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Effects of length of dry period on yields of milk fat and protein, fertility and milk somatic cell score in the subsequent lactation of dairy cows

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The objective was to utilize data from modern US dairy cattle to determine the effect of days dry on fat and protein yield, fat and protein percentages, days open, and somatic cell score in the subsequent lactation. Field data collected through the dairy herd improvement association from January 1997 to December 2003 and extracted from the Animal Improvement Programs Laboratory national database were used for analysis. Actual lactation records calculated from test-day yields using the test-interval method were used in this study. The model for analyses included herd-year of calving, year-state-month of calving, previous lactation record, age at calving, and days dry as a categorical variable. Fat and protein yield was maximized in the subsequent lactation with a 60-d dry period. Dry periods of 20 d or less resulted in substantial losses in fat and protein yield in the subsequent lactation. In contrast to yields, a short dry period was beneficial for fat and protein percentages. Short dry periods also resulted in fewer days open in the subsequent lactation; however, this was entirely due to the lower milk yield associated with shortened dry period. When adjusted for milk yield, short dry periods actually resulted in poorer fertility in the subsequent lactation. Long days dry improved somatic cell score in the subsequent lactation. Herds with mastitis problems should be cautious in shortening days dry because short dry periods led to higher cell scores in the subsequent lactation compared with 60-d dry.

Keywords: Days dry, yield traits, fertility, somatic cell score.

Optimum length of the dry period has been a topic of interest for many years, with recorded debate beginning as early as 1805 (Grummer & Rastani, 2004). During recent years there has been a renewed interest in dry period length, perhaps partly because of an ever increasing need for dairy farmers to maximize their income on investment. In the USA, costs of production have risen dramatically while farm milk price has remained basically flat (National Agricultural Statistics Service, 2004). Furthermore, much of the research on dry period length is at least 20 years old, and cows have certainly changed genetically over the last 20 years (Animal Improvement Programs Laboratory, 2005), as have management practices. Increased potential for milk yield may have made cows more tolerant of shorter dry periods. Conversely, higher production may also result in a demand for a longer rest period in order to maintain production, health and fertility in the subsequent lactation. The effect of variation in dry period length on subsequent lactation performance, for modern day dairy cattle, is largely unknown and warrants re-evaluation.

Considerable research has been done regarding the effect of days dry (DD) on subsequent lactation milk yield but far less research is available on the effects for other economically important traits such as milk components or fertility. Several recent studies (e.g., Gulay et al. 2003; Annen et al. 2004; Rastani et al. 2005) considered effects of DD on fat, protein and somatic cell score (SCS). However, all of these studies were based on small numbers of cows and, although collectively such studies can be informative if enough of them are conducted, individually they lack adequate power to be conclusive (Kuhn & Hutchison, 2005). Furthermore, of the studies that have examined DD effects on fat and protein yield, all have reported results in terms of either yield/d for partial lactations or in terms of 305-d, mature-equivalent lactational yield. Recent research has shown, however, that DD

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has larger effects on actual lactational milk yield than on records standardized to a 305-d basis; the very standardization of records to a common lactation length (305 d) and mature-equivalent basis, in effect conceals variation in production caused by DD partly because of DD effects on DIM and culling in the subsequent lactation (Kuhn et al. 2005b). Given the high phenotypic correlation of milk yield with both fat and protein yield (Welper & Freeman, 1992), it is likely that actual lactational records would be more informative for fat and protein yield as well. Since dairy producers are paid for actual yield rather than standardized yields, effects of DD on actual yields should be ascertained. Information on the effects of DD on fertility in the subsequent lactation is quite sparse and appears to be limited primarily to cursory examination by Schaeffer & Henderson (1972), and Rémond et al. (1992). Thus, investigation of the effects of DD on milk components and fertility, using extensive data, is warranted.

The objective of this research was to utilize data from modern day dairy cattle to determine the effect, in the subsequent lactation, of DD on actual fat and protein yield, fat and protein percent, days open (DO) as a measure of fertility, and SCS (defined as $\log_2$(somatic cell count/100 000)+3, where somatic cell count is the number of somatic cells/ml of milk). Analyses were done separately for parities 2–4 inclusive to determine whether DD effects differed by lactation.

Materials and Methods

Data

Field data collected through dairy herd improvement association (DHI) and extracted from the Animal Improvement Programs Laboratory national database were used for analysis. Actual lactation records were used in this study because 305-d records can conceal variation caused by DD if, for example, short dry periods led to earlier culling or dry off in the subsequent lactation (Kuhn et al. 2005b). The only standardization done was to a twice-daily milking basis for fat and protein yields. Records less than 305 d were not extended to 305 d and all production beyond 305 d was included. The only restriction put on length of lactation was that lactations >2 years long were deleted. For herds on a supervised DHI testing programme in the USA, a DHI technician visits enrolled herds approximately once a month (the so-called 'test-day') to collect a milk weight and milk sample (for determination of fat and protein percentage and SCS) for each lactating cow. Actual lactational fat and protein yields were calculated from these test-day fat and protein records using the test-interval method (Sargent et al. 1968) and the adjustment factors of Shook et al. (1980).

The national database at Animal Improvement Programs Laboratory contains calving date and total days in milk (DIM) for each lactation. Thus, DD was calculated as calving interval minus total DIM in the previous lactation. As an example, if a cow initiated her first lactation on 1 January 2000 and calved the second time on 1 January 2001 (a 365-d calving interval) and her total DIM in first lactation was 320, then she had DD=365−320=45.

Only data for US Holstein cows first calving on or after 1 January 1997 were included for analysis because complete lactation information was not kept prior to 1997. Records were also required to be initiated no later than 31 December 2002. Herds were required to be on test for the entire period from January 1997 to December 2003. Herds needed to be on test throughout 2003 in order to ensure nearly complete information for cows that initiated their records in late 2002. Finally, in regard to herd edits, the date at which complete lactation information was available varied somewhat across dairy record processing centres because not all centres began sending complete lactation information at the same time. Thus, the January 1997 lower limit for date of inclusion had to be moved forward for some herds. This change in edit affected herds in the western US the most.

Records initiated by abortion were excluded as well as cows known to be embryo transfer donors because these two factors could lead to dry periods or lactations of abnormal length. Cows were required to have 0–120 DD; records where DD was >120 d were deleted. Cows with dry periods >120 d constituted only about 3% of the original, unedited data and over half of that 3% had DD ⩽150 d. Preliminary analyses included lactations with DD up to 150 d and this made no difference in the results, compared with an upper limit of only 120 d.

Another important edit was that the expected calving date, based on last reported DO, and the actual calving date had to agree within 10 d. Some researchers (Bachman & Schairer, 2003; Rastani et al. 2005) have argued that analyses using DHI data are biased because the short dry periods included are primarily those that are unplanned and if the cow had a known calving date, she would have been managed differently for the short DD. This edit ensured that the producers knew when the cow was going to calve because, in effect, they reported it to DHI.

Categories for DD were formed for analysis. The 16 categories used for analysis are defined in Table 1 along with the number of records in each category for fat and protein yields, DO and SCS for each parity. Categories with small intervals are most desirable because they portray the most information in regard to response to increasing or decreasing DD. However, both short and long dry periods were less frequent than more mid-range dry period lengths. Therefore, 10-d intervals were used for DD <31 and DD >65, so as to maintain reasonable sample sizes, and 5-d intervals were used for dry periods between 31 and 65 d. After edits, there were, for example, 299 568 second lactation fat yield records (Table 1) from 3543 herds in 42 states. Arithmetic means for each trait, by parity, are in Table 2.

Table 1. Days dry (DD) categories and corresponding dry period lengths with sample sizes for fat and protein yield, days open, and somatic cell score (SCS) for each parity

DD category	DD	Fat			Protein			Days Open			SCS		
		Parity 2	Parity 3	Parity 4	Parity 2	Parity 3	Parity 4	Parity 2	Parity 3	Parity 4	Parity 2	Parity 3	Parity 4
1	0–10	1551	418	149	1551	418	149	1110	280	95	1591	427	156
2	11–20	1201	271	84	1200	271	84	988	216	57	1169	271	81
3	21–30	3538	938	348	3538	938	348	3301	836	302	3481	906	346
4	31–35	4322	1258	412	4322	1258	412	4204	1209	383	4267	1237	409
5	36–40	8606	2904	1002	8604	2904	1002	8589	2785	918	8556	2878	980
6	41–45	17 574	6285	2144	17 566	6284	2144	18 082	6166	2017	17 852	6299	2169
7	46–50	34 333	12 557	4355	34 271	12 550	4355	36 104	12 686	4208	35 816	12 991	4400
8	51–55	56 544	21 675	7291	56 452	21 666	7291	60 785	22 472	7182	60 542	22 875	7639
9	56–60	66 506	26 338	9141	66 407	26 328	9142	71 889	27 623	9142	71 778	28 284	9693
10	61–65	49 367	20 943	7356	49 260	20 935	7357	53 649	22 032	7379	53 600	22 533	7827
11	66–70	24 062	11 443	4177	23 997	11 435	4178	26 175	11 924	4176	26 218	12 316	4463
12	71–80	15 821	9491	3679	15 791	9483	3679	16 694	9655	3594	16 835	10 054	3869
13	81–90	6957	5473	2235	6949	5473	2235	7111	5495	2143	7319	5733	2317
14	91–100	4297	3798	1482	4295	3796	1482	4429	3751	1412	4586	3959	1558
15	101–110	2830	2691	952	2827	2691	952	2989	2668	907	3070	2814	1003
16	111–120	2059	1803	659	2054	1802	659	2177	1860	639	2245	1941	699
	Total	299 568	128 286	45 466	299 084	128 232	45 469	318 276	131 658	44 554	318 925	135 518	47 609

Table 2. Arithmetic means for fat and protein yield (kg), fat and protein percent, days open (DO) and somatic cell score (SCS)

Trait	Parity 2	Parity 3	Parity 4
Fat	395	405	403
Protein	329	332	328
Fat %	3·56	3·58	3·59
Protein %	2·96	2·92	2·91
DO	148	146	147
SCS	2·93	3·28	3·55

Model for analysis

The three-step approach of Kuhn & Hutchison (2005) was used for the analysis of each trait. This approach was: (1) estimation of cow effects from an animal model, (2) prior correction of records for cow effects and (3) estimation of DD effects from a model that included the previous lactation record. Kuhn et al. (2005a) found that DD correlated with previous lactation fat and protein percent, DO, SCS, and milk yield. The correlation with milk yield implies a correlation with fat and protein yield as well. If not accounted for, these correlations can cause bias in estimates of DD effects (Kuhn & Hutchison, 2005). However, Kuhn & Hutchison (2005) showed that the above approach estimates DD effects without bias by cow effects, in spite of correlations with previous lactation records (PrevLR). An animal model estimates, and thereby adjusts for, the permanent, inherent effects particular to an individual cow including both genetic and non-genetic effects.

The linear, fixed effects model used for analysis of each trait was:

$$y^* = HY + YR\text{-}ST\text{-}MO + \beta_1{*}\text{PrevLR} + \beta_2{*}\text{Age} + \beta_3{*}\text{Age}^2 + \text{DD} + \text{e}, \quad (1)$$

where y* was fat yield, protein yield, fat percent, protein percent, DO, or SCS records, corrected for cow effects, HY was herd-year of calving, YR-ST-MO was year-state-month of calving, Age was age at calving, DD was a categorical variable for dry period length, defined in Table 1, and β_1, β_2, and β_3 were regression coefficients. Herd-year was used, instead of HY-season, to avoid small group sizes. Month was added to the model to account for season effects. Month effects were allowed to differ by state as well as year, hence YR-ST-MO. Separate analyses were done two to four inclusive to determine length results differed by lactation. Preliminary analyses for fat and protein yield included current DO in the model but it had little effect on differences between DD categories and so was not included in the final model for analysis.

For estimation of cow effects, additive genetic and permanent environmental effects were added to equation [1] and PrevLR was dropped from the model. Multiple trait models were used for estimation of cow effects to increase accuracy of estimates, relative to a single trait model. For fat and protein yield, cow effects were estimated from a three-trait model which included milk yield, in addition to fat and protein yields. Two-trait models were used to estimate cow effects for the remaining traits; fat and protein percent were analysed together and DO and SCS were each analysed simultaneously with milk yield. Cows were required to have a first lactation but were not required to have a second or later lactation for estimation

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Table 3. Days dry (DD) effects on the yield of milk fat

DD category[2]	DD	Fat[1], kg Parity 2	Parity 3	Parity 4
1	0–10	−76±2·5[3]	−73±5·3[3]	−61±10·4[3]
2	11–20	−72±2·8[3]	−67±6·5[3]	−64±14·5[3]
3	21–30	−46±1·7[3]	−48±7·8[3]	−36±6·8[3]
4	31–35	−32±1·5[3]	−29±3·1[3]	−20±6·2[4]
5	36–40	−23±1·1[3]	−23±2·1[3]	−20±4·1[3]
6	41–45	−16±0·9[3]	−16±1·5[3]	−12±3·0[4]
7	46–50	−10±0·7[3]	−12±1·2[3]	−12±2·3[3]
8	51–55	−7±0·6[3]	−6±1·0[3]	−4±1·9[5]
9	56–60	−3±0·5[3]	−2±0·9[5]	−1±1·8[7]
10	61–65	0	0	0
11	66–70	1±0·7[7]	−4±1·2[4]	2±2·2[7]
12	71–80	−7±0·9[3]	−8±1·3[3]	−5±2·4[5]
13	81–90	−10±1·2[3]	−11±1·6[3]	−4±2·8[7]
14	91–100	−15±1·5[3]	−10±1·8[3]	−6±3·3[6]
15	101–110	−8±1·8[3]	−8±2·1[4]	−2±4·0[7]
16	111–120	−12±2·1[3]	−5±2·5[5]	−11±4·8[5]

[1] Difference in fat (kg): days dry category i minus days dry category 10±SED where $i=1$ to 16; P values correspond to a two-tailed t test for the null hypothesis of no difference between category i and category 10
[2] Categories 1 to 3 inclusive and 11 to 16 inclusive are in 10-d intervals; all other categories are in 5-d intervals
[3] $P \leqslant 0{\cdot}00001$
[4] $0{\cdot}00006 \leqslant P \leqslant 0{\cdot}0015$
[5] $0{\cdot}01 \leqslant P \leqslant 0{\cdot}05$
[6] $0{\cdot}05 \leqslant P \leqslant 0{\cdot}1$
[7] $0{\cdot}1 < P$

Table 4. Days dry (DD) effects on the yield of milk protein

DD category[2]	DD	Protein[1], kg Parity 2	Parity 3	Parity 4
1	0–10	−59±2·1[3]	−57±4·3[3]	−54±8·5[3]
2	11–20	−56±2·3[3]	−50±5·4[3]	−45±11·8[4]
3	21–30	−34±1·4[3]	−36±2·9[3]	−25±5·6[3]
4	31–35	−23±1·3[3]	−22±2·5[3]	−11±5·1[5]
5	36–40	−17±0·9[3]	−17±1·7[3]	−14±3·4[4]
6	41–45	−11±0·7[3]	−11±1·3[3]	−8±2·4[4]
7	46–50	−7±0·6[3]	−8±1·0[3]	−9±1·9[3]
8	51–55	−5±0·5[3]	−4±0·8[3]	−2±1·6[7]
9	56–60	−2±0·5[4]	−2±0·8[5]	0±1·5[7]
10	61–65	0	0	0
11	66–70	0±0·6[7]	−4±1·0[4]	1±1·8[7]
12	71–80	−7±0·7[3]	−8±1·0[3]	−6±1·9[4]
13	81–90	−11±1·0[3]	−12±1·3[3]	−6±2·3[4]
14	91–100	−15±1·2[3]	−11±1·5[3]	−9±2·7[4]
15	101–110	−10±1·5[3]	−9±1·7[3]	−4±3·3[7]
16	111–120	−13±1·8[3]	−7±2·1[4]	−14±3·9[4]

[1] Difference in protein (kg): days dry category i minus days dry category 10±SED where $i=1$ to 16; P values correspond to a two-tailed t test for the null hypothesis of no difference between category i and category 10
[2] Categories 1 to 3 inclusive and 11 to 16 inclusive are in 10-d intervals; all other categories are in 5-d intervals
[3] $P \leqslant 0{\cdot}00001$
[4] $0{\cdot}00004 \leqslant P \leqslant 0{\cdot}0015$
[5] $0{\cdot}01 \leqslant P \leqslant 0{\cdot}05$
[6] $0{\cdot}05 \leqslant P \leqslant 0{\cdot}1$
[7] $0{\cdot}1 < P$

of cow effects. Following the approach of Kuhn & Hutchison (2005), lactation one records were given their own unique DD category for estimation of cow effects.

An additional analysis for DO was done to determine the direct effect of DD on fertility, independent of milk yield. The linear and quadratic effects of subsequent (or current) lactational milk yield were added to model [1] for this analysis.

Results and Discussion

Effects of DD (Tables 3–9) are expressed relative to category ten; i.e., as category i minus category ten, for $i=1$ to 16. As an example of interpretation, the −76 kg for DD category one in second lactation for fat yield (Table 3) means that cows with 0 to 10 DD produce 76 kg less fat than cows given a 61–65-d dry period.

Fat and protein yield

Results for fat and protein yields, Tables 3 and 4, were very similar and followed the same pattern as that reported by Kuhn et al. (2005b) for milk yield. Effects of DD on yield were, for the most part, consistent across lactations, although dry periods of <20 d were somewhat more detrimental to second lactation fat and protein yield than for later lactations. Fat and protein yields in the subsequent lactation were generally maximized with a 61–65-d dry period, regardless of parity.

All dry periods of 60 d or less resulted in a loss of production in the subsequent lactation, except for 56–60 DD for protein yield in parity four, which showed no difference. Dry periods of 20 d or less were severely, and by far the most, detrimental. Cows with 10 or fewer DD produced 76 kg less fat and 59 kg less protein in second lactation than cows with 61–65 DD. For lactation two, moving from a dry period of 10 d or less to a dry period of 11–20 d increased fat and protein yield by only 4 kg and 3 kg, respectively, whereas moving to 21–30 DD increased fat and protein yield by 26 kg and 22 kg, respectively. Thereafter, fat and protein yield increased, with increasing DD, at a decreasing rate, although another large increase in fat and protein yields occurred when DD increased to 31–40 DD; fat increased by 24 kg with this 10-d increase in DD and protein increased by 17 kg. However, moving from 31–40 DD to 41–50 DD, for example, increased fat and protein yields by only 12 kg and 10 kg, respectively in the second lactation.

Although 60–65 d maximized yields in the subsequent lactation, losses with dry periods of at least 45 d were fairly minor and might be easily offset by the yield gained in the previous lactation. Cows in their second lactation with 46–50 DD, for example, produced only 10 kg and

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Table 5. Days dry (DD) effects on the concentration of milk fat (%)

DD category[2]	DD	Fat[1], % Parity 2	Parity 3	Parity 4
1	0–10	0·13±0·005[3]	0·07±0·012[3]	0·09±0·023[4]
2	11–20	0·11±0·006[3]	0·07±0·014[3]	0·01±0·032[7]
3	21–30	0·06±0·004[3]	0·03±0·008[4]	0·02±0·015[7]
4	31–35	0·04±0·003[3]	0·03±0·007[4]	0·01±0·014[7]
5	36–40	0·04±0·002[3]	0·03±0·005[3]	0·03±0·009[4]
6	41–45	0·03±0·002[3]	0·01±0·003[4]	0·02±0·007[4]
7	46–50	0·02±0·001[3]	0·01±0·003[4]	0·02±0·005[4]
8	51–55	0·01±0·001[3]	0·01±0·002[3]	0·02±0·004[3]
9	56–60	0·01±0·001[3]	0·00±0·002[7]	0·00±0·004[7]
10	61–65	0	0	0
11	66–70	0·00±0·002[7]	0·00±0·003[7]	0·00±0·005[7]
12	71–80	0·00±0·002[7]	0·00±0·003[7]	0·01±0·005[5]
13	81–90	0·00±0·003[7]	0·00±0·003[7]	0·01±0·006[6]
14	91–100	−0·01±0·003[4]	0·00±0·004[7]	0·02±0·007[4]
15	101–110	0·00±0·004[7]	0·01±0·005[5]	0·02±0·009[5]
16	111–120	0·00±0·004[7]	0·01±0·006[6]	0·02±0·011[6]

[1] Difference in fat %: days dry category *i* minus days dry category 10±SED where *i*=1 to 16; *P* values correspond to a two-tailed *t* test for the null hypothesis of no difference between category *i* and category 10
[2] Categories 1 to 3 inclusive and 11 to 16 inclusive are in 10-d intervals; all other categories are in 5-d intervals
[3] $P \leqslant 0·00001$
[4] $0·00006 \leqslant P \leqslant 0·005$
[5] $0·01 \leqslant P \leqslant 0·05$
[6] $0·05 \leqslant P \leqslant 0·1$
[7] $0·1 < P$

Table 6. Days dry (DD) effects on the concentration of milk protein (%)

DD category[2]	DD	Protein[1], % Parity 2	Parity 3	Parity 4
1	0–10	0·16±0·002[3]	0·12±0·005[3]	0·08±0·010[3]
2	11–20	0·14±0·003[3]	0·11±0·006[3]	0·10±0·014[3]
3	21–30	0·10±0·002[3]	0·07±0·003[3]	0·08±0·007[3]
4	31–35	0·06±0·001[3]	0·05±0·003[3]	0·06±0·006[3]
5	36–40	0·06±0·001[3]	0·05±0·002[3]	0·05±0·004[3]
6	41–45	0·04±0·001[3]	0·04±0·001[3]	0·04±0·003[3]
7	46–50	0·03±0·001[3]	0·03±0·001[3]	0·03±0·002[3]
8	51–55	0·02±0·001[3]	0·02±0·001[3]	0·02±0·002[3]
9	56–60	0·01±0·001[3]	0·01±0·001[3]	0·01±0·002[3]
10	61–65	0	0	0
11	66–70	−0·01±0·001[3]	−0·01±0·001[3]	−0·01±0·002[3]
12	71–80	−0·02±0·001[3]	−0·02±0·001[3]	−0·02±0·002[3]
13	81–90	−0·03±0·001[3]	−0·02±0·001[3]	−0·02±0·003[3]
14	91–100	−0·03±0·001[3]	−0·02±0·002[3]	−0·03±0·003[3]
15	101–110	−0·03±0·002[3]	−0·02±0·002[3]	−0·01±0·004[4]
16	111–120	−0·03±0·002[3]	−0·03±0·002[3]	−0·03±0·005[3]

[1] Difference in protein %: days dry category *i* minus days dry category 10±SED where *i*=1 to 16; *P* values correspond to a two-tailed *t* test for the null hypothesis of no difference between category *i* and category 10
[2] Categories 1 to 3 inclusive and 11 to 16 inclusive are in 10-d intervals; all other categories are in 5-d intervals
[3] $P \leqslant 0·00001$
[4] $0·01 \leqslant P \leqslant 0·05$

7 kg less fat and protein, respectively, than cows with dry periods of 60–65 d. Considering a 60-d *v.* 45-d dry period, if a cow averaged 0·67 kg/d and 0·47 kg/d of fat and protein, respectively, during the last 15 d of lactation, the additional 10 kg and 7 kg of fat and protein from first lactation would offset the loss in the subsequent lactation.

These results agreed well with those of Sorensen & Enevoldsen (1991) who reported a loss of fat and protein

Table 7. Days dry (DD) effects on days open

DD category[2]	DD	Days Open[1] Parity 2	Parity 3	Parity 4
1	0–10	−14±2·2[3]	−5±4·5[7]	−17±8·4[5]
2	11–20	−16±2·3[3]	−12±5·1[5]	−1±11·7[7]
3	21–30	−10±1·3[3]	−8±2·6[4]	0±4·8[7]
4	31–35	−7±1·2[3]	−7±2·2[4]	−3±4·3[7]
5	36–40	−5±0·9[3]	−6±1·5[4]	3±2·8[7]
6	41–45	−4±0·6[3]	−2±1·1[6]	1±2·0[7]
7	46–50	−2±0·5[4]	−2±0·8[5]	−2±1·5[7]
8	51–55	−2±0·4[3]	−1±0·7[7]	0±1·3[7]
9	56–60	−1±0·4[5]	−1±0·6[6]	2±1·2[6]
10	61–65	0	0	0
11	66–70	0±0·5[7]	−2±0·8[5]	3±1·4[5]
12	71–80	0±0·6[7]	−1±0·9[7]	2±1·6[7]
13	81–90	0±0·9[7]	−2±1·1[6]	4±1·9[5]
14	91–100	−2±1·1[6]	−2±1·3[7]	−1±2·2[7]
15	101–110	−1±1·3[7]	−2±1·5[7]	1±2·7[7]
16	111–120	−2±1·5[7]	−3±1·7[6]	−4±3·2[7]

[1] Difference in days open: days dry category *i* minus days dry category 10±SED where *i*=1 to 16; *P* values correspond to a two-tailed *t* test for the null hypothesis of no difference between category *i* and category 10
[2] Categories 1 to 3 inclusive and 11 to 16 inclusive are in 10-d intervals; all other categories are in 5-d intervals
[3] $P \leqslant 0{\cdot}00001$
[4] $0{\cdot}00006 \leqslant P \leqslant 0{\cdot}005$
[5] $0{\cdot}01 \leqslant P \leqslant 0{\cdot}05$
[6] $0{\cdot}05 \leqslant P \leqslant 0{\cdot}1$
[7] $0{\cdot}1 < P$

Table 8. Days dry (DD) effects on days open adjusted for milk yield

DD category[2]	DD	Days Open[1] Parity 2	Parity 3	Parity 4
1	0–10	14±1·7[3]	14±3·6[4]	2±6·7[7]
2	11–20	11±1·8[3]	10±4·1[5]	12±9·3[7]
3	21–30	8±1·0[3]	7±2·1[4]	12±3·8[4]
4	31–35	5±0·9[3]	4±1·7[5]	4±3·4[7]
5	36–40	4±0·7[3]	2±1·2[6]	9±2·2[4]
6	41–45	3±0·5[3]	2±0·8[5]	4±1·6[5]
7	46–50	2±0·4[3]	1±0·6[6]	2±1·2[6]
8	51–55	1±0·3[4]	1±0·5[6]	1±1·0[7]
9	56–60	0±0·3[7]	0±0·5[7]	1±0·9[7]
10	61–65	0	0	0
11	66–70	0±0·4[7]	1±0·6[6]	3±1·1[4]
12	71–80	3±0·5[3]	4±0·7[3]	5±1·2[4]
13	81–90	5±0·7[3]	5±0·9[3]	9±1·5[3]
14	91–100	5±0·8[3]	5±1·0[3]	4±1·8[5]
15	101–110	6±1·0[3]	6±1·2[3]	6±2·1[4]
16	111–120	5±1·2[4]	4±1·4[4]	4±2·5[7]

[1] Difference in days open: days dry category *i* minus days dry category 10±SED where *i*=1 to 16; *P* values correspond to a two-tailed *t* test for the null hypothesis of no difference between category *i* and category 10
[2] Categories 1 to 3 inclusive and 11 to 16 inclusive are in 10-d intervals; all other categories are in 5-d intervals
[3] $P \leqslant 0{\cdot}00001$
[4] $0{\cdot}00006 \leqslant P \leqslant 0{\cdot}007$
[5] $0{\cdot}01 \leqslant P \leqslant 0{\cdot}05$
[6] $0{\cdot}05 \leqslant P \leqslant 0{\cdot}1$
[7] $0{\cdot}1 < P$

yield for a 30-d dry period treatment when compared with a 50-d treatment. Sorensen & Enevoldsen (1991) also found virtually no difference between a DD of 50 and 70, which is similar to the results in this study. There was little difference between DD categories 8 and 12 for both fat and protein yield.

Cows with 20 or fewer DD averaged 329 DIM in this study. Thus, the results in Tables 3 and 4 imply losses of 0·22 kg/d for fat and 0·17 kg/d for dry periods of <21 d, compared with dry periods of 61–65 d, which are similar to the losses reported by Rastani et al. (2005) for 0 *v.* 56 DD. Cows in this study with dry periods between 21 d and 80 d averaged 345 DIM, implying daily losses of 0·09 kg fat/d and 0·07 kg protein/d for dry periods of 31–35 d, compared with DD of 61–65 d. These are slightly higher than those reported by Rastani et al. (2005), but they reported on production only through the first 70 d of production.

There were also losses in both fat and protein yield associated with long dry periods, although these losses were not as large as those for short DD. Lower yields associated with dry periods >60 d were not due to poorer cows receiving longer dry periods more often than higher producing cows, because cow effects were adjusted for in this study. Kuhn & Hutchison (2005) clearly showed that, with the methodology used in the present study, all dry period categories are estimated without bias from cow effects, even when lower producing cows receive longer dry periods. Kuhn et al. (2005b) also found lower milk yield for DD >70. Higher body condition score has been associated with lower lactational milk yield (Waltner et al. 1993; Dechow et al. 2002). Thus, a possible explanation would be that cows gain too much weight during these long dry periods, which then leads to the lower yields observed.

A possible point of interest in this study is the extent of usage of bovine somatotropin (bST) amongst herds included in this research. Which cows received bST was unknown, however, and therefore could not be included in the model. Monsanto (2005) estimates that about 35% of US dairy cows receive some bST treatment and a similar frequency could probably be assumed for the data used in this study. There are two main points in regard to bST and the results obtained in this research. First, if bST was used uniformly within a herd, it would cause no bias in the estimates of DD effects because the bST effect would be completely partitioned into the herd effect. Secondly, if bST was used in conjunction with shortened dry periods, in an attempt to mitigate the (negative) effects on subsequent lactation yield, then this would mean that the estimates in Tables 3 and 4 for dry periods of <60 d are underestimates. This is relevant because the recent interest in dry period length (Bachman & Schairer, 2003; Gulay

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Table 9. Days dry (DD) effects on lactational somatic cell score (SCS)

DD category[2]	DD	SCS[1] Parity 2	Parity 3	Parity 4
1	0–10	0·18 ± 0·03[3]	0·20 ± 0·06[4]	0·00 ± 0·12[7]
2	11–20	0·10 ± 0·03[4]	0·02 ± 0·07[7]	0·18 ± 0·17[7]
3	21–30	0·07 ± 0·02[4]	0·10 ± 0·04[5]	0·12 ± 0·08[7]
4	31–35	0·05 ± 0·02[5]	0·07 ± 0·03[5]	0·02 ± 0·07[7]
5	36–40	0·02 ± 0·01[5]	0·05 ± 0·02[5]	0·10 ± 0·05[5]
6	41–45	0·02 ± 0·01[5]	0·06 ± 0·02[4]	0·16 ± 0·03[3]
7	46–50	0·02 ± 0·01[5]	0·05 ± 0·01[3]	0·09 ± 0·03[4]
8	51–55	0·01 ± 0·01[7]	0·03 ± 0·01[4]	0·05 ± 0·02[5]
9	56–60	0·00 ± 0·01[7]	0·02 ± 0·01[5]	0·03 ± 0·02[7]
10	61–65	0	0	0
11	66–70	−0·03 ± 0·01[4]	0·00 ± 0·01[7]	0·00 ± 0·02[7]
12	71–80	−0·01 ± 0·01[7]	−0·04 ± 0·01[4]	−0·05 ± 0·03[6]
13	81–90	−0·04 ± 0·01[4]	−0·07 ± 0·02[4]	−0·09 ± 0·03[4]
14	91–100	−0·06 ± 0·02[4]	−0·07 ± 0·02[4]	−0·07 ± 0·04[6]
15	101–110	−0·01 ± 0·02[7]	−0·05 ± 0·02[5]	−0·15 ± 0·04[4]
16	111–120	−0·06 ± 0·02[4]	−0·13 ± 0·03[3]	−0·09 ± 0·05[6]

[1] Difference in SCS: days dry category i minus days dry category 10 ± SED where i = 1 to 16; P values correspond to a two-tailed t test for the null hypothesis of no difference between category i and category 10
[2] Categories 1 to 3 inclusive and 11 to 16 inclusive are in 10-d intervals; all other categories are in 5-d intervals
[3] $P \leqslant 0{\cdot}00001$
[4] $0{\cdot}00006 \leqslant P \leqslant 0{\cdot}005$
[5] $0{\cdot}01 \leqslant P \leqslant 0{\cdot}05$
[6] $0{\cdot}05 \leqslant P \leqslant 0{\cdot}1$
[7] $0{\cdot}1 < P$

et al. 2003; Annen et al. 2004; Grummer & Rastani, 2004; Rastani et al. 2005) has focused primarily on whether dry periods can be shortened without severe consequences in the subsequent lactation. The answer from Tables 3 and 4 is already clearly, no: DD certainly cannot be shortened to <30 d or even 40 d without considerable losses in production. If bST was used in some herds that also utilized shortened dry periods, this would only add even greater emphasis to the answer of no to this general question.

Conversely, there might be concern that bST usage was confounded with average or moderate dry period lengths (e.g. 50–60 DD) which would exaggerate negative consequences of shortened DD. It is emphasized, however, that such a bias could only occur if bST was not used uniformly within a herd. In particular, for this bias to occur farmers would have to use bST intentionally on cows with, say, 60 DD and not use it on cows with fewer DD. It is unlikely that this would actually occur, however, because such a practice would be counterproductive: it would mean withholding bST from the cows that would benefit from it the most (cows with shorter DD) while giving it to the cows that would benefit less (cows with 50–60 DD). Furthermore, the general agreement of the results for production between this study and designed trials also suggests that such a bias did not occur. This further emphasizes the usefulness and complementarity of studies based on field data and designed trials: observational studies have much greater statistical power and accuracy of estimates but lack control over some unknown variables; designed trials generally lack power and accuracy but have more control over some extraneous variables and thereby provide confirmation for results found in observational studies.

Fat and protein concentration

Days dry effects on fat and protein percent (Tables 5 and 6) were fairly consistent across lactations. In contrast to yields, shorter dry periods favour higher percentages. Cows with ten or fewer DD had 0·13 percentage units higher fat and 0·16 percentage units higher protein in the second lactation than cows with 61–65 DD. These advantages in milk concentrations decreased as dry period length increased.

Although results for the two percentages were similar, DD does appear to have a somewhat larger effect on protein content than on fat content. Overall, fat percent declined up to 61–65 DD, then remained fairly constant for longer DD. Protein percent also decreased up to 61–65 d but, in contrast to fat percent, was also lower for dry periods >65 d.

Numerous studies found that milk yield increases as DD increases up to 60 d (Bachman & Schairer, 2003; Grummer & Rastani, 2004; Kuhn et al 2005b; Rastani et al. 2005). Given the negative correlation between percentages and milk yield (Welper & Freeman, 1992), the higher percentages associated with shorter DD would be expected. However, in a supplemental analysis that included subsequent lactation milk yield as a covariate for fat and protein percent in model [1], estimates of DD effects were nearly identical to those in Tables 5 and 6. Thus, the effect of DD on percentages appears to be independent of effects on milk yield.

Rémond et al. (1992) also found higher protein percent for cows with no dry period compared with cows with 60 DD, as did Rastani et al (2005). In general, Annen et al. (2004) also found higher fat and protein percentages with fewer DD, but only for second lactation cows; there was no clear pattern for higher parity cows. It should be noted, however, that Annen et al. (2004) utilized bST in all treatment groups, which may have affected results for all traits since milk yield loss, generally associated with fewer DD, might have been mitigated by the use of bST in their study. Madsen et al. (2004) found very similar results to those in the present study: higher fat and protein percentage with no dry period *v.* a 7-week dry period and a larger effect on protein than on fat. In contrast to the results of this study, Gulay et al. (2003) found a 0·06 higher fat percent for 60 DD compared with a 30-d dry period treatment during the first 10 weeks of lactation. However, they also reported a 0·11 lower protein percent for the 60-d dry treatment compared with the 30-d dry treatment

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during the first 10 weeks of lactation, which is consistent, at least in direction, with the results of the present study. Variation among results is expected when sample sizes are small (Kuhn & Hutchison, 2005) as it was in the designed trials just discussed. Nonetheless, the general result of lower fat and protein yield but higher fat and protein percentages has been fairly consistent across studies.

Days open

Results for DO (Table 7) indicate that short dry periods actually favour fertility. Dry periods of 30 d or less resulted in considerably fewer DO in the subsequent lactation. Cows with 0–10 DD, for example, had 14 fewer DO than cows with 61–65 DD. However, as indicated in Table 8, this advantage was due entirely to the lower milk yield associated with short dry periods. When DO is adjusted for milk yield, short DD actually resulted in poorer fertility in the subsequent lactation. Thus, while the net effect of short dry periods on DO is beneficial, the direct effect is detrimental. After adjusting for milk yield, cows with 0–10 DD, for example, had 14 more DO than cows with 61–65 DD. From Tables 7 and 8 it can be seen that DO did not change markedly after a minimum of 40 DD. Adjustment for level of milk yield (Table 8) also indicated that cows with long DD had slightly longer DO than cows with 61–65 DD, although the difference was much less than for short DD.

There is very little published research on the effect of DD on DO for comparison. Rémond et al. (1992) commented that the number of cows pregnant after second service was similar for their two groups of cows (0 *v.* 60 DD) but sample sizes were very small. Schaeffer & Henderson (1972) took a cursory look at this relationship. Based on phenotypic correlations of 0·01, −0·05, and −0·03 for second, third and later lactations, they concluded there was no relationship between DD and DO. The linear correlations, however, would not necessarily detect a relationship if that relationship was quadratic in nature. Moreover, mean DO ranged only from 99 d to 101 d across parities in their data. Mean DO has certainly increased since then (VanRaden et al. 2004) and perhaps its relationship with DD has changed as well.

Somatic Cell Score

Results for SCS are in Table 9. Effects of DD on SCS were consistent across lactations although, owing to lower sample sizes in older cows, lactations three and four had greater variation between DD categories than did parity two. Overall, the results show that the longer the dry period, the lower the SCS in the following lactation. All dry periods of 60 d or less resulted in a higher SCS in the subsequent lactation, except for a few categories which showed no difference. Dry periods of 20 d or less were by far the most detrimental for parity two. Cows with 10 or fewer DD had a 0·18 greater SCS in second lactation than cows with 56–65 DD. For lactation two, moving from a dry period of 10 d or less to a dry period of 11–20 d showed a 0·08 decrease in SCS, whereas moving to 21–30 DD decreased the SCS by 0·02. After a dry period of at least 35 d, SCS was only 0·01–0·02 higher relative to cows with 61–65 DD. After DD category ten, SCS continued to decrease by 0·01 up to 0·06 with longer DD for parity two.

Adjustment for milk yield made little difference in the second lactation results for SCS, except in the first two DD categories. When adjusted for milk yield, SCS in the second lactation for DD category one was only 0·13 higher (compared with 0·18 in Table 9) than for cows with 61–65 DD and category two was only 0·08 higher compared with cows with 61–65 DD. Welper & Freeman (1992) reported a phenotypic correlation of only −0·04 between milk yield and SCS and therefore little change with adjustment for milk yield would be expected.

Consistent with the present results, Annen et al. (2004) reported higher somatic cell counts for dry periods of <60 d. Cows with no dry period had an average cell count of 17 000 greater, although there was essentially no difference through the first 15 weeks of lactation (Annen et al. 2004). Gulay et al. (2003) is one of the few studies to look at DD effects on somatic cells in milk. In contrast to the present results, it found a lower somatic cell count with a 30-d dry treatment compared with a 60-d dry treatment during the first 10 weeks of lactation. The comparison was not significantly different from zero and was based on a small sample. Although not statistically significant, results of Rastani et al. (2005) also show higher SCS for cows with longer dry periods. This variation in results almost certainly reflects small sample sizes for a trait subject to large environmental effects.

Restriction on available data

One important consideration in the present study is that information on lactations in which the cow was culled prior to first test-day was not available. For example, if a cow calved into her second (or later) lactation and was culled, say, 14 d after calving, before the tester visited the herd, her 'record' would not have been in the data set. If information on such lactations had been available, one approach to using them would have been to set the lactational yield to, basically, zero and then include it, along with its DD, in the data for analysis. Such an approach, however, would probably be more appropriate or more important for analysis of lifetime yield where the intent would be to study not only yield per lactation but DD effects on number of lactations (herd life) as well. With respect to DD effects on lactational yield, 'survival to first test-day' might, appropriately, be considered an important but separate trait. In any event, the DD effects, estimated in this study, are for cows surviving to first test.

Further research

While determination of DD effects on subsequent lactation is useful, it is also true that production in the previous lactation is sacrificed by dry off. Thus, one aspect of future research should be to determine the dry period length that maximizes production across adjacent lactations as well as lifetime production. Determination of effects on lifetime yield are particularly important to account for additional culling that may be related to dry period length, either shorter or longer DD. After more complete information is available on the phenotypic consequences of alternative dry period lengths, then an economically optimum dry period length could be determined. Research to determine the biological bases for results found, especially for effects of long DD and perhaps effects on percentages, may also be useful in formulating optimal management recommendations. Finally, as pointed out by Linn (2004), the feasibility of shortened DD for a particular herd will also be affected by factors such as available labour and pen space as well as the additional parlour pressure that would be introduced by shortening the dry period.

Conclusions

As with milk yield, fat and protein yields are maximized in the subsequent lactation with a 60-d dry period. Dry periods of 20 d or less result in substantial losses in kg of fat and protein in the subsequent lactation. Conversely, a short dry period is beneficial for fat and protein percent, and this effect appears to be independent of milk yield.

Short dry periods also result in fewer DO in the subsequent lactation. However, this is entirely due to the lower milk yield associated with shortened dry periods. When adjusted for milk yield, short DD actually results in poorer fertility in the subsequent lactation. Short dry periods are also detrimental to SCS in the subsequent lactation. Therefore, herds with mastitis/SCS problems should be cautious in considering shortened dry periods, especially dry periods of <50 d.

This research is one of the few studies to examine DD effects on subsequent lactation for traits other than milk yield, and in particular fertility. However, further research is needed to determine effects on lifetime performance, which would account not only for yield losses in previous lactation but any effects on herd life as well. Research to determine the biological bases for results found, especially those related to percentages, may also be useful in further understanding the effects of dry period length as well as enhancing formulation of appropriate management recommendations.

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