Italian Journal of Animal Science 2010; volume 9:e20

PAPER

Omission of dry period and effects on the subsequent lactation curve and on milk quality around calving in Italian Holstein cows

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Abstract

The aim of this study was to investigate the effect of dry period omission on subsequent milk production over a whole lactation and the effect on milk quality around calving. Seventeen Italian Friesian cows, homogeneous for milk yield and parity, were managed either with a traditional dry-off period of 55 d (CTR group; n=8) or continuously milked up to parturition (CON group; n=9). Milk yield was recorded daily from 75±7 d before expected calving date to the end of subsequent lactation to fit the lactation curve. Before parturition milk samples were collected at -70 d, -60 d, and -55 d for CTR and CON groups and at -40 d, -30 d, and -7 d for CON cows. After calving, six milk samples were taken from 1 d to 90 d from both groups and analyzed for fat, protein, lactose, MUN and somatic cells. Body weight (BW) and body condition (BCS) were obtained 7 times from -55 d before expected calving to 90 d after calving. The omission of the dry period modified the shape of lactation in CON cows that reached the peak 10 d earlier and producing -5.5 kg/d than CTR. Over a 305 d period, the milk yield reduction was of -2241 kg in CON group. The higher amount of milk produced before calving, i.e., 560 kg of milk in 52 d of mean pre-partum period, did not compensate the milk yield reduction after a continuous lactation. Milk quality was unaffected by the omission of dry period after calving, and animals in both lactation groups showed a similar decreasing trends over time for fat and protein, and increasing trends for lactose and MUN. Somatic cell score remained greater (4.54 *vs* 3.40) in CON than in CTR cows after calving. No different BW or BCS changes were observed for both groups after calving. We conclude that despite the absence of great differences in milk quality, the complete omission of the dry period in cows reduce significantly the milk yield, suggesting no economical benefit from this management strategy.

Introduction

Milk production systems have traditionally been designed for maximisation of daily yield in the belief that this would increase economic efficiency. Therefore, research has been mainly concentrated on factors (i.e., genetic, nutrition, management), aimed to increase milk production at the peak of lactation. In this respect, a dry period lasting approximately 60 days has been recommended to guarantee a maximum milk yield in the subsequent lactation (Sorensen and Enevoldsen, 1991). However, the optimum dry period length was determined mainly by retrospective studies on field data, which should be carefully interpreted and are not free from criticisms (Bachman and Schairer, 2003; Gallo *et al*., 2008). At present, extended lactations lasting up to 18 month are involving an increased number of cows in many countries (Vargas *et al*., 2000; Gallo *et al*., 2008). These extended lactations raise the problem of both a correct modelling of the lactation trajectory for a correct management policy in dairy herds (Grossman and Koops, 2003), and a correct use of milk test day in the genetic evaluation of animals. Indeed, most of models used at present for genetic evaluation are based on test day records and, with few exceptions (Druet *et al*., 2002), the proposed models have dealt with a standard 305 lactation length, not considering the gestation status (Jensen, 2001). Together with the modification of the lactation cycles as possible strategy to overcome gestational problems of high producing dairy cows (Bertilsson *et al*., 1997), increasing attention has been addressed to the possible reduction of the dry period as a system to circumvent problems related to the high amount of milk still produced at the time of dry-off. Indeed, both mammary infections during the dry-off (Rajala-Schultz *et al*., 2005), and metabolic stress due to the transition period (Bell, 1995), which has been indicated as cause of different diseases observed in early lactation (Fleisher *et al*., 2001), may be reduced by shortening the dry off period. Data obtained from planned animal studies (reviewed by: Bachman and Schairer, 2003; Annen *et al.*, 2004a) suggest that the dry period could be reduced to 30-40 days without compromising milk production in the subsequent lactation. Similarly, results obtained from early planned animal experiments performed with low yielding cows showed that the complete omission of the dry period resulted in milk yield reduction in the subsequent lactation ranging from 17 to 38% (Swanson, 1965; Smith *et al.*, 1967; Rémond *et al.*, 1992). More recent research using today's high yielding animals (Rastani *et al*., 2003; Annen *et al*., 2004b) indicates that primiparous cows continue to require a 60 day dry period, and also modern animals showed a considerable milk yield reduction in the subsequent continuous lactation, although modern management and feeding practises were used. However, in multiparous cows, milk losses can be compensated by bST treatment (Annen *et al.*, 2004b) and by increased milking frequency. However, in the EU context where bST use is forbidden, feeding techniques may be able to modulate mammary cell proliferation and apoptosis controlling the milk loss due to continuous lactation (Weber *et al*., 2000; Stefanon *et al*., 2002). The objective of the present experiment was to study the effects of the suppression of the dry period in dairy cows managed for continuous lactation on the characteristics of the lactation curve and milk composition. To study the characteristics of the lactation curve subsequent to a continuous or normal lactation with a dry period, the model described by Wilmink (1987) was used. This model was chosen because it allows both an easy computation by simple lin-

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Key words: Continuous lactation, Lactation curve, Milk quality, Dairy cows.

Acknowledgments: the authors are grateful to Dr. Laura Da Dalt, Dr. Alberto Simonetto and Mr. Tommaso Brogin for their skilled technical support. This study was supported by the Ministry of University (PRIN 2001 and PRIN 2005), Italy.

Received for publication: 6 March 2009.
Accepted for publication: 9 September 2009.

Licensee PAGEPress, Italy
Italian Journal of Animal Science 2010; 9:e20
doi:10.4081/ijas.2010.e20

Table 1. Chemical composition of the basal diets used during the experiment (AOAC, 2000).

Chemical composition	Pre-parturition				Post-partum*
	CTR		CON		
	-55 to -20 d	-20 to 0 d	-55 to -20 d	-20 to 0 d	
DM, %	51.7	55.8	54.3	57.0	66.0
CP, % DM	11.6	12.5	12.3	13.0	15.3
Lipids, % DM	3.4	3.7	3.3	3.5	2.3
NDF, % DM	56.0	50.7	52.8	48.4	35.6
Starch, % DM	20.7	20.9	22.9	23.2	24.9
Net energy, MFU/kg DM	0.74	0.76	0.80	0.79	0.91

CTR= cows having a 55 d dry period; CON= cows of continuous lactation group; MFU= Milk Feed Units (INRA, 1988). *Diets of CTR and CON cows were the same after calving.

ear model technique, statistical inference among groups, and a biological interpretation of the estimated parameters of the lactation curve.

Materials and methods

Experimental groups, diets and data recording

Seventeen Holstein Friesian dairy cows (7 primiparous and 10 multiparous) were divided in two experimental groups and placed in two distinct pens in the dairy herd of the experimental farm at the University of Padova (Legnaro, PD, Italy). The control group (CTR, n=8) was traditionally conducted, with a dry period of 55 d and an expected calving interval of 13 months, while a continuous lactation group (CON, n=9) undergone to milking until parturition. The animals were assigned to each experimental group to get homogeneous average milk yield, expressed as mature equivalent cow (CTR=10.508±1.157 kg; CON= 10.925±1.425 kg), days from the parturition (CTR=109±80; CON=99±79) and parity (CTR=1.75±1.04; CON=1.89±0.78). The CTR cows were dried off by a single milking per day for the last 5 days of lactation and then, on the 6th day, milking was suppressed. All procedures were carried out in respect of the Italian legislation on animal care (DL n.116, 27/1/1992).

All cows had free access to water and were fed once a day. During the dry period cows of CTR group received *ad libitum* a diet based on grass hay (22.1%), straw (27.9%), maize meal (20.6%) and a specific mixed commercial feed (29.4%) prepared by Petrini Spa company, Italy, formulated in order to supply the nutritional requirements (INRA, 1988; NRC, 2001). The chemical composition (AOAC, 2000) of total mixed ration (TMR) was on average: 11.6% CP, 56% NDF and 0.74 Milk Feed Units - MFU - on DM basis. The forage to concentrate ratio was 50:50. Starting from 55 d before the expected calving date, the cows of CON group received the same diet of CTR group, but supplemented with a mixture of commercial feed for lactating cows (25%), soybean meal (25%), maize meal (25%) and barley meal (25%) given by automatic feeders and in accordance to individual milk yield (7.7, 8.7, 9.7 and 11.5 kg/head for production levels of 20-27, 28-34, 35-40 and >40 kg milk/day, respectively). Animals of both groups were subjected to steaming-up program from 20 d before calving with increasing amounts of mixed commercial feed for lactation cows formulated by Petrini Spa company, Italy (from 1 to 4 kg/d per head). During the subsequent lactation period the two groups were fed *ad libitum* with a diet based on grass hay (11.7%), alfalfa hay (16.4%), dehydrated alfalfa hay (21.1%), soybean meal (4.7%), dried beet pulp (9.4%), maize meal (24.9%) and mixed commercial feed for lactating cows previously reported (11.7%). The mean chemical composition of TMR was: 15.3% CP, 36% NDF and 0.91 MFU on DM basis (AOAC, 2000). The TMR was balanced to meet the nutritional requirements of cows producing 20 kg/d of milk (INRA, 1988; NRC, 2001) and a forage to concentrate ratio of 50:50. However, the additional requirements of higher producing cows were assured by separate addition of concentrate mixture using automatic feeders. The changes of the diets chemical composition during the experiment are reported in Table 1 (AOAC, 2000).

Daily milk yield was recorded from 75±7 d before expected calving date to the end of the subsequent lactation using an automatic milking system for a herringbone parlor coupled with an automatic recording software (ALPROTM by DeLaval©, Tumba, Sweden). The subsequent lactation lasted on average 337 d for CTR and 302 d for CON cows.

Milk samples were collected before expected parturition at -70 d, -60 d, -55 d for CTR, and -40 d, -30 d, -7 d for CON, and after parturition at 1 d, 7 d, 15 d, 30 d, 60 d and 90 d for both groups. Milk samples were taken from the p.m. and a.m. milking and the composite samples were analyzed for fat, total protein and lactose contents by infrared analysis (Biggs, 1978) using a Milk-o-Scan apparatus (Foss Electric, DK-3400, Hillerød, Denmark). Milk urea nitrogen (MUN) was measured automatically by the conduct metric-enzymatic method (CL 10 micro analyser, Eurochem, Roma, Italy). Somatic cell were counted on a Bentley Somacount 150 (Bentley, USA) and expressed as logarithmic form using the following equation: $SCS = 3 + \log_2(SCC/100{,}000)$.

Animals were weighed and evaluated for body condition score (BCS) using a five-point scale (1= thin; 5= obese; Edmonson *et al.*, 1989) at -55 d and -15 d before expected calving date, and at 1 d, 15 d, 30 d, 60 d and 90 d after calving. BCS and body weight (BW) changes were obtained for each animal as differences between each recorded value and the value at -55 d.

Statistical analyses

Data on milk yield (MY) recorded daily after calving were all analyzed. A preliminary analysis on all raw data was performed with a non linear regression method (PROC NLIN, SAS Institute, 2000) to estimate the exponential part of the curve. Due to the results obtained (confidential interval at 95% for k exponent between 0.011 and 0.072), it was assumed a constant k exponent of 0.05 as suggested by Wilmink (1987), in the subsequent linear model analysis. Specifically, the following hierarchical linear model for repeated measures using the PROC MIXED (SAS Institute, 2000) was used for all milk yield data:

$$y_{ijkl} = \mu + L_i + P_j + LP_{ij} + C_{k:ij} + w1_{ij}\, DIM_{ijkl} + w2_{ij}\, \exp^{(-0.05\, DIM_{ijkl})} + e_{ijkl}$$

where:

y_{ijkl} = MY of cow k in lactation group i and parity j;

μ = overall mean;

L_i = fixed effect of lactation group (i=1, CTR; i=2, CON);

P_j= fixed effect of parity (j=1, primiparous; j=2, multiparous);

LP_{ij} = fixed effect of interaction between lactation group i and parity j;

$C_{k:ij}$ = random effect of cow within LP;

$w1_{ij}$, $w2_{ij}$ = fixed coefficient of regression of Wilmink lactation curve (Wilmink, 1987) across and within LP;

DIM_{ijkl} = days in milk;

e_{ijkl} = random error term $\sim N(0, \sigma^2_e)$.

Due to the use of a model for fitting lactation curves, no relationship among repeated measures could be considered, i.e. no repeated statement. The cow within LP variance (15 degrees of freedom) was directly used by PROC MIXED (SAS Institute, 2000) as error term for L, P and LP effects (main plot). Intercepts (w0) for each level of L_i, P_j and LP_{ij} were estimated by weighting the LSMEANS of each effect in the main plot. Regression coefficients were estimated for each level of L_i and P_j by weighting LSMEANS of LP_{ij} effect to obtain w1 and w2 coefficients for each level of L_i and P_j. Using the contrast statement the following hypotheses associated with the estimates were also tested: the null differences between coefficients (w1 and w2) of CTR and CON lactation group, the null differences between coefficients of primiparous and multiparous, the null differences between coefficients of CTR-primiparous and CTR-multiparous and the null differences between coefficients of CON-primiparous and CON-multiparous. Estimated intercepts (w0) and regression coefficients (w1 and w2) obtained for the Wilmink function and described above were then used for fitting the lactation curve in L_i, P_j and LP_{ij} groups. Integration of these functions gave an estimate of total milk yield over 305 d. Time at peak and peak yield were also obtained from each extrapolated function, and a persistency of lactation after peak was calculated as daily milk reduction (g/d) dividing the difference between MY at 305 DIM and MY at peak by the time differences between 305 and day of peak.

Table 2. Results of mixed model ANOVA for test day milk yield in the lactation subsequent to CTR or CON treatments.

Source	DF	F	P
Lactation group (L)	1	3.76	0.08
Parity (P)	1	3.73	0.08
LxP	1	0.64	0.43
w1xLxP (Across & Within)*	4	2116.32	< 0.001
w2xLxP (Across & Within)*	4	521.44	< 0.001
Residual	4750	-	-

CTR= cows having a 55 d dry period; CON= cows of continuous lactation group. *Across and within regression coefficients of Wilmink function for the lactation curve, where: w1= regression coefficient on DIM and w2= regression coefficient on $\exp^{-0.05\times DIM}$ (Wilmink, 1987).

Due to the nature of the results obtained, they were not subjected to other statistical analysis, but simply reported as result of the study itself.

Milk quality data, BW and BSC changes were analyzed using the same hierarchical linear model for repeated measures using the PROC MIXED (SAS Institute, 2000), although for milk quality data the repeated statement was used assuming a first order autoregressive covariance structure among repeated measures (SAS Institute, 2000). Because of no algorithm convergence, for BW and BCS changes it was not possible to consider any relationship among repeated measures. The model used was as follows:

$$y_{ijklm} = \mu + L_i + P_j + LP_{ij} + C_{k:ij} + S_l + LS_{il} + PS_{jl} + LPS_{ijl} + e_{ijklm}$$

where:

y_{ijklm}= single record of cow k in lactation group i and parity j;

μ= overall mean;

L_i= fixed effect of lactation group (i=1, CTR; i=2, CON);

P_j= fixed effect of parity (j= 1, primiparous; j= 2, multiparous);

LP_{ij} = fixed effect of interaction between lactation group i and parity j;

$C_{k:ij}$ = random effect of cow within LP;

S_l = repeated effect of sampling time l at fixed period before expected calving date or after calving (1=1-12 for milk quality and l=1-7 for BW and BCS changes);

LS_{il} = fixed effect of interaction between lactation group i and sampling time l;

PS_{jl} = fixed effect of interaction between lactation parity j and sampling time l;

LPS_{ijl} = fixed effect of interaction between lactation group i, parity j and sampling time l;

e_{ijklm}= random error term $\sim N(0, \sigma^2_e)$.

Also in this case the cow variance was used as error term for the main plot effects. As regard the data on milk quality, the degrees of freedom of the LS effect were used to test the null hypotheses of a linear component for both pre-partum and post-partum periods. Because of the pre-partum period had only 3 sampling for CTR group, not allowing the test of higher degree components, only the linear pattern was tested for all LS levels. In addition, the null hypotheses of a comparison between CTR and CON pooling all milk quality data collected after calving was also tested. For BW and BCS changes the degrees of freedom of the LS effect were used for testing the null hypotheses of differences between CTR and CON groups pooling the data obtained both before and after calving.

Results

The main effects of lactation group (L_i), parity (P_j) and their interaction (LP_{ij}) were not significant (Table 2) for the lactation that followed the different treatment of animals as regards the presence (CTR) or the absence (CON) of a dry period. However, by fitting the regression coefficients of Wilmink function for the lactation curve (Wilmink, 1987) both across (1 degree of freedom for each coefficient) and within the main plot effects (3 degrees of freedom for each coefficient fitted within L_i, P_j and LP_{ij}, respectively), significative F statistics were obtained. This, in particular, for the coefficient directly associated with DIM or, from the biological point of view, the coefficient related to the adaptation period of lactation up to peak. The F statistics for this effect was indeed fourfold higher than that showed by the coefficient of the Wilmink function related to the decreasing phase of lacta-

Table 3. Within Lactation group (L), Parity (P) and interaction LxP estimated regression coefficients and standard error (SE) estimates for the Wilmink function used to describe the lactation curve.

Item	Regression coefficients*					
	w0		w1		w2	
	coefficient	SE	coefficient	SE	coefficient	SE
Lactation group(L)						
CTR	41.905	1.902	-0.067	0.001	-22.546	0.668
CON	36.893	1.749	-0.085	0.001	-17.246	0.601
Contrast for L	-	-	< 0.001	-	< 0.001	-
Parity (P)						
Primiparous	36.903	1.646	-0.072	0.002	-21.058	0.719
Multiparous	41.894	1.992	-0.081	0.001	-18.733	0.539
Contrast for P	-	-	< 0.001	-	0.010	-
LxP						
CTR-primiparous	40.443	3.010	-0.062	0.002	-24.597	1.106
CTR-multiparous	43.366	2.327	-0.073	0.001	-20.495	0.750
Contrast for P within CTR	-	-	< 0.001	-	0.002	-
CON-primiparous	33.363	2.611	-0.082	0.002	-17.520	0.920
CON-multiparous	40.423	3.329	-0.088	0.002	-16.972	0.773
Contrast for P within CON	-	-	0.017	-	0.649	-

*w0= intercept, w1= regression coefficient on DIM, w2 regression coefficient on $exp^{-0.05xDIM}$, (Wilmink, 1987). CTR= cows having a 55 d dry period; CON= cows of continuous lactation group.

Table 4. Characteristics of the lactation curves obtained from estimated regression coefficients of Wilmink function (Wilmink, 1987).

	305 Milk Yield (kg)	Peak DIM (d)	Yield at peak (kg)	Persistency*
Lactation group (L)				
CTR	9198	56	36.8	-62
CON	6957	46	31.3	-78
Parity (P)				
Primiparous	7502	54	31.6	-66
Multiparous	8653	49	36.3	-74
LxP				
CTR-primiparous	8976	60	35.5	-57
CTR-multiparous	9420	53	38.0	-67
CON-primiparous	6029	47	27.9	-75
CON-multiparous	7884	45	34.7	-81

CTR= cows having a 55 d dry period; CON= cows of continuous lactation group. *Expressed in g/d and calculated as: (MY at 305 d-MY at peak)/(305-Peak DIM).

tion, i.e. w2 (Macciotta *et al*., 2005). Both coefficients estimated were significantly different form zero and contributed highly to reduce the residual standard deviation, which value of milk yield was of 4 kg/d, i.e. about 15% of the average milk production exhibited by cows over the entire lactation that resulted equivalent to 27.5 kg/d (*data not presented*).

Estimated regression coefficients for Wilmink function within factors included in the main plot of ANOVA are reported in Table 3. Due to the method used to estimate different intercepts, no comparison among these coefficients related to peak was possible. The intercepts ranged from 33.4 for CON-primiparous to 41.9 for all animals in CTR group of lactation, i.e. with a dry period. The coefficients that describe the adaptation to lactation up to the peak, i.e. w1, were always different when compared within groups, i.e. between CTR and CON group (-0.067 *vs* -0.085, respectively; P<0.001), between parities (-0.072 *vs* -0.081, P<0.001 for primiparous and multiparous, respectively) and between parities within the lactation group (-0.062 *vs* -0.073, P<0.001 for CTR-primiparous and CTR-multiparous, respectively, and -0.082 *vs* -0.088, P=0.017 for CON-primiparous and CON-multiparous, respectively). The standard error estimates of all these coefficients resulted always very low. With the only exception of CON-primiparous *vs* CON-multiparous, all the comparisons indicated different coefficients also for the reduction phase of the lactation (i.e., w2 coefficient). However, the standard error of estimates obtained for these coefficients resulted in some cases slightly greater than the standard error obtained for w1 coefficients.

Figure 1 shows the lactation curve obtained for the different parities within lactation group as a result of the implementation of the estimated coefficients reported in Table 3, while Table 4 reports the summary descriptive values of the lactation curve obtained. As shown, a continuous lactation resulted in a shift of the subsequent lactation curve that was characterized by an earlier peak of production, a lower production at peak and a reduced persistency. These effects were of higher magnitude in younger than in older cows, since the primiparous cows showed a strongly earlier peak and a dramatically lower peak production compared with the counterpart cows in the CTR lactation group. As a consequence of these great changes in the shape of the lactation curve after a continuous lactation, CON cows exhibited a general reduction of milk yield over the entire lactation, with still a stronger effect in primiparous cows than in multiparous. Indeed, the average reduction in milk yield of about -2241 kg of milk between CON and CTR animals over a 305d period, resulted 30% lower in primiparous cows when compared across lactation groups, i.e. -2947 kg of milk yield differences for CON and CTR primiparous. However, this reduction should be considered in light of the additional milk yield obtained during the normal dry period of the CTR cows.

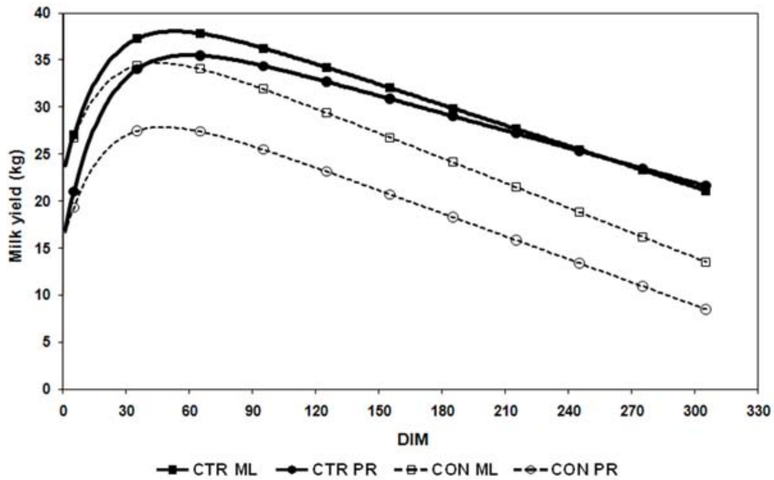

Figure 1. Estimated shape of the lactation curve subsequent to a different lactation length treatment (CTR, continuous lines; CON, dotted lines) and parities (squares for Multiparous, ML, circles for Primiparous, PR). CTR=cows having a 55 d dry period; CON=cows of continuous lactation group.

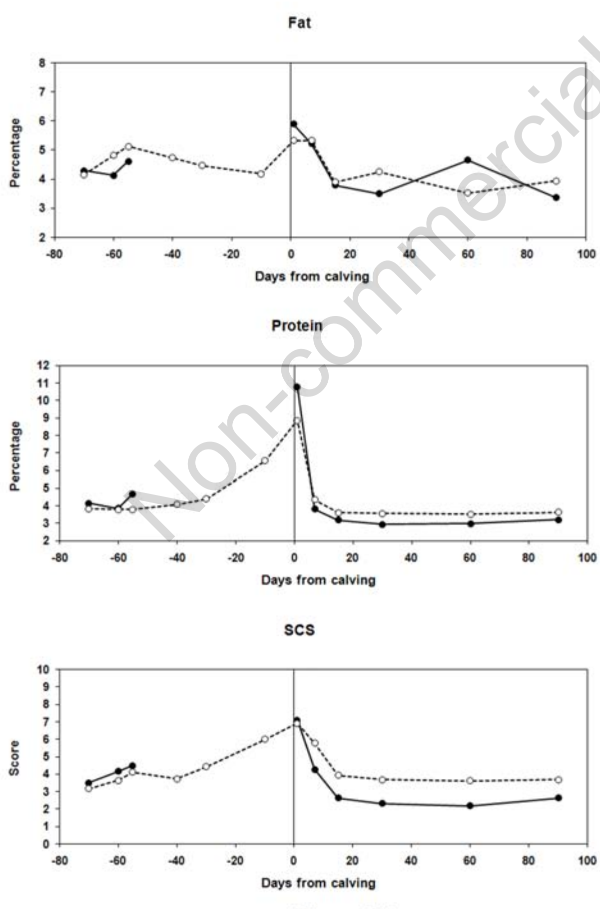

Figure 2. Pattern of fat, protein and somatic cell score (SCS*) in milk in different lactation groups (CTR, continuous lines; CON, dotted lines) around calving. *SCS= 3+$\log_2$ (SCC/100,000). CTR= cows having a 55 d dry period; CON=cows of continuous lactation group.

On average, the total amount of milk produced by CON cows up to the calving was about 560 kg of milk in 52 d of a mean pre-partum period, i.e. about 10.8 kg/d (*data not presented*).

No significant effects of lactation group, parity and LP interaction on the milk quality were observed (Table 5). With the only exception of MUN, sampling time affected significantly, as expected, milk parameters (Table 5). The milk fat contents were similar for two lactation groups and quite steady before calving: on average the fat percentages of CON (six samplings) and of CTR (three samplings) group were 4.58% and 4.34%, respectively (Figure 2). On the other hand, milk fat percentage tended to decrease linearly after calving from 5.32 to 3.94% (linear component: P=0.022) and from 5.89 to 3.37% (linear component: P<0.01) in CON and CTR groups respectively, but with a same pattern between lactation groups.

Protein content of CON group (Figure 2), increased linearly (linear component: P<0.01) from 3.85 to 6.55% from 70 d to 7 d before calving. A lower protein content in milk of CON cows as respect to the CTR animals was observed at the first sampling (1 days) after calving (8.85 and 10.80%, respectively). However, a week after calving a rapid decrease of protein content was observed in both groups (P<0.001 for post-partum linear components) reaching a mean value of 4.36 and 3.81% for CON and CTR lactation groups, respectively. These values were relatively steady during the subsequent three months of lactation and no differences between two experimental groups were detected. The lactose content in the milk decreased linearly during the dry period in the CON group (pre-partum linear component: P<0.001). Small differences between the experimental groups were observed during the colostrums phase, but subsequently the patterns of CON and CTR groups were very similar (*data not shown*). Somatic cell score (SCS, Figure 2) increased linearly in CON group up to calving (P<0.01). The highest value of SCS was achieved in milk samples collected 1d after calving in both lactation groups (6.93 and 7.09 for CON and CTR, respectively). After calving, SCS mean value of the CON group remained greater (P<0.05) than that of CTR group (4.61 *vs* 3.53). Mixed model ANOVA for BW and BCS changes (*data not shown*), indicated a main effect of period (days from calving) on both variables. As expected, the increase of BW during the last phase of pregnancy (from -55 d to -15 d before calving) was the greatest (+42 and +35 kg for CON and CTR, respectively), but not different between groups. In addition, during this period, no differences were obser-

Table 5. Results of mixed model ANOVA for milk quality reported as values of F statistics.

Source	DF	Fat (%)	Protein (%)	Lactose (%)	MUN (mg/dL)	SCS
Lactation group (L)	1	0.10	0.03	3.23	0.44	1.82
Parity (P)	1	0.23	0.27	3.62	0.65	2.23
LxP	1	0.16	0.01	2.84	0.25	4.19
Sampling time (S)	11	2.12*	16.98***	15.39***	1.33	8.63***
LxS	8	0.83	0.97	1.46	1.27	1.00
PxS	11	0.96	0.52	1.58	0.28	0.87
LxPxS	8	0.70	0.34	0.82	1.87	1.05
Residual	98	-	-	-	-	-

*P<0.05; **P<0.01; ***P<0.001. SCS = 3 + $\log_2$ (SCC/100,000).

ved in BCS changes between groups (+0.13 and +0.13 for CON and CTR, respectively). After calving the BW and BCS losses were similar in both lactation groups.

Discussion

The present study was planned under the hypothesis that a continuous lactation would have lead to a slower increase of the milk yield after calving with a reduced production at peak, but more persistent milk production after peak. Based on the main results observed during the study we reject this hypothesis. Despite the reduced number of animals used in the trial, the experimental design and the daily milk records gave a good fitting of the lactation curve subsequent to CTR or CON lactation (low residual standard deviation), also allowing an estimate of the persistency and the average milk production over a 305 d for cows of different lactation groups and/or parities. Other recent studies (Annen *et al*., 2004b; Andersen *et al*., 2005) did not report a measurement of the whole lactation, and, therefore, of the declining phase of lactation. Consequently, the results of our study could not be compared with others in terms of lactation persistency.

The Wilmink function was chosen for fitting the lactation curve because of its linearity and the linkage of the mathematical model with the biology of the milk production process (Jensen, 2001; Macciotta *et al.*, 2005). Many other functions have been reported in literature, both linear (Ptak and Shaeffer, 1993) and non-linear (Vargas *et al*., 2000) for fitting lactations of different lengths (i.e., normal or extended). Recently, Legendre polynomials and/or cubic spline have been proposed as the most flexible methods to fit fixed and random effects in the genetic analysis of milk yield using test day records, due to the independency among coefficients, the easy implementation of the linear parameters and the accurate fitting (Jensen, 2001). However, in the present study a large amount of data available throughout the lactation avoided problems with the fitting of the lactation curve and the use of the Wilmink model allowed a more direct statistical inference between different lactation groups and/or parities as regards the peak and the persistency of lactation.

The milk production recorded over a whole lactation indicated that cows milked continuously between two subsequent lactations had a reduced milk yield of 24% over a 305 d period, reached the peak 10 d before dried cows and produced less milk at peak (31.3 *vs* 36.8 kg), but had also a lower persistency of the lactation (i.e. quicker decrease of milk yield). This tendency was more marked in primiparous cows that reduced the overall milk yield of 33% in 305 d of lactation and showed a lower persistency than the multiparous cows undergoing a normal dry period. A different effect of the dry period omission in primiparous rather than in multiparous cows was reported also by Annen *et al*. (2004b), even though cows in different parities were continuously milked and treated with bST up to calving. The magnitude of milk loss observed by Annen *et al*. (2004b) was of 15-20% of the daily milk yield in primiparous bST treated cows, while multiparous ones were not affected by CON lactation. The observation period in this experiment, carried out with high producing cows, was 120 days before and after calving. Suppressing the dry period resulted in a 22% lower milk production within the first 5 weeks in the study of Andersen *et al.* (2005), even in this case higher producing animals (i.e. 45 kg of expected milk yield at peak) were used compared with the cows used in the present study (expected peak yield of about 35 kg of milk). An estimate of milk loss in our study, during the same period length as the one analysed by Annen *et al*. (2004b) or by Andersen *et al.* (2005), led to a mean reduction of about 15% and 10%, respectively for 17 or 5 weeks after calving. Therefore, the lower milk production potential of cows used in our experiment than in previous ones seems to reduce the magnitude of milk loss due to the CON lactation, shortening the period of observation. However, cows used in our study were within the average milk production level reported by the national breeders association (i.e. mean milk yield for CTR cows of 9.198 kg *vs* mean national milk yield of 8,945 kg for the year 2006; ANAFI, 2006).

The comparison of milk production results due to dry period omission reported in older studies and related to a whole lactation, indicated a more similar range of milk loss due to CON lactation than the one observed in our research. Indeed, Swanson (1965) reported an overall 25% of milk loss in the first lactation subsequent the omission or the keeping of the dry period in five pairs of twins. Rémond *et al*. (1997) reported a reduction of milk yield between 18 to 29% due to the omission of dry period surveying French farms that adopted this management strategy.

The possible relationship between milk loss due to CON lactation and production potential of animals (i.e., genetic merit), raised the subject of a possible interaction between the magnitude of mammary cells turnover and apoptosis with milk loss due to the omission of dry period. Indeed, cells turnover seems essential to get a high milk yield at peak (Capuco *et al*., 1997; Capuco and Akers, 1999; Annen *et al*., 2004b), while apoptosis (programmed cell death, Accorsi *et al*., 2002) is considered at present the process explaining the post peak reduction of milk yield (i.e. lactation persistency). These processes seem to be linked as hypothesized by Annen *et al*. (2004b) to explain both a reduced peak production and the persistency in CON cows, since a reduced turnover could lead to a greater number of older mammary cells that get into a new lactation, with less chances to survive longer during the whole lactation, thus reducing the secretion potential of the mammary during lactation. Despite of the fact that we can only speculate on this phenomenon, the comparison of our study with previous ones carried out with cows of higher genetic merit could lead to the theory of a superior sensitiveness of high producing cows to the physiological processes of cells turnover and apoptosis. Therefore, a no-lactating period in late pregnancy could be more important in high genetic merit cows to obtain the maximum milk production potential.

In regard to the overall milk production, the results of this study do not substantiate any better economical effect of CON as compared to CTR lactation. Indeed, the greater milk yield exhibited by CON cows before calving (i.e., 560 kg of milk on average) does not balance the loss of milk yield in the whole subsequent lactation (i.e., 2.241 kg of milk on average). Despite of the different nature of this study if compared with the studies simulating a complete suppression of dry period (Lormorel and Galligan, 2001; Rotz *et al*., 2005), it seems that no beneficial effects, from an economical point of view, are coming by suppressing the dry-off. However, this study dealt with a dry-off suppression with a pregnancy in CON cows, while simulated models never consider subsequent pregnancies in cows after the first one, i.e. perennial cows.

Milk fat concentration resulted unchanged between CON and CTR cows after calving, and this is in agreement with data reported postpartum by Rèmond *et al*. (1992) and by Andersen *et al*. (2005) in continuously milked cows. Therefore, due to the lower milk production, cows in CON group had a lower milk fat yield after calving. Reviewing the literature on this topic, Annen *et al.* (2004a) have suggested a relationship between a reduced fat yield (i.e., not different fat concentration) and reduced mobilization of adipose tissue, due to an improved energy balance in CON milked cows after calving. However, we could not substantiate such hypothesis, because of the lack of physiological data regarding this part of the experiment. While fat concentration remained basically steady during the last two months of gestation, not confirming the findings by Rémond *et al*. (1992) and by Andersen *et al*. (2005), milk protein content increased linearly as previously reported by these authors. As indicated by Annen *et al*. (2004b), colostrum secretion could begin before parturition in CON cows and, despite of the lack of measurement on milk's immunoglobulin (Ig), in our study we could speculate on an enrichment of Ig before calving, correlated with the very high amount of protein observed just before parturition. In addition, the reduced protein concentration at calving in CON compared with CTR cows is in agreement with previous studies (Annen *et al*., 2004b; Andersen *et al*., 2005; Rastani *et al*., 2005), that have linked this reduction to a lower Ig amount in the colostrum.

SCS resulted considerably great in CON group before parturition and, despite this trend should be expected both comparing similar studies involving CON milking cows (Annen *et al.*, 2004b; Andersen *et al*., 2005) or reports on SCS trend over lactation (Sewalem *et al*., 2006), it raises a concern about the marketability of such a milk. During the last three weeks before calving, CON cows had a SCS higher than 5, i.e. a concentration of milk somatic cells greater than the legal limit of 400,000 cells/mL, which is the threshold value established by EU regulation to commercialize the product (Council Directive 92/46/EEC, European Economic Community, 1992). In this regard, many dairies in Italy provide payment of milk on the basis of this threshold or lower, reducing proportionally the milk price depending on the amount of somatic cells in milk. Therefore, high SCS in milk lead often to a very low milk price in many Italian or European market situations, suggesting no advantage in selling milk with SCS content over the threshold limit. After calving, SCS reached an expected steady value within two weeks in both groups (Laevens *et al*., 1997), although it tended to be greater for CON than CTR animals. Regardless of general animal health that resulted unaffected by the presence or omission of the dry period, the udder of CON cows resulted in lower health status than that of CTR animals, due to the greater SCS up to 90 d after calving. Several studies have demonstrated that greater somatic cell count (SCC) in early lactation is correlated with subsequent SCC level in middle and late lactation (Coffey *et al*., 1986; De Vliegher *et al.*, 2004) and our results, even if limited at 90 d after parturition, seem to confirm these previous findings, adding another negative concern about the management practice of avoiding the dry period in cows.

Conclusions

Our results show that the complete omission of the dry period in cows greatly modify the shape of the subsequent lactation curve, with an average reduction in milk yield of about -2241 kg of milk in a 305 d period. Primiparous cows undergo to a more dramatic decrease in production than multiparous cows (-30%), and, apart from the parity order, the general reduction in milk yield is not balanced by the milk production up to calving.

Therefore, continuous milking up to calving does not produce a slower increase in milk yield with a reduced peak but more persistent lactation, as we hypothesized. Around calving the main difference in milk quality due to continuous milking is the very high protein concentration and the SCS level registered few weeks before calving, suggesting concerns about the marketability of such a product. In general, the complete omission of the dry period in cows reduces significantly the milk yield, suggesting no economical benefit from this management strategy.

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