J. Dairy Sci. 106:2630–2641
https://doi.org/10.3168/jds.2022-22326

Observational study on dry period length and its associations with milk production, culling risk, and fertility in Italian dairy farms

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ABSTRACT

From an initial data set involving 84,189 lactations, this research evaluated the relationship between dry period length (DPL) and milk production, culling risk, and fertility. The data set included a total of 48,297 multiparous cow lactation records, with a calving event occurring in 2019 and 2020, belonging to 62 Italian herds with at least 150 cows. The DPL was classified into 5 categories (<40, 40–49, 50–60, 61–70, and >70 d) and these categories were used to establish the association between DPL and the outcome variables. All data obtained were assessed with simple and multiple linear regressions and Cox proportional hazard models. Cumulative milk production at 60 d in milk (DIM) was the highest in DPL categories of 61 to 70 d (2,480.29 kg/cow) and 50 to 60 d (2,474.39 kg/cow), and the lowest in <40 d (2,281.29 kg/cow). Similarly, DPL categories 61 to 70 d (10,830.94. kg/cow) and 50 to 60 d (10,817.48 kg/cow) had the highest 305-d milk production, whereas the <40 d (10,200.96 kg/cow) had the lowest one. The groups with a DPL of 40 to 49 d and >70 d had slightly, but significant, lower milk production both as cumulative 60 DIM and predicted 305-d milk production. Culling risk had a curvilinear behavior, with DPL <40 d and DPL >70 d showing significantly higher odds for culling during the first 60 DIM compared with DPL of 50 to 60 d [relative risk (RR): 1.53; RR: 1.46]. Within the same comparison, DPL of 61 to 70 d also had a slightly higher risk for culling (RR: 1.13). The DPL was associated also with fertility, with DPL of 40 to 49 d and 50 to 60 d having the greatest odds for pregnancy within the first 200 DIM. The DPL of <40, 61 to 70, and >70 d were negatively associated with fertility and showed pregnancy risks of 0.87, 0.95, and 0.94, respectively. This paper reinforces the importance of DPL as we demonstrated its association with milk production, culling, and fertility. Despite being attractive for high production dairy cows, very short dry periods are at the same time also associated with higher culling risk, lower milk production and fertility. Long DPL is detrimental, especially regarding culling and fertility. In summary, reducing variability in DPL and avoiding extremes by improving reproductive performance, maximizing late lactation milk production and making wise decisions on dry-off timing, may lead to better performances and lower early culling under Italian dairy conditions.
Key words: Italian dairy farm, dry period length, milk production, culling, fertility

INTRODUCTION

Dry period length (**DPL**) has been a topic of discussion in various publications and knowledge about DPL in dairy cows has grown over time. When considering milk yield (Dias and Allaire, 1982), 51 to 60 d was given as the standard duration (Church et al., 2008). Improvements in farm's organization, feeding strategies, and genetics have increased milk production over the last 3 decades. Long dry period can be determined by low milk production at the end of the lactation or udder health issues. Due to higher treatment success at dry-off of certain IMI some farmers often dry off cows ahead of time hoping for a cure. On the other hand, short DPL might be associated with shorter gestation lengths or a choice by the farmer of delaying dry-off after the due date dictated by days carried calf in high production cows. The DPL adjustments and an increase in milk production in early lactation may be of interest to some dairies. Some observational studies viewed a 9% reduction in milk yield with a shortened (40 d) DPL, whereas others reported a decrease in yield

Received May 25, 2022.
Accepted October 17, 2022.
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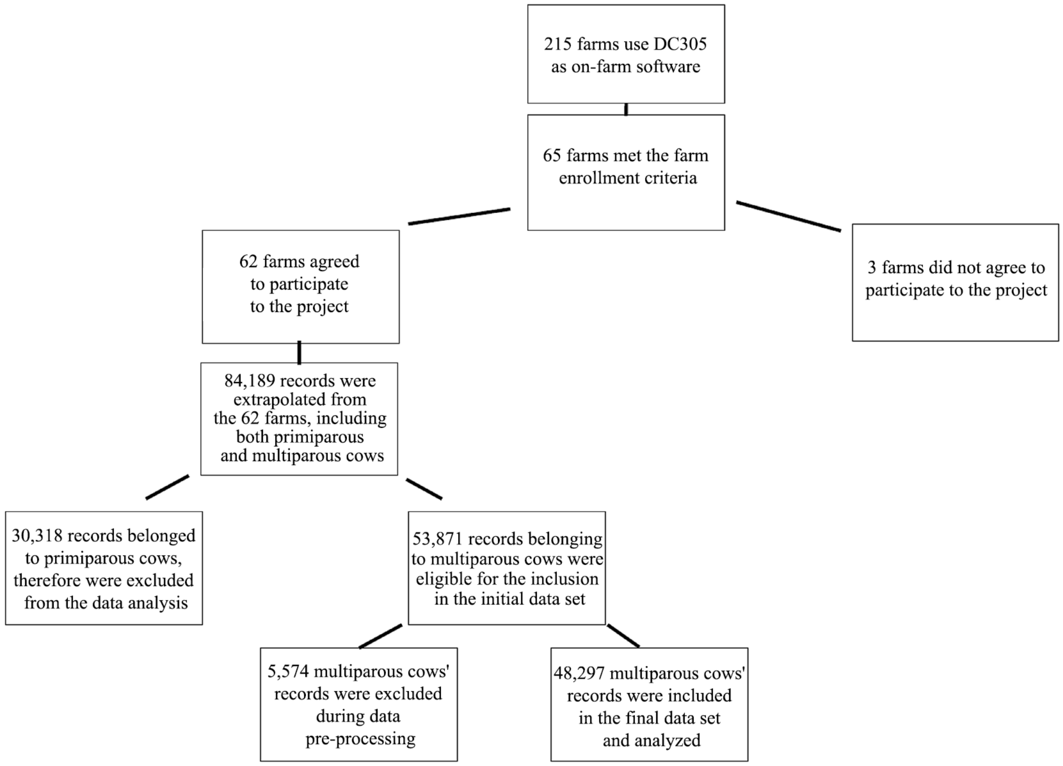

Figure 1. Data source flowchart shows data selection from the total number of farms enrolled to the final number of records analyzed. DC305 = Dairy Comp 305 software (Valley Ag Software).

of around 1% with a DPL of 31 to 52 d (Pinedo et al., 2011; Khazanehei et al., 2015). Several arguments have been given in favor of a shorter (30 d) dry period, including an increase of income from milk yield at late lactation and improvement of the nutrition level (Bachman and Schairer, 2003; Gulay et al., 2003). In other observational studies, it was recorded that milk production of cows with long dry periods (77–110 d) was lower in the following lactation in comparison to cows with a conventional DPL (Pinedo et al., 2011; Atashi et al., 2013).

Regarding fertility, several studies showed effects of a shortened DPL. Cows with short DPL demonstrated a lower number of days open and an earlier first ovulation (Gümen et al., 2005; Watters et al., 2009; Santschi et al., 2011). In other studies, it was shown that shortening DPL compared with maintaining a conventional 60-d dry period did not affect days open, conception, or pregnancy rates (Pezeshki et al., 2008; Watters et al., 2009; Chen et al., 2015). A long DPL of 77 to 142 d decreased reproductive performance. This was measured and observed as calving to first service interval and calving-to-conception interval compared with a conventional DPL (Pinedo et al., 2011). The main goal of this study was to evaluate the associations between different DPL with (1) cumulative milk production at 60 DIM and estimated 305-d milk, (2) culling risk within the first 60 DIM, and (3) pregnancy risk within the first 200 DIM.

MATERIALS AND METHODS

Herd Selection and Management

Out of approximately 215 farms using Dairy Comp 305 (**DC305**, Valley Ag Software) in Italy, 65 herds met the enrolling criteria of having DC305 as on-farm software for more than 2 yr at the time of data collection, were regularly enrolled in DHIA testing and had parlor milk meters. Out of 65 herds, 62 agreed to participate to the project (Figure 1).

Milking frequency was 3 (58%) or 2 (42%) times a day, with 53 farms (85%) using conventional milking parlors, one farm (2%) using an automated milking system (**AMS**), and 8 farms (13%) using a conventional milking parlor and AMS. Reproductive management consisted of AI based on estrus detection or ovulation-synchronization protocols; after a voluntary waiting period specific for each herd (39–86 d), cows underwent different protocols for their first insemination using frozen semen. Fifty-five farms performed fixed-time AI for first insemination by following a Presynch-OvSynch protocol (10 farms; Pursley et al., 1997a,b) or a Double-OvSynch protocol (45 farms; Souza et al., 2008). On the other 7 herds, farm managers used only estrus detection. Veterinarians confirmed pregnancy status using manual rectal palpation or ultrasounds.

Data Source

The data set was extracted directly from DC305 software (Valley Ag Software) used on farm. Farmers were trained on the correct use of the software and assisted by the software support team for any problems with data registration. From an initial data set involving 84,189 lactations, 53,871 were multiparous cow, and 30,318 were primiparous. Only 53,871 multiparous cows with a calving date between January 1, 2019, and December 31, 2020, were selected (Figure 1). Lactation records included data regarding farm identification, milking frequency at farm level, calving date, calving month and season, parity, breed, age at first calving, previous gestation length, DPL, previous lactation 305-d mature equivalent (**305-d ME**), 60 DIM cumulative milk production, predicted 305-d milk production, calving-to-conception interval of current and previous lactation, and culling date. Herd and cow identifications were coded and known only to the DC305 support team.

Data Analysis

Data Preprocessing. Data from each herd were exported from DC305 herd management software to a Microsoft Excel spreadsheet (Microsoft Corp.), and statistical analyses was performed using JMP15.1 (SAS Institute Inc.).

Lactations where the previous gestation was <260 d were excluded, as were records with a missing value for DPL. Records with obvious errors, such as DPL >200 d or previous gestation length >320 d, were removed from the data set. The final data set was composed of 48,297 lactation records belonging to 35,692 cows.

The DPL was classified into 5 categories (<40, 40–49, 50–60, 61–70, and >70 d) by adapting and modifying Andrée O'Hara et al. (2020) approach to our data set. The adopted categorization allowed us to represent different DPL categories with a fair number of records so that conclusions of this paper could be useful in the Italian field.

Calving month and year were extrapolated from the calving date. Descriptive statistics were calculated, and the mean ± standard deviation was expressed as continuous variables, whereas categorical variables were conveyed as frequencies and percentages.

Three herd-size categories were established based on the average number of calvings/herd per year in 2019 and 2020: <500 calvings/herd per year; 500 to 1,000 calvings/herd per year, and >1,000 calvings/herd per year. Cow breeds were regrouped into the following categories: Holstein, crossbred, and other breeds. Previous lactation calving-to-conception intervals were divided into categories of ≤200 d and >200 d, with the purpose of focusing on cows with a long interval. A summary of the variables included in the final data set is shown in Table 1.

Descriptive statistics on DPL both as a continuous and categorical variable were used to describe this pa-

Table 1. Summary of the variables included in the data set with total number of observations, number of missing observations, number of categories for categorical variables and minimum, maximum, mean, and SD for each continuous variable

Variable	Observations (no.)	Missing observations (no.)	Categories	Minimum	Maximum	Mean	SD
Farm	48,297	0	62				
Breed	48,297	0	3				
Previous gestation length in days	48,297	0		260	300	277.17	5.35
Previous days dry	48,297	0		1	200	63.21	18.83
Previous lactation calving-to-conception interval	48,286	11		20	667	122.44	62.04
Previous lactation 305-d ME (kg)	46,130	2,167		700	25,300	12,897.43	2,515.51
Calving date	48,297	0		Jan. 6, 2019	Dec. 20, 2020		
Parity group	48,297	0	2				
Predicted 305-d milk production (kg)	40,641	7,656		3,220	21,850	11,145.69	2,137.81
60 DIM cumulative milk production (kg)	39,061	9,236		600	5,760	2,538.61	492.71
DIM at culling	11,906	36,391		1	691	151.43	135.78
Days open	48,297	0		0	702	115.57	86.27

Table 2. Dry period length (DPL) categories with frequency distribution, arithmetic mean, and standard deviation by category[1]

DPL category (d)	Frequency (no.)	Mean (d)	SD	Q1	Q3
<40	591	34.67	5.77	33	38
40–49	5,278	46.09	2.54	44	48
50–60	20,926	55.49	3.04	53	58
61–70	13,305	64.50	2.72	62	67
>70	8,197	93.94	26.47	75	104
Total	48,297	63.21	18.83	54	66

[1]Q1 and Q3 represent 25% and 75% quantiles.

rameter over the entire data set, stratifying by farm and parity. Mean, standard deviation, median, and quartiles were calculated overall (continuous DPL; Table 2) and for each DPL category.

Data Modeling as a Function of DPL. To address differences in the distribution of DPL categories among farms, parity groups, and previous lactation calving-to-conception intervals (in categories), separate contingency analyses based on the χ^2 test were performed (DPL vs. all other listed variables, pairwise). To estimate the least square means (**LSM**) for cumulative milk production at 60 DIM and for predicted 305-d milk over DPL categories, 2 multiple linear regression models were considered.

Both models included the following independent variables: farm, parity, previous lactation 305-d ME, month of calving, year of calving, cow breed, previous gestation length, and DPL categories.

$$\mathrm{my}_{\mathrm{ijkmyblp}} = \mu + \mathrm{farm}_i + \mathrm{parity}_j + \mathrm{prev305ME}_k + \mathrm{calvm}_m + \mathrm{calvy}_y + \mathrm{breed}_b + \mathrm{prevGestL}_l + \mathrm{DPL}_p + e_{\mathrm{ijkmyblp}}, \quad [1]$$

where $\mathrm{my}_{\mathrm{ijkmyblp}}$ is milk yield (either cumulative 60 DIM milk production or predicted 305-d milk production), from farm i, at parity j, with previous 305-d ME milk yield k, that calved in month m of year y, belonging to breed b, with previous pregnancy length l and DPL p, and μ is the overall mean. All effects in Equation 1 were treated as systematic fixed effects, except the residual e_{ijkmyblp}, with variance $\mathrm{I}\sigma_e^2$.

To investigate the relationship between DPL categories and time to culling in the first 60 DIM, a Cox proportional hazard model was built including farm, parity, previous lactation 305-d ME, month of calving, year of calving, cow breed, previous gestation length, previous calving-to-conception interval categories and DPL as explanatory variables (Equation 2). To address the association between DPL categories and pregnancy risk by 200 DIM another similar Cox proportional hazard model was used to evaluate time to pregnancy.

Both Cox proportional hazard models were nonparametric. The culling/pregnancy risk was modeled as the probability of being culled/get pregnant at a given time t, conditional on already having survived/remained open that long, as a function of the variables (risk factors) included in the model:

$$\mathrm{h(t)} = \mathrm{P(T = t \mid T > t)} = \mathrm{h_0(t)\,exp(farm + parity + DPL + prev305ME + prevGestL + calvm + calvy + breed + prevCTCI)}, \quad [2]$$

where h(t) is the risk (hazard) of either being culled or getting pregnant at time t; $\mathrm{P(T = t \mid T > t)}$ is the probability of event T (culling/pregnancy) at time t conditional of survival/being open until time t; $\mathrm{h_0(t)}$ is the baseline risk (nonparametric part of the model); exp is the exponential function, with all terms in the exponent as defined in Equation 1 except prevCTCI, which is the calving-to-conception interval in the previous lactation. Model coefficients from Equations 1 and 2 were considered significantly or tending to be significantly different from 0 when $P < 0.05$ and $P < 0.1$, respectively.

To test if any difference existed in models' outcome among parities, the interaction between DPL and parity was fitted into each model. When this interaction was significant, the model was recalculated separately for cows in second lactation (**LACT2**) and third lactation or greater (**LACT3+**).

RESULTS

Descriptive Results

The 62 Italian herds included in the study were 53 (85%) from the northern area, 3 (5%) from the central area and 6 (10%) from the southern area and islands. Farm size was categorized based on the average number of calvings per year into 3 groups as follows: <500 (n = 28), 500 to 1,000 (n = 22), and >1,000 (n = 12). Regarding herd size, the distribution of lactations records was 12,400 for herds with <500 calvings per year, 17,357 for herds with 500 to 1,000 calvings, and 18,540 for herds with >1,000 calvings per year.

The average number of calving per herd in 2019 and 2020 was 678 per year (median = 567), ranging from 178 to 1,941. In the whole data set, the parity distribution was 36% (n = 30,318) first lactation, 27% (n = 22,841) LACT2, and 37% (n = 31,030) LACT3+. We analyzed data from 48,297 multiparous cows' lactation records

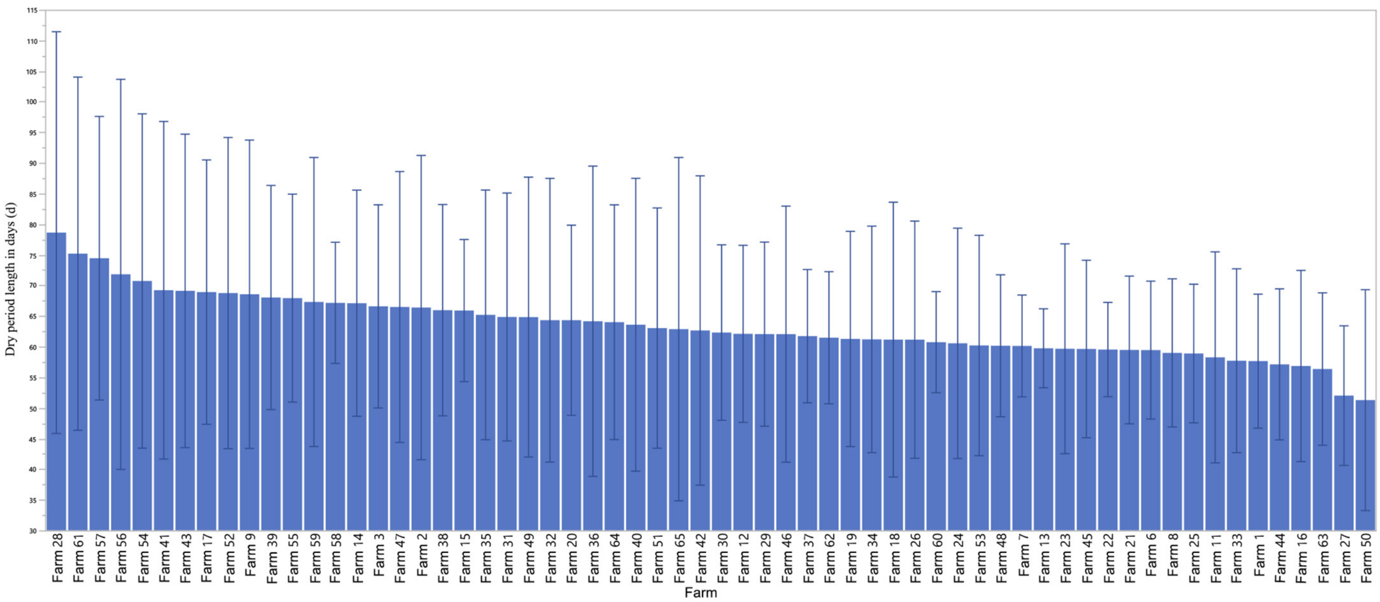

Figure 2. Dry period length in days for each farm (mean ± SD) enrolled in the study.

by breed as follows: 43,972 were Holsteins (91%), 3,927 Crossbred (8%), and 398 Brown Swiss/Jerseys (<1%).

In Figure 2 we analyzed the mean and standard deviation of DPL for each farm; the lowest mean was 51 ± 18 d and the highest mean was 78 d ± 33 d. Figure 3 shows the distribution of DPL categories per farm, where the contingency analysis found significant differences among farms ($P < 0.0001$). Most of the lactation records fall into the DPL categories of 50 to 60 and 61 to 70 d.

When we analyzed data by parity group, we observed relevant significant differences ($P < 0.0001$): for LACT2, 49.3% had a DPL of 50 to 60 d, and 26.4% a DPL of 61 to 70 d, whereas for LACT3+, 39% had a DPL of 50 to 60 d, and 28.4% had a DPL of 61 to 70 d. The biggest difference among parities regarded DPL >70 d with 9.7% for LACT2 and 22.3% for LACT3+ (Figure 4). A significant difference ($P < 0.0001$) was also found when DPL categories were analyzed by previous calving-to-conception interval categories, with

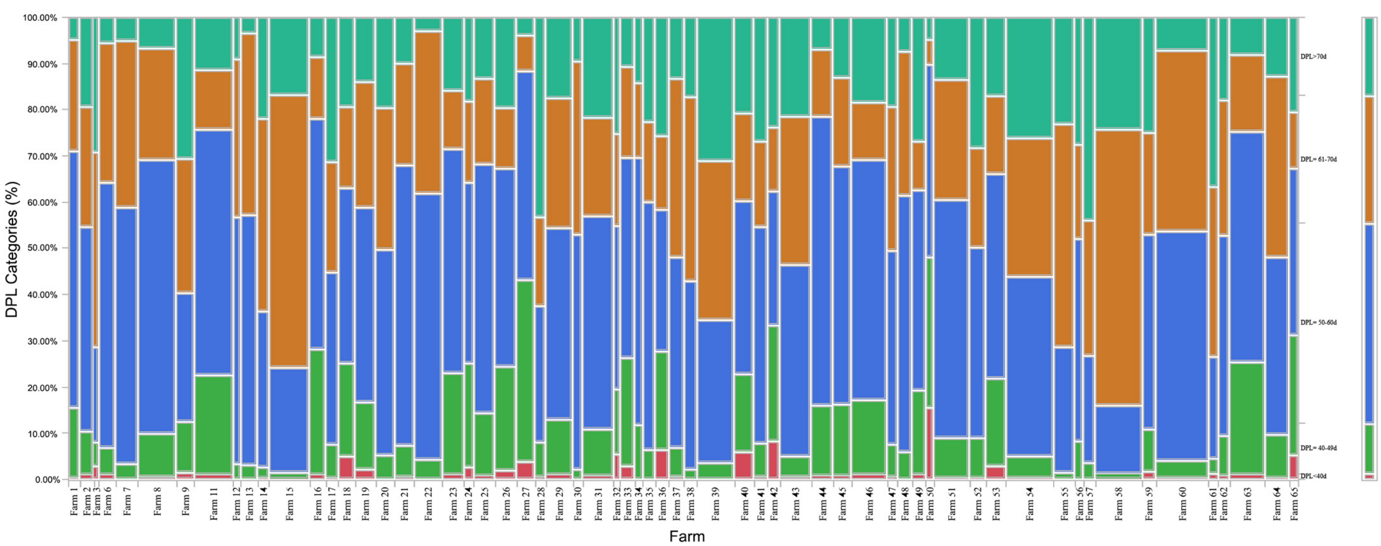

Figure 3. Dry period length (DPL) categories by single farm. Column width is related to the number of observations. Right column represents the whole data set.

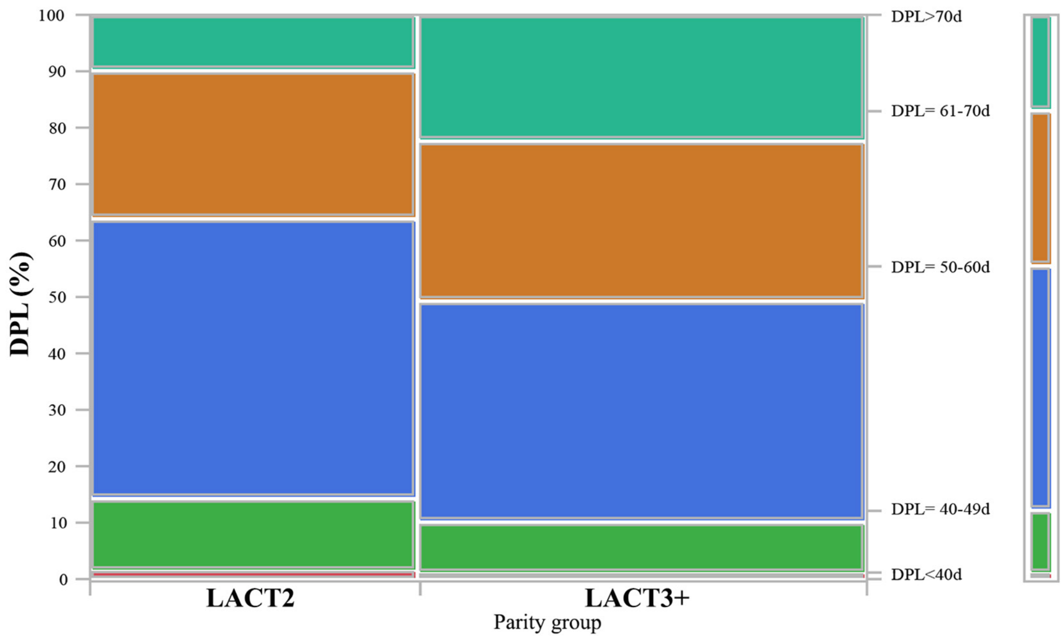

Figure 4. Dry period length (DPL) categories by parity group. Column width is related to the number of observations. Right column represents the whole data set. LACT2 = second lactation; LACT3+ = third lactation or greater.

a higher proportion of DPL >70 for previous calving-to-conception interval >200 d (39.5%) compared with previous calving-to-conception interval ≤200 d (14%).

Association of DPL with Subsequent Lactation Performance at 60 DIM and Estimated 305-d Milk

The LSM for cumulative milk production at 60 DIM (Table 3, Figure 5) was the highest in the 61 to 70 d (2,480.29 kg/cow) and 50 to 60 d (2,474.39 kg/cow) DPL categories and the lowest in the <40 d (2,281.29 kg/cow) category. Cows with a DPL <40 d produced 199 kg less milk compared with the highest DPL category (61–70 d). Similarly, cows with DPL >70 d produced 34 kg less milk compared with DPL of 61 to 70 d.

The projected 305-d milk production LSM (Table 4, Figure 6) was highest in the 61 to 70 d (10,830.94 kg/cow) and 50 to 60 d (10,817.48 kg/cow) DPL groups, lowest in the <40 d (10,200.96 kg/cow) group. The DPL >70 d and 40 to 49 d produced slightly less milk with an LSM of 10,733.54 kg/cow and 10,621.96 kg/cow, respectively. Milk yield in the subsequent lactation was maximized when the dry period lasted 50 to 60 d or 61 to 70 d and the highest milk loss was 630 kg for DPL <40 d when compared with DPL of 61 to 70 d. Interaction with DPL and parity group was not significant in both models, so the analysis by parity group was not repeated.

Association of DPL with Culling Risk in the First 60 DIM

Overall culling risk in the first 60 DIM was 9% (n = 4,359), 4% in LACT2 (n = 902) and 12% in LACT3+ (n = 3,457). Significant differences in the culling risk

Table 3. Least squares means for 60 DIM cumulative milk yield (kg) by dry period length (DPL) category, with 95% CI

DPL category (d)	Observations (no.)	60 DIM cumulative milk yield (LSM)	95% CI	Significant pairwise comparisons[1]
<40	449	2,281.29	2,251.01–2,334.20	a
40–49	4,079	2,407.61	2,391.24–2,435.40	b
50–60	16,204	2,474.39	2,461.86–2,499.45	c
61–70	10,451	2,480.29	2,466.41–2,505.92	c
>70	6,044	2,446.34	2,433.59–2,475.48	d
Total	37,227			

[1]LSM significant differences at $P = 0.05$; levels not connected by same letter are significantly different.

Table 4. Least squares means for 305-d milk yield (kg) by dry period length (DPL) category, with 95% CI

DPL category (d)	Observations (no.)	Predicted 305-d milk yield (LSM)	95% CI	Significance[1]
<40	464	10,200.96	10,016.35–10,351.95	a
40–49	4,241	10,621.96	10,606.76–10,785.03	b
50–60	17,115	10,817.48	10,851.51–11,002.96	c
61–70	11,025	10,830.94	10,858.59–11,017.70	c
>70	6,291	10,733.54	10,670.53–10,839.36	b
Total	38,672			

[1]LSM significant differences at $P = 0.05$; 1evels not connected by same letter are significantly different.

within the first 60 DIM were present among DPL categories.

After controlling for covariates (Table 5), culling risk between DPL 40 to 49 d and DPL 50 to 60 d was not statistically different. Compared with a DPL 50 to 60 d, DPL <40 and DPL >70 d showed culling risks of 1.53 (95% CI: 1.17–2.00) and 1.46 (95% CI: 1.33–1.60), respectively. The DPL 61 to 70 d had a slightly higher culling risk compared with DPL of 50 to 60 d with a hazard ratio (**HR**) of 1.13 (95% CI: 1.04–1.23).

As the interaction between DPL and parity was significant, parity groups were analyzed separately as follows: in LACT2, only DPL >70 d showed a significantly higher culling risk compared with other DPL categories (HR: 2.14; 95% CI: 1.72–2.68), whereas in LACT3+, culling risk followed a curvilinear pattern with culling risk being equally the highest for DPL <40 d (HR: 1.55; 95% CI 1.14–2.12) and DPL >70 d (HR: 1.37; 95% CI: 1.23–1.51) and the lowest, with no differences among each category, for DPL of 40 to 49 d and 50 to 60 d. A DPL of 61 to 70 d had a slightly but significantly higher risk for culling compared with DPL of 50 to 60 d (HR: 1.12; 95% CI: 1.02–1.24).

Association of DPL with Pregnancy Risk by 200 DIM

In the present study, the mean voluntary waiting period at farm level was 69 ± 9 d. From the survival curve for time to conception, we obtained an overall median of 123 d with an interquartile range (**IQR**) of 81 to 202 d. Second-lactation cows had median time to conception of 117 d (IQR: 80–187), whereas LACT3+ had a median of 130 d (IQR: 83–220 d). At farm level, the lowest median time to conception was 93 d (IQR: 79–136 d), whereas the highest was 194 d (IQR: 177 to >607 d, where 607 d is the largest returned value). It

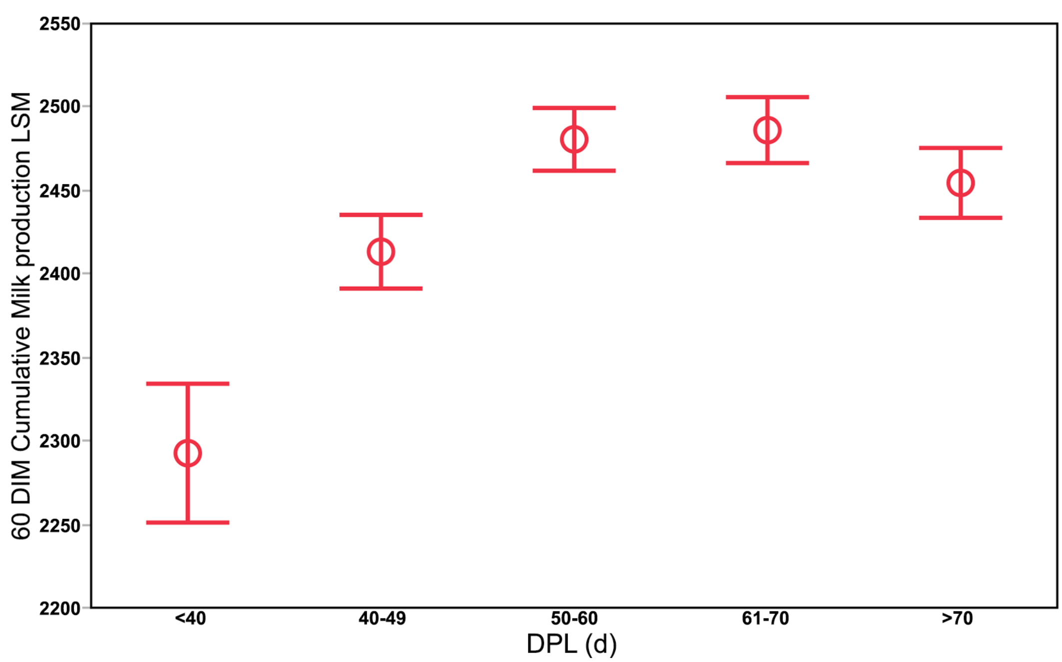

Figure 5. Association of dry period length (DPL) with 60 DIM cumulative milk production (kg). Error bars indicate 95% CI.

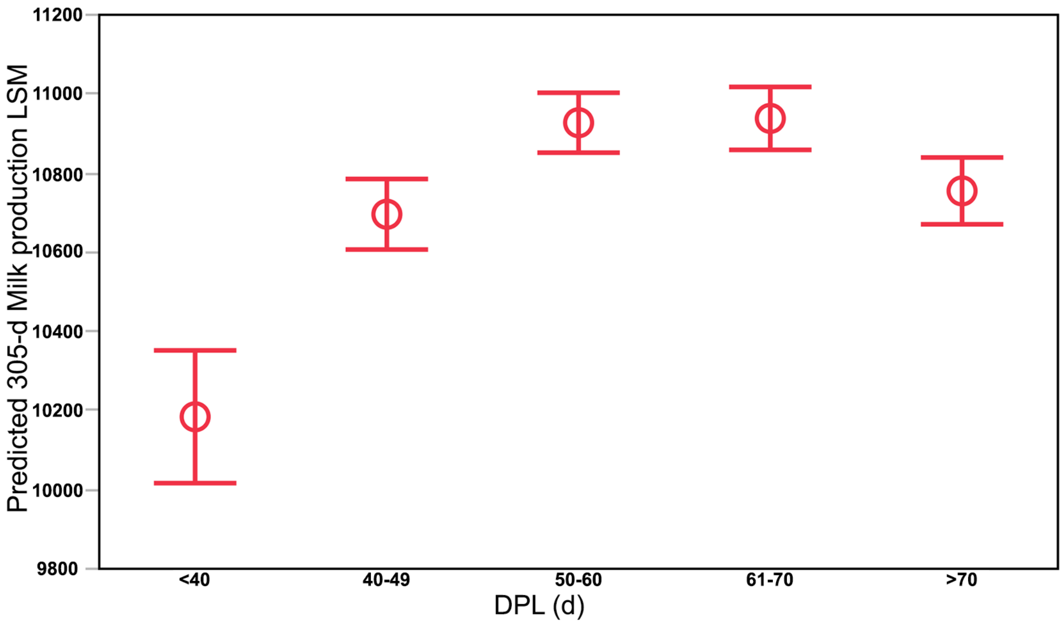

Figure 6. Association of dry period length (DPL) and predicted 305-d milk production (kg). Error bars indicate 95% CI.

was not possible to calculate the third quartile value for the farm with the highest median time to conception, as in the present data set this farm never reached 75% of cows being pregnant.

When accounting for farm, parity, previous lactation 305-d ME, month of calving, year of calving, cow breed, previous gestation length, previous calving-to-conception interval categories, DPL <40 d had significantly lower risk of pregnancy (HR: 0.87; 95% CI: 0.77–0.99) compared with DPL of 50 to 60 d. No significant difference was found in the risk of pregnancy for DPL of 40 to 49 d compared with DPL of 50 to 60 d (Table 6). Dry period length of 61 to 70 d and >70 d showed a small decrease in pregnancy risk compared with DPL of 50 to 60 d, with an HR of 0.95 (95% CI: 0.91–0.98) and 0.94 (95% CI: 0.89–0.98), respectively. In the current model, no significant interaction between DPL and lactation group was detected; thus, the interaction was withdrawn from the model.

DISCUSSION

It is a common concept to consider a dry period of 60 d as the gold standard, but in the past decade there has been a rise in interest toward reconsidering DPL. Research from the 1930s to the 1980s concluded that when considering milk production, a dry period of 56 d is optimal (Dias and Allaire, 1982). Different researchers hypothesized that reducing DPL could be potentially beneficial for reproductive efficiency, as described by Gümen et al. (2005), even if they did not support the hypothesis with enough cows per treatment group.

The aim of our study was to collect data from lactating dairy cows in different Italian commercial dairies and provide for the first time new information on the effect of DPL on milk production, culling risk, and fertility in Italian dairy cattle. The only data available on DPL in Italy are reported by Gallo et al. (2008), who

Table 5. Culling risk by 60 DIM and hazard ratios (HR) from Cox regression model for dry period length (DPL) categories

DPL category (d)	n	HR	95% CI	*P*-value
50–60	548	Referent	Referent	<0.0001
<40	4,932	1.53	1.17–2.00	
40–49	20,015	0.99	0.87–1.12	
61–70	12,844	1.13	1.04–1.23	
>70	7,785	1.46	1.33–1.60	
Total	46,124			

Table 6. Pregnancy risk by 200 DIM and hazard ratios (HR) from Cox regression model for dry period length (DPL) categories

DPL category (d)	n	HR	95% CI	*P*-value
50–60	548	Referent	Referent	<0.0001
<40	4,932	0.87	0.77–0.99	
40–49	20,015	0.97	0.93–1.02	
61–70	12,844	0.95	0.91–0.98	
>70	7,785	0.94	0.89–0.98	
Total	46,124			

found an average dry period of 67 d, with nearly 20% of cows with a DPL >80 d.

Milk Production

Several studies report a 9% reduction in milk yield with shortened (40 d) DPL, whereas in others, the observed milk loss was only around 1% with a DPL of 31 to 52 d (Pinedo et al., 2011; Khazanehei et al., 2015). As observed among experimental studies, milk production varies considerably; Safa et al. (2013) reported a decrease of 20% when shortening the DPL to 20 d, and Shoshani et al. (2014) stated that reduction for cows on a short (40 d) DPL was 4%. The results obtained by this study are similar to previous studies, which reported that cows with less than 40-d dry period produced less milk in the following lactation compared with cows with longer dry periods (Funk et al., 1987). Kuhn and Hutchison (2005) reported that minimum DPL of 50 to 60 d and 61 to 70 d maximized production across second lactations. Rastani et al. (2005) indicated that milk production from 1 to 70 DIM was greater in cows with 56-d versus 28-d dry period. In our study, we found that cows with a DPL of 50 to 70 d produced significantly more milk than cows with DPL <40 or >70 d, in agreement with Watters et al. (2008).

The association of DPL with cumulative milk yield at 60 DIM was considerably lower in early lactation for cows with previous short dry periods (<40 d). After controlling for significant variables, the LSM of 60 DIM cumulative milk yield was 199 and 193 kg lower for a short dry period (<40 d) compared with DPL of 61 to 70 d and 50 to 60 d, respectively. The largest value for relative milk yield in the first 60 DIM was for intermediate length of dry period with 50 to 60 d and 61 to 70 d. Likewise, the lowest 305-d predicted milk yield was for cows with a short previous dry period (<40 d; LSM = 10,200.96 kg). The greatest 305-d milk production was for the intermediate dry period categories 50 to 60 d (10,817.48 kg) and 61 to 70 d (10,830.94 kg). Some studies disagree with the present one, indicating no significant differences in subsequent lactation milk yield between shorter dry periods (30–35 d) compared with a conventional (42–60 d) dry period (Gulay et al., 2003; Pezeshki et al., 2007).

Other studies concur our one finding of no significant differences by parity group in the association between DPL and milk production, although shortening the dry period resulted in similar milk deficit compared with a standard dry period in both parity groups (van Knegsel et al., 2013; Chen et al., 2015). Conversely, Santschi et al. (2011) reported that shortening DPL decreased milk yield for cows in parity 2, but had no effect on the milk yield of older cows.

The decrease of milk production due to a shorter dry period observed in our study supports past findings in observational studies that reported a milk yield reduction of 1 to 5% (Dias and Allaire, 1982; Pinedo et al., 2011) and in experimental studies with 5 to 15% (Andrée O'Hara et al., 2018).

In addition to milk losses in the subsequent lactation reported in our study for shorter DPL, it is also useful to account for the milk being produced in late lactation before dry-off. Cows with shorter DPL will spend a few more days producing milk compared with longer DPL cows. This may be relevant, especially for herds where the production level is high or lactation curve persistency is strong. In our study DPL >70 d and 40 to 49 d showed a slight, but significant milk loss compared with DPL of 50 to 60 d and 61 to 70 d in agreement with Andrée et al. (2020).

Culling Risk

Categories of DPL were significantly associated with the culling risk during the first part of the lactation. Cows with previous short DPL (<40 d; RR: 1.53; 95% CI: 1.17–2.00) or longest DPL (>70 d; RR: 1.46; 95% CI: 1.33–1.60) had the highest odds of being culled by 60 DIM, when compared with the reference group (50–60 d).

Our findings of a higher hazard of culling in early lactation for short DPL disagree with reports that short or omitted dry periods lead to improvement of the metabolic status and energy balance in the early part of the subsequent lactation (de Feu et al., 2009; Andrée O'Hara et al., 2018). According to these studies a better energy balance is thought to reduce the incidence of metabolic diseases in early lactation (Lucy, 2001) despite other researchers found no effects of short DPL on animal health (Santschi et al., 2011). Short DPL are also associated with lower milk, protein, and fat yield across a lactation (Kuhn et al., 2006; Safa et al., 2013; Pattamanont and De Vries, 2021) but not necessarily during the peak of lactation. Some reports found that short DPL were associated with increased SCC (Kuhn et al., 2006), but others found no significant effects (Church et al., 2008; Watters et al., 2008) or a lower SCC (Gulay et al., 2003; Pinedo et al., 2011). Collectively, the hazard of culling is the net effect of these factors on culling decisions by dairy farmers. We found that both short and long DPL were associated with greater hazards of culling later in lactation. Pattamanont and De Vries (2021) reported that short and long DPL can be correlated with an increased risk of culling over the length of the lactation (1–450 DIM). In the same study, older cows appeared to be less affected by changes in DPL, in disagreement with our study where we found a significant increase in culling risk for long and short DPL for LACT3+ cows, whereas in LACT2 only DPL >70 d was significantly associated with increased culling risk. A similar small increase in the hazards of culling for short DPL was reported for large field studies with Holsteins (Kuhn and Hutchison, 2005) and Jerseys (Kuhn et al., 2007). A study with Polish breeds also found greater hazards of culling for short and long DPL (Sawa et al., 2012). In an experimental study with 850 cows, Santschi et al. (2011) found that DPL in second parity cows did not affect culling hazard, but it was significantly lower in multiparous cows following a short DPL. In a Swedish study, the odds of culling were lower in cows with DPL categories of 40 to 49 d and 50 to 59 d, and culling hazard was greater when DPL was >70 d. They also found that culling hazards following different DPL were not associated with breed or parity (Andrée O'Hara et al., 2020). Collectively, in agreement with our findings, the literature suggests that the hazards of culling tend to increase slightly with short and long DPL, compared with the reference DPL of 50 to 60 d.

Reproduction

In the observational study done by Pinedo et al. (2011), there were no differences in interval from calving to first insemination or to conception among DPL groups when comparing short dry periods (31–52 d) to conventional DPL. The number of services per conception was lower for cows with the shorter DPL, suggesting that those cows had a higher chance of being fertile. It is arguable whether fewer services per conception is a valuable measure in an observational study because other variables such as poor heat detection and long insemination intervals might affect conception. In the present study, the chosen metric to evaluate fertility was pregnancy risk by 200 DIM, as information regarding the first insemination outcome was not available for all farms. In our study we found that, compared with DPL of 50 to 60 d, DPL <40 d had the worst reproductive performance, and we detected lower odds for pregnancy in DPL of 61 to 70 d and >70 d. Time to conception is influenced by the voluntary waiting period length at farm level. As most of the farms in this study were performing the first insemination after an ovulation-synchronization protocol, there are not big differences in the voluntary waiting period among farms. Overall, our observations indicate that cows with a short and long DPL have a lower risk of pregnancy compared with cows with an intermediate DPL of 50 to 60 d. Pinedo et al. (2011) discovered cows with DPL >77 d had a longer interval to first insemination, longer calving-to-conception interval, and more services per conception compared with cows with a conventional DP.

Long DPL cows are known to be more prone to accumulate body fat. Probo et al. (2022) attributed the higher risk for assisted calvings in cows with DPL >70 d to the higher fat deposition in the birth canal. In the same study, assisted calvings had lower odds for pregnancy in the subsequent lactation. Cows with greater fat deposition are more prone to metabolic issues concerning calving (Duffield, 2000). Santschi, et al. (2011) reported that cows with a dry period longer than 2 mo were at higher risk of developing ketosis, which can negatively affect fertility in terms of first service conception rate (Walsh et al., 2007).

Kuhn et al. (2006) stated that cows with a short DPL had lower days open than cows with a conventional DPL. It was also observed that the favorable outcome for pregnancy at first insemination with short DPL was only a consequence of the decreased milk production and it resolved once when they corrected for milk production in the model. Watters et al. (2009) found no discrepancy in interval to first insemination, whereas Shoshani et al. (2014) reported a significant advantage for cows with short DPL. It seems likely that this is also a correlation of the improved energy balance and reduced milk production.

In our study, part of the negative association between long DPL and fertility observed in other studies, attributed to negative energy balance, might be mitigated by the long average voluntary waiting period of our data set (69 ± 9 d). It is interesting to notice that in the present study, no difference was detected among parity groups in the association between DPL and fertility, which agrees with Andrée O'Hara et al. (2019).

We realize that some limitations are part of our study, as the enrolled farms were well above the average Italian herd from size and management point of view, and the majority of cows were Holsteins. We believe that the strength of our work is in the ability to compare farms with different type of management, housing, feeding practices, and production level, using detailed high-quality Italian records and performing a deep analysis about DPL.

Future line of research may address the association between DPL and transition disorders. Moreover, it could be interesting to define for each herd the optimal DPL based on milk production and fertility.

CONCLUSIONS

This paper is, to our knowledge, the first of its kind using DPL data from Italian herds. As dry period is one of the key factors for the success of a dairy enterprise, it may be very useful to have more insight on this subject, to allow producers to manage the dry period in the best possible way. Dry period length has been largely debated and, in many cases, it is established based on management choices, milk production, and reproductive management. Our study shows evidence that an intermediate DPL can maximize milk production without negatively affecting culling and fertility. It reinforces the importance of reducing DPL variability and avoiding DPL that are too long or too short. Our data might allow producers to make the best choices on DPL, establishing the best time for drying off cows and by maximizing milk production and fertility in a virtuous cycle.

ACKNOWLEDGMENTS

This study received no external funding. We thank all farmers involved in this project. The authors have not stated any conflicts of interest.

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