Effective lactation yield: A measure to compare milk yield between cows with different dry period lengths

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ABSTRACT

To compare milk yields between cows or management strategies, lactations are traditionally standardized to 305-d yields. The 305-d yield, however, gives no insight into the combined effect of additional milk yield before calving, decreased milk yield after calving, and a possible shorter calving interval in the case of a shortened dry period. We aimed to develop a measure that would enable the comparison of milk yield between cows with different dry period (DP) lengths. We assessed the importance of accounting for additional milk yield before calving and for differences in calving interval. The 305-d yield was compared with a 365-d yield, which included additional milk yield in the 60 d before calving. Next, an effective lactation yield was computed, defined as the daily yield from 60 d before calving to 60 d before the next calving, to account for additional milk yield before calving and for differences in calving interval. Test-day records and drying-off dates of 15 commercial farms were used to compute the 305-d, 365-d, and effective lactation yields for individual cows. We analyzed 817 second-parity lactations preceded by no DP, a short DP (20 to 40 d), or a conventional DP (49 to 90 d). Compared with cows with a conventional DP, the 305-d yield of cows with no DP was 7.0 kg of fat- and protein-corrected milk (FPCM) per day lower, and the 305-d yield of cows with a short DP was 2.3 kg of FPCM per day lower. Including additional milk yield before calving in the 365-d yield reduced this difference to 3.4 kg of FPCM per cow per day for cows with no DP and to 0.9 kg of FPCM per cow per day for cows with a short DP. Compared with cows with a conventional DP, median days open were reduced by 25 d for cows with no DP and by 18 d for cows

with a short DP. Accounting for these differences in calving interval in the effective lactation yield further decreased yield reductions for cows with no DP or a short DP by 0.3 kg of FPCM per cow per day. At the herd level, estimated 365-d yield losses for cows with no DP or a short DP differed from effective lactation yield losses by 0.4 to −0.8 kg FPCM per cow per day. Accounting for additional milk yield before calving had a major and consistent effect on yield comparisons of cows with different DP lengths. The effect of correcting for calving interval was more variable between farms and will especially be important when calving interval is affected by DP length.

Key words: milk yield, dry period length, productivity, calving interval

INTRODUCTION

Milk yield of cows is an important determinant of the economic and environmental impact of management strategies in dairy farming. Milk yield directly relates to farm revenues (Santschi et al., 2011c), and environmental impacts per kilogram of milk often decrease when milk yield levels increase (Wall et al., 2010; van Middelaar et al., 2014). To compare milk yields between cows, lactations are traditionally standardized to 305-d yields (Ashton, 1956; Patton et al., 2006; Windig et al., 2006).

Recently, shortening the dry period (DP) has been suggested as a management strategy to reduce the negative energy balance in early lactation and to increase fertility in dairy cattle (Andersen et al., 2005; van Knegsel et al., 2013). Shortening the DP results in additional milk yield before calving but reduced milk yield after calving (Annen et al., 2004; Santschi et al., 2011a; van Knegsel et al., 2013, 2014). The additional milk yield before calving can be accredited to the choice of DP length. The 305-d yield does not include this additional milk yield, and, therefore, is less suitable for assessing the effect of DP length on milk yield.

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To compare milk yield between cows with different DP lengths, various lactation lengths and summations of milk yield before and after calving have been used (Annen et al., 2004; Santschi et al., 2011a; Steeneveld et al., 2014). Steeneveld et al. (2014), for example, accounted for additional milk yield by adding the milk yield from the 60 d before expected calving to the 305-d yield after calving.

Shortening the DP may also improve fertility (Gümen et al., 2005; Watters et al., 2009; Chen et al., 2015), although not all studies found this (Pezeshki et al., 2007; Santschi et al., 2011b). Improved fertility can partly compensate for milk losses related to a shortened DP if the calving interval is shortened (Inchaisri et al., 2010). To correct for calving interval while accounting for additional milk yield before calving, a measure of milk yield similar to a whole-lactation yield (i.e., milk yield from one calving to the next calving) is required. Santschi et al. (2011a) combined additional milk yield before calving and the lactation yield after calving in an expression of kilograms of milk per cow per year. However, because this measure included milk yield until drying off, it could lead to double counting of the additional milk yield if multiple consecutive lactations are assessed.

The first aim of this study was to develop a measure that would enable comparison of milk yields between cows with different DP lengths. The second aim was to assess the importance of accounting for additional milk yield before calving and for differences in calving interval when evaluating the effect of DP length on milk yield.

MATERIALS AND METHODS

Definition of Yield Measures

Three measures of milk yield were compared in this study: conventional 305-d yield, a 365-d yield, and an effective lactation yield. First, the conventional 305-d yield sums milk yield from calving to 305 DIM. Second, as an equivalent of the conventional 305-d yield that accounts for additional milk yield before calving, a 365-d yield was defined as the sum of the milk yield in the 60 d before calving and the 305-d yield after calving. We assumed that the conventional DP lasts 60 d (Bachman and Schairer, 2003). Milk produced from 60 d before calving until calving was therefore considered additional milk due to the decision to shorten the DP. Third, effective lactation yield was defined as milk yield from 60 d before calving to 60 d before the next calving, to adjust milk yield for length of calving interval. The effective lactation thus corresponds to the period

from one dry period decision to the next dry period decision, as opposed to the period from calving to next calving. Milk yield in the last 60 d before next calving was considered attributable to the next dry period decision and was therefore excluded from the present effective lactation. Like the conventional whole-lactation yield, the duration of the effective lactation is equal to the calving interval. To facilitate comparison, all 3 measures of milk yield were standardized to kilograms of fat- and protein-corrected milk (**FPCM**) per day.

Application of Yield Measures

In total, 15 commercial Dutch farms that apply or recently applied a short DP or no DP provided their test-day milk records and drying off dates. Half of the farms (A, B, C, D, E, G, and H) applied one DP strategy at a time for all cows, whereas the other half (F, I, J, K, L, M, N, and O) selected cows with high yields and low SCC in late lactation for short or no (mainly farms F and I) DP. The farms differed in herd size, milk yield level, housing system, milking frequency, and diets. Diets mainly comprised grass, grass silage, and maize silage supplemented with concentrates. In total, 10 of 15 farmers applied no DP and 14 applied a short DP during the period of analysis. Table 1 shows the number of cows included in the analysis, median calving intervals, and first-lactation 305-d yields per farm.

Test-day milk records were recorded every 4 to 6 wk from January 2007 to September 2014 by the Dutch national milk recording organization (CRV, Arnhem, the Netherlands). These milk records were combined with drying-off records to compute lactation lengths and DP lengths. To clearly illustrate the effect of different measures of milk yield, strict selection criteria were applied to the data set. In short, lactations with implausible drying-off dates were excluded, and only second-parity lactations preceded by specific DP lengths and with regular milk records were included in the analysis. The final data set included 817 cows with 17,333 milk records on their complete first and second lactations.

Drying-Off Records. Drying-off records were combined with lactation data based on cow identity, parity, and calving date. These combinations were validated as follows. If milk records occurred after the date of drying-off, the date was assumed incorrect and the lactation was excluded. If no drying-off date was present and the farmer stated that he or she did not practice continuous milking, the drying-off date was considered missing and the lactation excluded. If continuous milking until parturition occasionally occurred, continuous milking was assumed if there was no drying-off date and no milk records were missing at the end of the

Table 1. First-lactation 305-d yield (kg of fat- and protein-corrected milk per cow) and median calving interval in second lactation of the cows included in the analysis per dry period (DP) category¹ per farm

Farm	First parity		Second parity					
			No DP		Short DP		Conventional DP	
	305-d	No.	Calving interval (d)	No.	Calving interval (d)	No.	Calving interval (d)	No.
A	7,922	136	373	43	366	82	383	11
B	8,947	61	362	42	336	3	405	16
C	7,279	39	347	39	—	—	—	—
D	7,048	70	357	36	360	25	363	9
E	5,937	40	340	25	365	2	402	13
F	6,335	86	385	19	357	39	360	28
G	7,400	33	365	14	378	5	392	14
H	7,129	39	378	7	378	14	369	18
I	8,255	60	357	7	346	14	381	39
J	9,132	24	367	2	354	22	—	—
K	7,950	85	—	—	371	39	414	46
L	9,108	31	—	—	379	29	366	2
M	7,009	58	—	—	365	27	375	31
N	7,650	30	—	—	401	12	412	18
O	8,424	25	—	—	435	10	432	15
Overall	7,618	817	359	234	368	323	385	260

¹Short DP = 20 to 40 d; conventional DP = 49 to 90 d.

lactation. If a farmer only applied continuous milking, all lactations were classified as such.

DP Categories. Lactations were categorized into 3 DP classes using the drying-off records: no DP, with an assumed continuous lactation ($n = 234$); a short DP, with a drying off date 20 to 40 d before calving (mean: 33.3 d; SD: 5.2 d; $n = 323$); and a conventional DP, with a drying-off date 49 to 90 d before calving (mean: 58.3 d; SD: 8.9 d; $n = 260$). Lactations with intermediate (i.e., from 1 d to 19 d, and from 41 to 48 d) and more extreme DP lengths were excluded ($n = 422$) to create clear contrasts.

Completeness. Milk records with missing values for milk yield, fat content, or protein content were excluded. Three additional requirements were defined to improve the data set, which resulted in the exclusion of 349 incomplete lactations. First, the first milk record for each first- and second-parity lactation had to occur earlier than 50 DIM. Second, the first- and second-parity lactations of each cow had to have at least 5 milk records and the period between these records could not exceed 90 d. Third, the calving interval from first to second and from second to third calving could not exceed 600 d.

Standard Lactation Curves. Milk yield was converted to FPCM yield, as follows (CVB, 2012):

$$\text{FPCM (kg)} = \text{milk (kg)} \times [0.337 + 0.116 \times \text{fat content (\%)} + 0.06 \times \text{protein content (\%)}].$$

Subsequently, a Wilmink lactation curve was fitted on the 17,333 milk records (in kg of FPCM):

$$y_t = a + b \times t + c \times \exp(-k \times t),$$

where y_t is the yield of a cow at t DIM, and a , b , c , and k are parameters that relate to the level of production (a), persistency after the peak yield (b), and slope toward and moment of peak yield (c and k ; Wilmink, 1987). The model was fitted using maximum likelihood in SAS (PROC NLMIXED; version 9.3; SAS Institute Inc., Cary, NC). The initial model had a fixed effect for parity (1 or 2) and, in the case of parity 2, for DP category (no, short, conventional) on parameters a , b , and c ; and included a random effect on parameters a , b , and c to account for repeated measures per lactation (817 cows $\times$ 2 lactations). No random effect on k was included to mitigate model convergence problems. Significance of fixed effects was assessed with a Wald test. The least-significant fixed effect was removed from the full model until the smallest Bayesian information criterion was reached. The resulting lactation curves for each parity $\times$ DP combination, presented in the Appendix, were used as standard lactation curves to interpolate and extrapolate milk yields of individual cows at regular intervals.

Interpolation and Extrapolation. First, milk yield (kg of FPCM) was interpolated at intervals of 20 d from 10 DIM to the end of each lactation, and on 0 DIM and 305 DIM, using

$$y_i = g_i + (x_i - x_1) \times [y_2 - y_1 - (g_2 - g_1)] / (x_2 - x_1) + (y_1 - g_1),$$

where y_i is the milk yield to be estimated at x_i DIM; x_1 , x_2 , and x_i are DIM at the moments of milk recording and the to-be-estimated day x_i (that is between x_1 and x_2 DIM); y_1 and y_2 are the measured milk yields at x_1 and x_2 DIM; and g_1 , g_2 , and g_i are the predicted milk yields at x_1 , x_2 , and x_i DIM according to the standard lactation curves (CRV, 2002).

Milk yields before the first milk record and after the last milk record were extrapolated, using

$$y_i = g_i + (y_1 - g_1),$$

where y_1 is the actual and g_1 is the predicted milk yield at the nearest milk record. Negative predictions of milk yield were set to zero.

In case cows in the second parity were dried off before they reached 305 DIM or 60 d before third calving (e.g., because of a short calving interval or because the farmer dried the cows off early), the lactation was extrapolated to estimate milk yield without bias due to choices regarding the next DP.

Cumulative Yields Cumulative milk yields were approximated by summing the measured and estimated milk records over the lactation interval, using

$$\sum_{i=1}^{n-1} [(INT_i - 1) \times y_i + (INT_i + 1) \times y_{i+1}] / 2,$$

where y_i is the recorded or estimated milk yield at i DIM, INT_i is the interval between this milk yield and the next in days; and n is the total number of milk records (CRV, 2002; ICAR, 2009). Milk records were summed from calving until 305 DIM, until 60 d before next calving, and until next calving. To compute the additional milk yield before calving, the milk yield until 60 d before second calving was subtracted from the total milk yield in the first-parity lactation. The additional milk yield in the first parity, and the milk yield until 305 DIM and until 60 d before next calving in the second parity were used to compute the 305-d, 365-d, and effective lactation yields.

Effect of DP Length. A mixed model using REML was used to assess the effect of DP category on 305-d, 365-d, and effective lactation yields in the second-parity lactation (PROC MIXED). Herd was included as a random effect, because multiple animals in the same herd cannot be regarded as independent units of observation. Moreover, a random herd $\times$ DP category

interaction effect was included to model possible differences in the effect of DP length on milk yield between farms. To standardize milk yield levels among cows and herds, the individual 305-d yield in the first lactation was used as a covariate for lactation potential (Kuhn and Hutchison, 2005; Pezeshki et al., 2007; Cermakova et al., 2014). An interaction effect of DP category and 305-d yield in the first lactation was included in the initial model. Only significant fixed effects based on Kenward-Roger approximate F-tests were retained in the model ($P < 0.05$). Random effects were retained in the model if their inclusion improved the model based on a likelihood ratio test ($P < 0.05$). Pairwise comparisons of milk yield per DP strategy were performed using Wald tests.

For illustrative purposes, milk yields were also predicted per DP category per farm, using the mean values per DP category (LSMEANS) and best linear unbiased predictions (ESTIMATE) of random effects per DP category per farm (Robinson, 1991). These predictions were used to calculate the effect of no DP or a short DP compared with a conventional DP on milk yield for all yield measures. In addition, the difference in effect between the 305-d and 365-d yields, and between the 365-d and effective lactation yields were computed.

The same mixed model and procedure were used to assess the effect of DP length on calving interval. The skewed distribution of calving interval was converted to a normal distribution by transformation to the natural logarithm of days open, where days open was defined as calving interval minus 280 d. Mean values (LSMEANS) of the lognormal distribution were transformed back to median days open [$\text{Median}(X) = \exp(\mu)$; Johnson et al., 1994].

To visually assess the effect of using an effective lactation yield versus a 365-d yield, the individual differences between the 2 yield measures were computed and plotted against calving interval.

RESULTS AND DISCUSSION

Milk Yield Measures

305-d Yield. Mean 305-d yields in the first lactation varied from 19.5 to 29.9 kg of FPCM per cow per day (5,937 to 9,132 kg of FPCM in 305 d) between farms (Table 1), with an overall mean yield of 25 kg of FPCM per cow per day. In the second lactation, the mean 305-d yield was 30.8 kg of FPCM per cow per day for cows with a conventional DP, whereas it was 28.4 kg of FPCM per cow per day with a short DP and 23.8 kg of FPCM per cow per day with no DP (Table 2).

Table 2. Least squares means milk yield (kg of fat- and protein-corrected milk per cow per day, FPCM) of second-parity cows per dry period (DP) category¹ for 3 measures of milk yield

Yield measure	Conventional DP		Short DP			No DP		
	FPCM	SE	FPCM	SE	%	FPCM	SE	%
305-d	30.8 ^a	0.58	28.4 ^b	0.57	-7.6	23.8 ^c	0.62	-22.8
365-d ²	26.0 ^{a*}	0.50	25.1 ^{a*}	0.49	-3.4	22.6 ^b	0.54	-13.1
Effective lactation ³	25.4 ^a	0.53	24.9 ^a	0.52	-2.2	22.4 ^b	0.57	-12.0

^{a-c}Different letters in the same row indicate significantly different means ($P < 0.05$).

¹Short DP = 20 to 40 d; conventional DP = 49 to 90 d. Relative differences between milk yield of cows with a short or no DP versus a conventional DP are given for each measure (%)

²Milk yield in the 60 d before second calving plus the 305-d yield after calving.

³Milk yield from 60 d before second calving until 60 d before next calving.

*0.05 < P < 0.10: tendency for a difference between means in the same row.

We detected no interaction between DP length and lactation potential, and the interaction term was removed from the model used to explain 305-d yield (Table 3). Therefore, the expected decrease in milk yield for cows with a short or no DP is a fixed amount (kg) of FPCM per cow per day, regardless of lactation potential. Hence, it might be more informative to express the effect of DP length on milk yield in kilograms reduction instead of percentage reduction of milk yield, unless cows of equal or standardized lactation potential are compared.

An experimental study observed daily yields of 35.9 kg of FPCM per cow after a conventional DP, 33.9 kg of FPCM per cow after a short DP, and 26.2 kg of FPCM per cow after no DP in second-parity Holstein cattle during 44 wk of lactation (van Knegsel, 2014). The reduction of 2 kg of FPCM per cow per day after a short DP is similar to the current results. Applying no DP, however, reduced milk yield by almost 10 kg of FPCM per cow per day in the experimental study of van Knegsel (2014), compared with 7 kg of FPCM per cow per day in the current observational study.

Whereas over 40% of cows with no planned DP dried off spontaneously in some experiments (Rémond et al., 1997; van Knegsel, 2014), the farmers in the current study indicated that few cows dry themselves off, which might partly explain the difference in milk losses.

365-d Yield. Additional milk yield [mean (SD)] in the 60 d before second calving was 77 (73) kg of FPCM for cows with a conventional DP, whereas it was 478 (161) kg of FPCM for cows with a short DP and 992 (308) kg of FPCM for cows with no DP. Other studies reported similar additional milk yields of 454 to 544 kg of milk per cow for short DP of 30 to 35 d and of 846 to 1,176 kg of milk per cow for no DP in primiparous cows (Annen et al., 2004; Watters et al., 2008; Santschi et al., 2011a; Steeneveld et al., 2013; van Knegsel et al., 2014).

Including the additional milk in the 365-d yield measure considerably reduced the difference in daily milk yield between conventional and short or no DP. Changing from the 305-d to the 365-d yield reduced milk losses for cows with a short DP from 2.3 to 0.9 kg of FPCM per cow per day, and for cows with no DP

Table 3. Effects of dry period (DP) length and yield level on 305-d, 365-d, and effective lactation yields (kg of fat- and protein-corrected milk per cow per day)

Variable	305-d			365-d ¹			Effective lactation ²		
	β	SE	P -value	β	SE	P -value	β	SE	P -value
Constant ³	15.7	1.13	—	12.3	0.95	—	12.7	0.95	—
Dry period ⁴									
No DP vs. conventional DP	-7.0	0.58	<0.001	-3.4	0.50	<0.001	-3.1	0.51	<0.001
Short DP vs. conventional DP	-2.3	0.51	0.002	-0.9	0.44	0.06	-0.6	0.45	0.22
Yield level ⁵	1.98	0.13	<0.001	1.80	0.11	<0.001	1.67	0.10	<0.001

¹Milk yield in the 60 d before second calving plus the 305-d yield after calving.

²Milk yield from 60 d before second calving until 60 d before next calving.

³Population mean of the conventional DP is the reference in the parameterization.

⁴Short DP = 20 to 40 d; conventional DP = 49 to 90 d.

⁵305-d yield in the first lactation (tonnes of fat- and protein-corrected milk).

from 7.0 to 3.4 kg of FPCM per cow per day (Table 3). Similarly, Schlamberger et al. (2010) found a decrease in 305-d milk yield of 6.1 kg of milk per cow per day when no DP was applied to multiparous Brown Swiss cows, which was reduced to 1.9 kg/cow per day when the 56 d of additional milk yield before calving was taken into account.

Shoshani et al. (2014) concluded that the additional milk yield resulted in a higher milk yield for second-parity cows with a DP length of 40 d as opposed to 60 d. In our study, 365-d milk yield of cows with a short DP (mean: 33.3 d; SD: 5.2 d) was 0.9 kg of FPCM per cow per day less than that of cows with a conventional DP, although some farms had increased 365-d yields (see appendix Table A2). The difference between our findings and the findings from Shoshani et al. (2014) could result from the different “short” DP lengths, as DP <40 d have a more detrimental effect on milk yield after calving (Kuhn et al., 2005).

Effective Lactation Yield. Compared with cows with a conventional DP, median days open were 18 d fewer for cows with a short DP and 25 d fewer for cows with no DP, with a relative ratio of days open (95% CI) of 0.77 (0.67–0.87) for a short DP and 0.83 (0.74–0.94) for no DP ($P < 0.01$). In other studies, mean days open were 52 d fewer after no DP compared with a conventional DP (Gümen et al., 2005), median calving interval tended to be 17 d shorter after a short DP

(Watters et al., 2009), and mean calving interval was 19 d shorter after a short DP (Santschi et al., 2011c). Some studies did not find an effect of DP length on days open or calving interval (Pezeshki et al., 2008; de Feu et al., 2009), but this could be due to the relatively small numbers of cows (61 and 40). Shorter calving intervals when applying a short or no DP could be caused by better energy balance, earlier onset of ovarian cyclicity, and more regular estrus cycles in early lactation (Gümen et al., 2005; de Feu et al., 2009; Watters et al., 2009; Chen et al., 2015).

Switching from 365-d yield to effective lactation yield, thus correcting for shorter calving intervals with a short or no DP, decreased the reduction in milk yield for cows with no DP and a short DP by 0.3 kg of FPCM per cow per day (Table 3). The effective lactation yield was not different between cows with a short and a conventional DP, whereas the effective lactation yield of cows with no DP was 3.1 kg of FPCM per cow per day lower than that of cows with a conventional DP.

Individual and Herd Variation

The effect of changing from a 305-d to a 365-d yield was consistent among herds (Figure 1). Including the additional milk decreased the reduction in milk yield by 3.0 to 4.1 kg of FPCM per cow per day for cows with

Figure 1. Change in reduction in milk yield due to no (no fill) or a short (solid fill) dry period compared with a conventional dry period when switching from a 305-d yield to a 365-d yield (diamonds) and from a 365-d yield to an effective lactation yield (triangles). Farms A to O are represented in alphabetical order from left to right, excluding farms C and J (farms C and J have no conventional dry period with which to compare the effect of no dry period or a short dry period; see Appendix Table A2). FPCM = fat- and protein-corrected milk.

Table 4. Change in predicted¹ 305-d, 365-d, and effective lactation yield (Eff.) for cows with no or a short dry period (DP)² compared with a conventional DP per farm (kg of fat- and protein-corrected milk per cow per day)

Farm	No DP			Short DP		
	305-d	365-d	Eff.	305-d	365-d	Eff.
A	-7.0	-3.6	-3.1	-3.0	-1.5	-0.9
B	-5.5	-1.4	-0.8	-1.6	0.2	1.0
C	—	—	—	—	—	—
D	-6.8	-3.2	-3.1	-3.2	-1.7	-1.6
E	-6.1	-3.0	-2.5	-2.3	-1.1	-0.8
F	-7.6	-4.0	-4.4	-2.7	-1.4	-1.4
G	-8.7	-4.7	-4.5	-2.4	-0.9	-0.8
H	-7.9	-4.2	-3.9	-2.6	-1.1	-0.8
I	-7.6	-3.9	-3.4	-3.2	-1.7	-1.1
J	—	—	—	—	—	—
K	—	—	—	-2.1	-0.6	0.0
L	—	—	—	-2.5	-0.9	-0.8
M	—	—	—	-1.3	0.0	0.2
N	—	—	—	-0.8	0.3	0.5
O	—	—	—	-3.2	-1.6	-1.4

¹Using SAS statements LSMEANS for fixed and ESTIMATE for random effects (version 9.3; SAS Institute Inc., Cary, NC).
²Short DP = 20 to 40 d; conventional DP = 49 to 90 d.

no DP, and by 1.3 to 1.8 kg of FPCM per cow per day for cows with a short DP (Table 4).

The difference between the 365-d yield and the effective lactation yield was small compared with the difference between the 365-d yield and the 305-d yield. One reason for this is that the 365-d yield, by definition, is identical to the effective lactation yield when the calving interval is 365 d, whereas the median calving interval for each DP category is close to this value (359 to 385 d). When individual differences between the 365-d yield and the effective lactation yield are plotted against calving interval, however, the difference between the 2 measures becomes apparent (Figure 2). Assuming that the effective lactation yield accurately reflects actual yield, the 365-d yield overestimates milk yield per day when the calving interval exceeds 365 d, whereas it underestimates milk yield per day when the calving interval is shorter than 365 d. The individual difference between 365-d yield and effective lactation yield ranged from -3.2 to 7.4 kg of FPCM per cow per day.

Figure 2. Individual differences (one dot per cow) between 365-d yield and effective lactation yield plotted against calving interval. FPCM = fat- and protein-corrected milk.

At the herd level, the difference in yield reduction due to no DP or a short DP between the 365-d yield and effective lactation yield ranges from 0.4 to -0.8 kg of FPCM per cow per day (Figure 1). Assuming that the effective lactation yield accurately reflects the actual yield, using the 365-d yield would lead to an underestimation of milk yield of up to (0.784×365) 286 kg of FPCM per cow per year for the entire herd. Figure 3 illustrates that this underestimation of milk yield due to no or a short DP is larger on farms where the calving interval was considerably shortened. For farm B, for example, correcting for a 30-d-shorter calving interval in the case of a short DP reduced milk losses for the effective lactation yield by 0.784 kg of FPCM per cow per day compared with the 365-d yield.

The Dutch mean calving interval for second-parity cows was 413 d in 2013–2014 (CRV, 2014), whereas in the current study, mean calving interval for second-parity cows with a conventional DP was 401 d. Differences between the 365-d yield and the effective lactation yield may therefore be more pronounced for an average Dutch farm, where calving intervals deviate more from 365 d.

365-d Yield Versus Effective Lactation Yield

Conclusions on the effect of DP length on milk yield depend on the measure of milk yield. Both proposed measures of milk yield—the 365-d yield and effective

lactation yield—include the additional milk yield before calving, which had a major effect on milk yield comparisons between cows with different DP lengths. Milk losses due to no DP declined from 23 to 12% by switching from the 305-d yield to the effective lactation yield. This 11 percentage unit difference in estimated milk losses could entirely change the economic prospects of the strategy. For example, labor income of a modeled Dutch dairy farm without milk quotas increased by €23,000 to €40,000 per year when milk losses due to no DP decreased from 23 to 13% (Heeren et al., 2014).

Although comparisons between DP strategies on average were similar for 365-d yield and effective lactation yield, the latter was more accurate for individual animals and when the calving interval was shortened by a short or no DP. Individual yields are required for any analysis that aims to optimize cow-specific DP lengths. Therefore, effective lactation yield seems more suitable when deciding which DP length is optimal for an individual cow or herd.

A disadvantage of the effective lactation yield, however, is that a next (expected) calving is required to approximate the yield of the current effective lactation. If cows are culled based on low milk yield or infertility (Rajala-Schultz and Gröhn, 1999; Brickell and Wathes, 2011), the effective lactation yield may be biased toward cows that have a lower reduction in milk yield after a short or no DP. This potential bias was not evaluated in the current study, in which only completed lactations

Figure 3. Change in reduction in milk yield due to no (no fill) or a short (solid fill) dry period compared with a conventional dry period when switching from a 365-d yield to an effective lactation yield, in relation to the reduction in median calving interval compared with a conventional dry period per herd. FPCM = fat- and protein-corrected milk.

were included. The 365-d yield does not require a next calving, thus culled animals can be evaluated using this measure. Depending on the aim of the study, another option besides exclusion could be to include the final lactation of dairy cows as an effective lactation until the moment of culling (Santschi et al., 2011a).

CONCLUSIONS

We proposed the 365-d yield and the effective lactation yield to compare individual milk yields between cows with different DP lengths. Both measures include the additional milk yield before calving. The effective lactation yield additionally corrects for calving interval, which especially affects milk yield comparisons when calving interval is shortened because of a short or no DP. The effective lactation yield was illustrated for second-parity cows and can now be applied to evaluate the effect of DP length on milk yield over multiple consecutive lactations.

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APPENDIX

Shortening the DP affected level of production and persistency after peak yield, as reflected by parameters a and b of the Wilmink curve, respectively (Table A1). The difference in persistency between DP categories affected the extrapolation of lactations in this study, whereas production level during inter- and extrapolation was determined by the individual cows' milk records and the curve shape only. Persistency after peak lactation, reflected by parameter b , differed slightly between the standard lactation curves of no, short, and conventional DP categories, with values of b of -0.072 , -0.075 , and -0.078 , respectively.

Table A1. Parameter estimates and SE¹ for the Wilmink curve² used as standard lactation curves for cows in parity 1, and additional effects (on a and b) for cows with no ($n = 234$), short ($n = 323$) or conventional ($n = 260$) dry period (DP) lengths in parity 2

Parameter ²	Parity 1		No DP, parity 2		Short DP, ³ parity 2		Conventional DP, ³ parity 2	
	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE
a	33.69	0.36	3.03	0.48	7.83	0.42	10.09	0.45
b	−0.046	0.0012	−0.0261	0.0016	−0.0291	0.0014	−0.0315	0.0015
c	−9.51	0.29						
k	0.0191	0.0012						
s_a^2	56.17	3.12						
s_b^2	0.00065	0.00004						
s_c^2	75.52	4.85						
cov_{ab}	−0.153	0.011						
cov_{bc}	0.138	0.013						
cov_{ac}	−37.36	3.72						
s_e^2	6.75	0.09						

¹Parameters were estimated using PROC NL MIXED; all effects were highly significant (Wald test, 1,631 df, $P < 0.001$).

²Yield (DIM) = $a + b \times \text{DIM} + c \times \exp(-k \times \text{DIM})$; with variance components (s^2) on a , b , and c , and error variance s_e^2 ; and covariance (cov) between parameters a , b , and c .

³Short DP = 20 to 40 d; conventional DP = 49 to 90 d.

Table A2. Estimates¹ for 305-d, 365-d, and effective lactation (Eff.) yields² and median days open (DO) of second-parity cows per dry period (DP) category per farm

Farm	No DP				Short DP ³				Conventional DP ³			
	305-d	365-d	Eff.	DO	305-d	365-d	Eff.	DO	305-d	365-d	Eff.	DO
A	24.6	23.0	22.6	90	28.6	25.1	24.7	92	31.7	26.6	25.6	112
B	27.5	26.2	26.4	77	31.3	27.8	28.1	85	32.9	27.6	27.1	114
C	25.3	23.8	24.1	70	—	—	—	—	—	—	—	—
D	23.0	22.1	21.8	86	26.6	23.6	23.3	90	29.8	25.3	24.9	105
E	23.1	21.4	21.4	77	26.8	23.4	23.1	90	29.1	24.5	23.9	114
F	21.7	20.8	20.2	93	26.5	23.4	23.2	87	29.3	24.8	24.6	93
G	20.8	20.4	20.0	85	27.1	24.2	23.6	94	29.6	25.1	24.4	111
H	22.6	21.6	21.5	82	27.9	24.8	24.6	89	30.6	25.9	25.4	98
I	24.3	22.9	23.1	75	28.7	25.2	25.4	76	31.9	26.8	26.5	96
J	24.9	23.9	24.0	78	30.7	27.2	27.3	81	—	—	—	—
K	—	—	—	—	28.4	24.9	24.5	101	30.5	25.5	24.5	129
L	—	—	—	—	30.2	26.7	26.6	94	32.7	27.6	27.4	106
M	—	—	—	—	25.6	22.7	22.3	91	26.9	22.7	22.1	105
N	—	—	—	—	29.2	25.7	25.0	101	30.0	25.3	24.5	115
O	—	—	—	—	29.4	25.8	25.0	103	32.6	27.5	26.4	122

¹Using SAS statements LSMEANS for fixed and ESTIMATE for random effects (version 9.3; SAS Institute Inc., Cary, NC).²In kilograms of fat- and protein-corrected milk per cow per day.³Short DP = 20 to 40 d; conventional DP = 49 to 90 d.