to determine relationships between lactation curve traits modeled using the MilkBot® Model, calving interval length, and milk production level in Holstein dairy cows as well as to evaluate economic results of individual groups of dairy cows in relation to level of milk yield and reproduction results.

Materials and methods

Data of 80 Holstein cows on 1st to 4th parity (1st n=36; 2nd n=28, 3rd and subsequent n=16) calved between January and August 2012 on the dairy farm of the Czech University of Life Sciences Prague were used for calculations. Differences between 3 milk production levels expressed as 305 days milk yield (MY1≥9500 kg, MY2 = 8000-9499, and MY3≤7999 kg) and 3 calving intervals length (CI1≥440 days, CI2 = 400-439 days and CI3≤399 days) were investigated to determine the effects on the lactation curve parameters and economic profitability. Fertility data (days after calving to first insemination, number of services per conception, days open period and calving interval length) were obtained from the farm evidence program (ALPRO Windows 6.65, DeLaval©), milk production data from the milk recording system applied under ICAR requirements. The MilkBot® Model developed by Ehrlich (2011) was used for individual lactation curves construction based on monthly test day milk yields.

The MilkBot® Model (1) predicts daily milk yield, Y(t) as a function of time (t). Four parameters, a (scale), b (ramp), c (offset), and d (decay), control the shape of the curve. The constant e is Euler's number (i.e. the root of natural logarithms, approximately 2.718).

$$1)\quad Y(t) = a\left(1 - \frac{e^{\frac{c-t}{b}}}{2}\right)e^{-dt}$$

Scale parameter a determines the overall magnitude of milk production in kg/day. This is the theoretical maximum daily milk yield, which is approached by actual peak production as ramp, and offset values approach zero (i.e. a lactation which peaks on the day of calving), or as decay approaches zero (infinite persistence). Ramp parameter express rate of rise in milk production in early lactation measured in days. Offset parameter represents the offset in time between calving and maximal growth rate of productive capacity in days and indicate the time of maximal creation of productive capacity. Decay parameter controls the loss of productive capacity. Decay is inverse-time (days-1). In frame of this model, persistence was calculated according to equation 2. Persistence is the time it would take for production to drop by half, if we were to ignore the growth side of the model. Since the growth function approaches one in late lactation, persistence, by this definition is close to the actual half-life for milk production in late lactation.

2) Persistence = 0.693/decay

The peak day (t_{peak}) we can calculate with mathematical manipulation of equation 1 by setting the derivative equal to zero (3), and then peak milk production (y_{peak}) by equation 4.

$$3)\quad t_{peak} = c - b\,\mathrm{Log}[(2\,bd)/(1 + bd)]$$

$$4)\quad y_{peak} = a\exp(-d\ (c - b\ \mathrm{Log}[2])[a,b,c,d])\ (1 - 1/2\exp((c - (c - b\ \mathrm{Log}[2])[a,b,c,d])/b))$$

Input economic data (daily costs, daily feeding costs, costs per one kilogram of milk and milk purchase price) for individual cow economic values calculation (milk income, incomes over feed costs - IOFC, total costs per CI, and milk production profitability - PROF), were used from comprehensive investigation of costs, monetization and profitability of milk production processed by Kopecek and Martinkova (2012). Costs are there calculated in regard to milk productivity level based on economic results of nearly 55000 dairy cows bred on more than 100 farms in Czech Republic. Output economic values are converted into Euro in exchange rate 1 EUR = 27.5 CZK.

Milk income was calculated as the sum of milk produced per whole lactation multiplied by milk purchase price. IOFC was calculated as difference between total milk income and total feeding costs per CI divided by calving interval length. Total costs were calculated multiplying daily costs by calving interval length. Profit value (PROF) was expressed as the difference between total costs and milk incomes per cow per day of calving interval.

The dataset was analysed by the GLM procedure of SAS 9.2 software (SAS Institute Inc. 2002-2005). The following statistical model with fixed effects was used for subsequent estimations:

$$Y_{ijk} = \mu + A_i + B_j + e_{ijk}$$

Where:

Y_{ijk} measured value of the dependent variables;

μ mean value of the dependent variables;

A_i fixed effect of parity i (i = 1st, n = 36; 2nd, n = 28; 3th and subsequent, n = 16);

B_j fixed effect of calving interval length j (j = ≥440 days, n = 22; 400-439 days, n = 33; ≤399 days, n = 25) or 305 days milk production level (j = ≥9500 kg, n = 23; 8000-9499 kg, n = 28; ≤7999 kg, n = 29);

e_{ijk} random residual effect.

Results and discussion

Based on our results (Table 1), it is evident, that high 305 days milk production is connected with poorer fertility. Slightly longer interval form calving to first insemination, higher number of services per conception and especially significantly (P<0.05) longer days open period for 38 days were detected in cows yielded more than 9500 kg through 305 days (group MY1) than cows with low milk productivity (≤7999 kg; MY3). Many studies have reported that higher milk yield was associated with longer time to resumption of ovarian activity and longer postpartum intervals (Stadnik and Louda, 1999; Lucy, 2001; Lopez-Villalobos et al., 2005) as a consequence of lower production of progesterone (Stadnik et al., 2009), or irregular oestrous cycles in cows selected for high milk yield (Stadnik et al., 2002; Walsh et al., 2011). On the other hand, there are also reports of no association between milk yield and recurrence of ovarian activity (Grosshans et al., 1997; Loeffler et al., 1999).

Scale-lactation curve parameter observed and calculated using MilkBot® model (Table 1) was significantly (P<0.01) higher for 6.1 kg/day in cows of MY1 group than in cows in group MY2 and for 11.36 kg/day than in MY3 group cows. Ramp parameter was nearly the same. Peak day occurred in MY1 group significantly (P<0.01; P<0.05) later after calving (for 10 and 13 days) with significantly (P<0.01) higher peak milk yield (for 5.4 and 10 kg) compared to MY2 and MY3 cows. Persistence, defined as half-life function of used model, was in MY1 group significantly (P<0.05) higher than in MY3 group, which reflect better ability of high producing cows to maintain milk production on high level beyond lactation peak. Although calving interval was in MY1 group the longest, due to high lactation persistence and high total yield through whole lactation, average daily milk yield per calving interval was in this group significantly (P<0.01) the highest (for 3.95 and 7.59 kg higher than MY2 and MY3 group respectively).

Several studies also found similar relationships between the lactation curve parameters, such as day of peak yield, peak yield, persistency, and milk productivity, affected by selection for higher milk yield. Buckley et al. (2003) investigated that the higher the peak yield is, that is the higher the total milk yield. Muir et al. (2004) estimated positive genetic correlations between 305 days yield and peak day (0.63±0.06) and persistency (0.21±0.06) indicating that as yield increased, the interval from initiation of lactation to peak yield and persistency increased as well. Estimated genetic correlation between peak day and persistency (0.54±0.07) indicated that prolongation of the interval from initiation of lactation to peak yield improved persistency.

Table 1. The influence of 305 days milk yield level on fertility, lactation curve traits and milk productivity

Traits	≥9500 (MY1)	8000-9499 (MY2)	≤7999 (MY3)
	n = 23	n = 28	n = 29
CFSI(days)	105	103	93
PCS	2.26	2.19	1.88
Days open (days)	182[a]	169	144[a]
Scale (kg/day)	51.52[A, B]	45.42[A, C]	40.16[B, C]
Ramp (DIM)	32.97	31.41	31.48
Offset	-0.259	-0.261	-0.248
Persistence (DIM)	545[a]	299	238[a]
Peak day (DIM)	69[A, b]	59[A]	56[b]
Peak milk (kg)	41.24[A, B]	35.89[A, C]	31.11[B, C]
MY/lactation (kg)	12 643[A, B]	10 605[A, C]	8 589[B, C]
MY/305 d (kg)	10 371[A,B]	8 837[A]	7 398[B]
MY/day/305 d (kg)	34.00[A, B]	28.97[A, C]	24.26[B, C]
MY/day/CI (kg)	27.36[A, B]	23.41[A, C]	19.77[B, C]

Abbreviations: CFSI - calving to first service interval; PCS - number of services per conception; DIM - days in milk, CI - calving interval, MY/lactation - total yield through whole lactation, MY/305 days - total yield through 305 days, MY/day/305 days - daily milk yield per 305 days, MY/day/CI - daily milk yield per CI;
a, b, c; A, B, C: Mean values with the same superscripts letters within row differ significantly at $P<0.05$; $P<0.01$.

Related to calving interval length, there were not observed any significant differences in lactation curve traits (table 2). Cows with the longest calving interval (CI1) tended to have higher scale, ramp, and peak yield occurring later after parturition. Their lactation curve seems to have slower milk production rise in early lactation with the higher maximal potential production, which correspond with significantly ($P<0.01$) the highest milk productivity. Also according to Andersen et al. (2011) peak yield as well as peak day, did not differ significantly with calving interval groups. Similarly, no significant differences between maximum milk productivity at different lactation lengths and only small significant differences between peak yields, with longer lactations having slightly higher peak yields were found by Pollot et al. (2011). Lopez-Villalobos et al. (2005) reported direct association between interval from calving to first oestrus and peak yield respectively inversely with peak yield day. Earlier investigation of Lee et al. (1997) detected longer days open period corresponding to high early milk yield, which presumably deepened NEB and thereby prolong the time to conception. Simultaneously, Pollot et al. (2011) explained that long lactation with high peak yield and possibly faster daily increases in milk yield early in lactation is typical for cows with deep NEB which cause conception rate decrease and calving interval prolongation over 365 days.

Despite the longer calving interval and only a small difference in 305 days milk productivity, average milk yield per day of calving interval was significantly ($P<0.05$) higher for 2.13 kg in group with middle calving interval length (CI2) compared to short calving interval length group (CI3). This fact may be due to combination of favourably high persistence and significantly ($P<0.01$) higher total yield through whole lactation for 1661kg in MY2 group. Also according to Andersen et al. (2011) and Atashi et al. (2013), the average daily milk production was directly impacted by the persistency of milk yield. Cows with shorter CI had low intercept, steep ascending slope and descending slope, were less persistent and produced less 305 days milk, although their first 120 days production were the highest.

Lower milk yield persistency of earlier conceiving cows was observed by Tekerli et al. (2000), Haile-Mariam et al. (2003) and Pollot et al. (2011). Pollot et al. (2011) found smaller difference in lactation persistency between the 305 days lactation length groups and 370 days groups compared to 370 and 440 days groups. Dekkers et al. (1998) referred, that increased persistency resulted in lower lactation yield for lactations that were

Table 2. The influence of calving interval length on lactation curve traits and milk productivity

Traits	≥440 (CI1)	400-439 (CI2)	≤399 (CI3)
	n = 22	n = 33	n = 25
Scale (kg/day)	46.80	46	44
Ramp (DIM)	32.36	31.22	31.70
Offset	-0.245504	-0.267273	-0.26836
Persistence (DIM)	375	401	262
Peak day (DIM)	64	62	57
Peak milk (kg)	37.29	36.52	34.24
MY/lactation (kg)	11 482$^{A, B}$	9 777$^{A, C}$	8 116$^{B, C}$
MY/305 d (kg)	9 184^{A}	9 035^{b}	8 119^{A,b}
MY/day/305 d (kg)	30.11^{A}	29.62^{b}	26.62$^{A, b}$
MY/day/CI (kg)	22.78	23.22^{a}	21.09^{a}

Abbreviations: DIM - days in milk, CI - calving interval, MY/lactation - total yield through whole lactation, MY/305 days - total yield through 305 days, MY/day/305 days - daily milk yield per 305 days, MY/day/CI - daily milk yield per CI; a, b, c; A, B, C: Mean values with the same superscripts letters within row differ significantly at P<0.05; P<0.01.

Table 3. The influence of 305 days milk productivity level on economic traits

Traits	≥9500 (MY1)	8000-9499 (MY2)	≤7999 (MY3)
Total costs/day (EUR)	8.07$^{A, B}$	7.03^{A,C}	6.29^{B,C}
Feeding cost/day (EUR)	3.76$^{A, B}$	3.15^{A,C}	2.56^{B,C}
Total costs/CI (EUR)	3 756.29$^{A, B}$	3 251.09^{A,C}	2 739.75^{B,C}
Costs/kg of milk (EUR)	0.25$^{A, B}$	0.26^{A,C}	0.29^{B,C}
Milk incomes (EUR)	3 801.27$^{A, B}$	3 168,55^{A,C}	2 597.42^{B,C}
IOFC/day (EUR)	4.48$^{A, B}$	3.84^{A,C}	3.43^{B,C}
PROF (EUR)	44.99$^{A, B}$	-82.55^{A,C}	-142.35^{B,C}

Abbreviations: IOFC - incomes over feed costs, PROF - difference between milk incomes and total costs.
A, B, C: Mean values with the same superscripts letters within row differ significantly at P<0.01.

shorter than 305 days and in greater lactation yield for lactations that were longer than 305 days.

Economic results shows (Table 3), that cows with the highest 305 days milk yield (MY1) reached significantly (P<0.01) the best economic parameters - the lowest costs per kg of milk, the highest IOFC, and finally the best profitability despite significantly (P<0.01) the highest daily as well as total costs per CI day.

The highest costs can be attributed mainly to the high variable costs, especially extra feeds to cover extra milk production, labour, and semen cost for breeding because of poorer fertility. At dairy farm, the highest cost is for animal feed (Očić et al., 2012). Vandehaar (1998) stated, that although feeds generally cost more as cows are fed for higher milk production, increased yield also enhances profitability, partly because of increased efficiency, but also because fixed costs are decreased relative to total costs as investigated.

Significantly (P<0.01) the worst economic results were presented in cows with the lowest 305 days milk yield (MY3). Costs per kg of milk were there for 0.05 and 0.04 EUR higher, daily IOFC for 1.05 and 0.41 EUR lower, and profit calculated per calving interval was reduced for 187.25 and 59.8 EUR compared to MY1 and MY2 cows. Also Krpalkova et al. (2014) concluded, that MY is a very important factor for dairy farm profitability. Cows having the highest MY achieved the highest net profit despite having greater fertility problems. Our results confirm these findings.

An increase in milk production for approximately 3000 kg per 305 days lactation increased profitability by almost 190 EUR. Similar results were published also by Vandehaar (1998).

Table 4. The influence of calving interval length on economic traits

Traits	≥440 (CI1)	400-439 (CI2)	≤399 (CI3)
Total costs/day (EUR)	7.37[a]	7.22	6.89[a]
Feeding cost/day (EUR)	3.30[a]	3.28[b]	2,95[a,b]
Total costs/CI (EUR)	3 728.65[A, B]	3 073.78[A, C]	2 687.49[B, C]
Costs/kg of milk (EUR)	0.263	0.262[a]	0.273[a]
Milk incomes (EUR)	3 610.40[A, B]	3 087.31[A, C]	2 647.60[A, C]
IOFC/day (EUR)	3.90	4.06	3.80
PROF (EUR)	-118.27[A]	13.50[A]	-39.89

Abbreviations: IOFC - incomes over feed costs, PROF - difference between milk incomes and total costs;
a, b, c; A, B, C: Mean values with the same superscripts letters within row differ significantly at P<0.05; P<0.01

As regards calving interval length (Table 4), the lowest total daily costs as well as daily feeding costs were observed in cows with the shortest calving interval (CI3). However the highest profitability, as the main indicator for the assessment of milk production economy was found in cows in CI2 group presenting the best combination of milk incomes and total milk costs. This may be attributed to the above mentioned (Table 2) highest average milk yield per day of calving interval.

According to Sorensen and Ostergaard (2003) income from milk and annual expenses were less for cows with longer calving interval. However, the costs reduction was not sufficient to compensate the income decrease. Arbel et al. (2001) found an economic advantage in extending lactations. Stated, that the benefit of extending the CI was mainly due to high persistency. Increase in profitability with longer CI due to the increase in persistency was reported also by van Amburgh et al. (1997) and Dekkers et al. (1998). Van Amburgh et al. (1997) detected cows managed for 16.5 month CI produced 31.7 % more milk and were more profitable due to increased persistency compared to cows with 13.2 month CI. Dekkers et al. (1998) documented, that persistency affected feed costs as well as returns from milk. Higher persistency had negative effect on milk returns for short lactations as well as positive for long lactations. Feed costs were lower in longer calving intervals with greater lactation yields and higher persistency, because high energy requirements were more than offset by reduced costs per unit of feed energy.

Long calving interval (≥440 days) resulted in a loss of 131.77 EUR, short calving interval (≤399 days) in a loss of 53.39 EUR compared to middle calving interval (400-439 days). According to Safiullah et al. (2001) increasing CI from 360 to 420 or 450 days caused loss of 0.70 to 2.33 or 0.94 to 3.15 USD. Groenendaal et al. (2004) calculated costs per extra day open between 0 and 3 USD, depending on the cow and herd characteristics, slightly higher in lower production levels and lower in cows with higher lactation persistency. This is in agreement with Strandberg and Oltenacu (1989), who found that a longer CI for high-producing cows does not decrease profitability as much as for low-producing cows.

Conclusion

The lactation curve parameters differ more in relation with milk production level than with calving interval length.

Lactation curve in cows with the highest MY was characterized with significantly higher overall magnitude of milk production, higher peak yield which occurred later and higher persistence which reflect their better ability to maintain milk production on high level beyond lactation peak. Cows with the longest CI tended to have higher scale, ramp, and peak yield occurring later after parturition. Due to combination of higher persistence and total yield, average milk yield per day of calving interval was significantly higher in cows with middle CI than in short CI. Optimal calving interval length should be assessed in relation with lactation persistence and milk production level. The highest individual profitability was reached by cows with the highest milk production level and middle calving interval length, might due to higher persistence. From these findings it could be concluded, that optimal calving interval length for conditions of individual dairy herds should be assessed only in relation with lactation persistency and milk production level. For high yielding cows, extended calving interval didn't cause profitability reduction due to their higher lactation persistency. Conversely in low producing cows, where persistency is low and intensively decreases the amount of milk in final part of lactation, the shorter lactation length is expected to be more profitable.

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Povezanost između razine proizvodnje mlijeka, duljine intervala teljenja, parametara laktacijske krivulje i ekonomskih rezultata u holstein krava

Sažetak

Cilj rada bio je procijeniti učinke razine proizvodnje mlijeka (MY1≥9500 kg, n = 23; MY2 = 8000-9499, n = 28, i MY3≤7999 kg, n = 29) i duljine intervala teljenja (CI1≥440 dana, N = 22; CI2 = 400-439 dana, n = 33, i CI3≤399 dana, n = 25) na parametre laktacijske krivulje, kod holstein krava, koji su analizirani MilkBot® modelom. Također su praćeni parametri ekonomske isplativosti. Podaci su dobiveni za 80 holstein krava koje su bile u proizvodnji od prve do četvrte laktacije, a sezona teljenja bila je između siječnja i kolovoza 2012. godine. Istraživanje je provedeno na farmi mliječnih krava Czech University of Life Sciences Prague. Parametri laktacijske krivulje razlikovali su se više u odnosu na razinu proizvodnje mlijeka nego u odnosu na duljinu intervala teljenja. Laktacijsku krivulju u krava s najvećom količinom mlijeka karakterizira značajno veća ukupna proizvodnja mlijeka (P<0,01), viša maksimalna proizvodnja (P<0,01), koja dolazi kasnije (P<0,05) i visoka perzistencija (P<0,05). Zbog kombinacije visoke perzistencije i ukupne količine, prosječni prinos mlijeka na dan intervala teljenja bio je značajno (P<0,05) veći u krava sa srednjim intervalom teljenja (CI) nego s kratkim CI. Optimalnu duljinu intervala teljenja treba procijeniti u odnosu na perzistenciju laktacije i razinu proizvodnje mlijeka. Najveća pojedinačna profitabilnost utvrđena je u krava MY1 i CI2 skupine.

Ključne riječi: mliječne krave, reproduktivni rezultati, laktacijska krivulja, perzistencija, troškovi, prihodi, profitabilnost

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