Event-Time Analysis of Reproductive Traits of Dairy Heifers

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ABSTRACT

Data on the reproductive traits of dairy heifers were analyzed using event-time techniques. Traits analyzed were age at first calving (n = 4631), days to first breeding, and days open (n = 1992) during the first lactation. A proportional hazard model was used that included fixed effects of herd-year, year-season, breed type, herd weight, and heifer weight. Body weights were recorded at 390 d of age, on average. The model for days open and days to first breeding included two additional fixed effects of herd and heifer milk yield at 100 d. A significant effect of heifer weight category on age at first calving was found. The chance of calving was consistently higher for herds and heifers with higher body weight at 390 d and decreased linearly from the top to the lowest quartiles. The effects of herd weight category on days to first breeding and days open were significant. Heifers in herds with a higher average body weight were less likely to be bred, and heifers in herds with lower average body weight were less likely to get pregnant. The effect of heifer weight category on days to first breeding or days open was not significant. The effect of herd milk yield on days to first breeding was significant. Heifers in herds with lower yield were more likely to be bred. The effect of heifer milk yield category on days to first breeding and days open was significant, but no linear trend was found for the estimates of the hazard ratios. The chance of a heifer being bred and becoming pregnant was similar among the first three quartiles and was lower for heifers in the lowest quartile. The probability of a heifer reaching a first calving can be improved by increasing the body weight at 390 d. Body weight at 390 d did not appear to have a large effect on reproductive performance after first calving. High milk yield appears not to have a large negative effect on days open, at least for the milk yield levels analyzed in this study.

(**Key words**: event-time analysis, dairy heifers, age at first calving, days open)

INTRODUCTION

Reproductive performance has a large impact on the economy of dairy farms (3, 14, 18), and factors that affect reproductive performance of dairy cattle have been extensively documented (5, 11, 12, 13, 15). Several, mainly linear, regression techniques have been applied to the analysis of reproductive traits. A disadvantage of these techniques is that they are not able to account for heifers that lack information on the trait under analysis [i.e., heifers that do not have a calving or conception date (1, 8, 11, 15)].

Several techniques allow a nonlinear analysis, such as logistic analysis, discriminant analysis, and event-time regression, and are more suitable for the analysis of reproductive traits. Event-time regression, also known as survival analysis or failure data analysis, enables the use of data on the reproductive traits of cows that have only partial records for a specific trait [i.e., cows that did not calve or become pregnant by the time at which data for the study were collected (1, 8, 11, 15)]. This methodology has been employed for the analysis of data when the outcome variable corresponds to the measure of the time elapsed from some starting point until the occurrence of an awaited event (11). The length of this interval may not be known because, prior to the event time, competing events may intervene and preclude further observation as occurs, for example, when cows are culled or sold. Additionally, the results obtained from event-time analysis are given in the form of time-specific probabilities, which can be included in bioeconomic models (15). Time-dependent covariates can also be added to the analysis (10) to enable measurement of the effect of a given risk factor on a response variable

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as well as the ability to model this effect along the time during which the individual is exposed to the factor.

An analysis of the effect of body weight on age at first calving using event-time regression has not been documented. Previous results, using mainly linear regression techniques, seem to agree that the onset of puberty and the chance to get pregnant are more related to growth parameters (i.e., body weight and size) than to chronological age (2, 9, 16, 17, 21). Conversely, the relationship between weight at first calving and subsequent reproductive performance does not appear to be strong (17). However, little is known about the strength of this relationship at the herd level.

The use of an event-time approach to analyze days open for dairy cattle has received considerable attention in recent years. Research has mainly focused on the effect of risk factors such as disease incidence, time-dependent covariates, milk yield category on days open, or days to first breeding (1, 11, 12, 13). Two studies (11, 12) indicate that 60-d milk yield has a minimal effect on pregnancy rate, and only cows with a very high milk yield category had a lower rate of conception than that of their herdmates. A third study (8) has found that cows in the highest category for cumulative individual 60-d milk yield show an increase of median days open and a 29% higher number of services per conception than do cows in the lowest category. Differences in the available results could be related to the way in which herd management practices are accounted for in the analysis. Herds with higher mean milk yields are associated with higher chances of conception (11, 12).

In this study, event-time regression is used to quantify the effect of breed type, herd weight level, and individual weight on the age at first calving. In addition, an analysis is performed of days to first breeding and days open postpartum to quantify the effect of herd as well as individual body weight and milk yield.

MATERIALS AND METHODS

Data Source

The analysis was performed on data provided by Universidad Nacional de Costa Rica (Heredia, Costa Rica). These data were collected from 1987 to 1994 on dairy farms in Costa Rica. Farms participated in a project that focused on the collection and analysis of data about health, milk yield, and reproduction performance (7) in order to provide advice to farmers and to identify adequate management practices. Body weight records, reproductive events, daily milk yield, and herd characteristics were entered in a modified version of the VAMPP software package (19) by the staff of Universidad Nacional de Costa Rica or directly by farmers.

Records of body weight were collected at fixed dates every 2 mo by a research team using either an electronic scale or heart girth measurements. Consequently, age at sampling was not uniform for all heifers. Data on milk yield and reproductive performance were collected either by the farmer using farm-owned equipment or by the research team. The frequency of milk sampling varied between daily to monthly recording schemes. The integrity and accuracy of this information were assessed by internal controls available within the software based on biological feasibility, population parameters, and the previous history of the individual heifer.

Trait Definition and Data Editing

For the analysis of age at first calving, heifers were used that had a record for body weight at 390 d of age. Heifers without records for body weight or heifers that were culled before 390 d were not included in the analysis. As a consequence, to fulfill the requirements of event-time regression analysis, the starting point of the measurement period was considered to be 390 d and not the date of birth.

Days to first breeding postpartum was defined as the period between first calving and the first recorded service. Days open was defined as the period between first calving and the day of subsequent pregnancy. Pregnancy was confirmed by a calving date. Body weight at 390 d of age and milk yield at 100 d of lactation were obtained by linear interpolation procedures from the individual observations. Heifers were required to have at least two records for body weight for the period from 9 to 17 mo of age. For the calculation of milk yield at 100 d of lactation, heifers were required to have at least 1 test day record in the periods 5 to 50, 50 to 100, and 100 to 150 d after calving (i.e., a minimum of three records before 150 d after calving).

Following the conventions of event-time analysis, all heifers that had a date of first calving, date of first service, or a date of pregnancy were considered to have a failure rate; therefore, this record was considered as being uncensored. Heifers that did not have a failure date were considered as having censored records, and the date of censoring had to be available. As performed in earlier research (11), for the present analysis, the record was considered to have been censored at the last date for which any herd record existed for that heifer. According to the information available in the data file, this date could have corresponded to a date of sampling (i.e., body weight or milk yield), a reproductive event, or a culling date.

Model

A semiparametric Cox proportional hazards model (4) was fitted to the data using The Survival Kit package (6). The model is represented as follows:

$$\lambda(t;\mathbf{x}) = \lambda_0(t)e^{(\mathbf{x}'\beta)}$$

where

$\lambda(t;\mathbf{x})$ = hazard of event for a heifer at time t with covariate $\mathbf{x}$,
$\lambda_0(t)$ = baseline hazard function describing the hazard of event for an hypothetical situation when all covariate values are set to zero, and
$e^{(\mathbf{x}'\beta)}$ = term specific to individuals with covariate $\mathbf{x}$ that is always positive and acts multiplicatively on the baseline hazard function.

The model is a semiparametric model because it does not require specification of a distribution for the baseline hazard function. The effects of the covariates on the event times are of a parametric form. The set of covariates $\mathbf{x}$ was defined:

HY_i = fixed effect of herd-year i in which the sample was taken (i = 1 to 222),
YS_j = fixed effect of year-season j in which the sample was taken (j = 1 to 15),
$BREED_k$ = fixed effect of breed type k (k = 1 to 3),
H_WE_l = fixed effect of herd weight category l (l = 1 to 3), and
C_WE_m = fixed effect of heifer weight category m (m = 1 to 4).

For the analysis of days to first breeding and days open, two additional effects were added to those already mentioned:

H_MY_n = fixed effect of herd milk yield category n (n = 1 to 2), and
C_MY_o = fixed effect of heifer milk yield category o (o = 1 to 4).

Heifers included in the analysis were of the following breed types: Holstein, Jersey, Guernsey, Brown Swiss, and combinations of *Bos taurus* × *Bos indicus* and *B. taurus* × *B. taurus* breeds. Because of the low number of records for some of the breed types, only three classes were formed (Holstein, Jersey, and others). Approximately 80% of the heifers included in the third breed class were Brown Swiss crosses. Two seasons were defined according to rainfall profiles for the regions where the farms were located. The length of the seasons ranged from 4 to 8 mo and accounted for climatic characteristics of the region (26).

The use of categorized variables was performed in order to look at possible nonlinear effects and to account for differences in variance within herds. Herd weight category (i.e., H_WE) was defined within every breed type by classifying the herds into three classes according to the average body weight of heifers at 390 d. Herds in class 1 (H_WE1) were those located in the top quartile, herds in H_WE3 were those located in the lower quartile, and herds in H_WE2 were those located in the second and third quartiles. This classification was intended to stratify the herds according to possible differences in genetic level for body growth or differences in management during the rearing period.

Heifer weight categories (i.e., C_WE) were defined by classifying the heifers within herds and breeds into four classes according to body weight at 390 d of lactation. Heifers in the highest category (C_WE1) had a body weight that was at least one standard deviation higher than the corresponding mean. Heifers in the lowest category (C_WE4) were those that had a body weight that was more than one standard deviation below the corresponding mean. Heifers in categories C_WE2 and C_WE3 were above or below the population mean but deviated less than one standard deviation from the mean, respectively. Body weight at 390 d was first adjusted for the factors of breed, herd-year-season, and herd weight and for significant interactions among factors. Adjustment factors were obtained from a least squares analysis (22).

Herd milk yield category (i.e., H_MY) was defined within every breed type by classifying the herds into two classes according to the median 100-d milk yield. Herds in class H_MY1 were those above the median, and herds in class H_MY2 were those located below the median. This classification was intended to stratify the herds according to differences in genetic level for milk yield or differences in management during the lactation.

Heifer milk yield categories (i.e., C_MY) were based on milk yield adjusted for factors of breed, herd-year-season, herd milk yield, and significant interactions. Adjustment factors were obtained from least squares analysis (22). The categories were defined by classifying the heifers into four categories according to the 100-d milk yield. Heifers in class

TABLE 1. Descriptive statistics of variables under analysis.

Factor	Age at first calving	Days to first breeding	Days open
Total records, no.	4631	1992	1992
Right censored records, no.	1087	69	183
Minimum censoring time, d	391	19	19
Maximum censoring time, d	760	436	610
Mean censoring time, d	456.1	155.0	183.5
Uncensored records, no.	3544	1923	1809
Minimum failure time, d	541	16	22
Maximum failure time, d	1751	220	338
Mean failure time, d	843.7	76.5	109.8
Herds, no.	73	48	48
Heifers per herd, no.	63	42	42
Years under analysis, no.	8	7	7

C_MY1 were those that had a 100-d milk yield that was at least one standard deviation above the population mean. Heifers in class C_MY4 were those that had a 100-d milk yield that was more than one standard deviation below the population mean. Heifers in classes C_MY2 and C_MY3 were above or below the population mean but deviated less than one standard deviation from the mean.

Construction of the Final Models

To assess the effect of heifer weight and heifer milk yield on the response variables, initial models were fitted to the data, including all main effects and relevant two-way interactions. This model was refined by following a backward elimination procedure dropping progressively nonsignificant effects using the chi-square probability test. The final model included the effects under analysis, all other significant main effects, and two-way interactions.

In order to assess the effect of herd weight and herd milk yield on the response variables, a reduced model was also fitted to the data. This reduced model included all effects in the full model except for herd-year, which, because of the large number of classes, would also explain the variance caused by herd weight and herd milk yield. Thus, results for test of significance and hazard ratios for herd weight and herd milk yield are given according to this reduced model.

The Survival Kit (6) pursues the maximization of the −2 log likelihood through an iterative procedure ending at a given convergence criterion, which, in the present analysis, was set to a value of 1×10^{-8}.

Coefficient estimates of the survivor function and hazard ratios were obtained for all classes within factors included in the final model. An additional analysis was performed stratifying the data file according to heifer weight and heifer milk yield categories in order to obtain Kaplan-Meier estimates of the survivor function for the different strata and to compare the pattern of the survival curves among strata.

RESULTS AND DISCUSSION

Age at First Calving

The mean age at first calving was 843.7 d (Table 1). A total of 23.5% of the heifers with a recorded body weight did not have a subsequent calving date. The number of censored records appears to be large; however, this situation could be due to the large variation and the high mean for age at first calving. In addition, only heifers with a confirmed date of calving were considered as having a failure date. All other heifers were included within the censored population, which consisted mainly of heifers undergoing pregnancy or heifers still waiting to be bred. A few other heifers left the herd because of disease or death or were sold for dairy purposes to other farms.

The range of variation in body weight at 390 d for classes of breeds, herd weight, and heifer weight was 60.2, 65.2, and 95.9 kg, respectively (Table 2). The

TABLE 2. The mean and standard deviation of body weight and milk yield of individual heifers in different categories.[1]

Factor	Class	n	$\overline{X}$	SD
	Body weight			
	General	4631	252.6	51.8
Breed	Holstein	2526	271.5	50.3
	Jersey	1269	211.3	34.3
	Others[2]	836	258.3	41.8
Herd weight	H_WE1	1602	277.9	44.7
	H_WE2	2241	248.6	49.9
	H_WE3	788	212.7	41.4
Heifer weight	C_WE1	570	307.0	44.8
	C_WE2	1838	261.8	46.1
	C_WE3	1637	238.3	44.1
	C_WE4	586	211.1	41.9
	Milk yield			
	General	1992	1897.8	540.9
Breed	Holstein	1114	2127.8	542.6
	Jersey	592	1586.8	362.9
	Others[2]	286	1646.0	387.0
Herd milk yield	H_MY1	1016	2151.5	521.6
	H_MY2	976	1633.7	421.2
Heifer milk yield	C_MY1	288	2482.0	493.3
	C_MY2	727	1983.7	474.7
	C_MY3	696	1728.6	435.3
	C_MY4	281	1496.1	416.1

[1]Yields within category were adjusted for variation from other factors.

[2]Approximately 80% of the heifers included in this class were Brown Swiss crosses.

TABLE 3. Chi-square values for factors included in the final model for the continuous traits age at first calving, days to first breeding, and days open.

Factor	Age at first calving			Days to first breeding			Days open		
	df	χ^2	$P > 0$	df	χ^2	$P > 0$	df	χ^2	$P > 0$
Herd year	221	1187.0	0.01	167	308.8	0.01	167	278.5	0.01
Year season	14	57.04	0.01	12	8.19	0.77	12	4.25	0.98
Breed	2	3.88	0.14	2	19.13	0.01	2	14.20	0.01
Herd weight[1]	2	454.4	0.01	3	13.66	0.01	3	16.77	0.01
Herd milk yield[1]	...	...	...	1	9.96	0.01	1	0.49	0.48
Heifer weight	3	79.14	0.01	3	2.45	0.48	3	3.65	0.30
Heifer milk yield	...	...	...	3	22.17	0.01	3	9.54	0.02

[1]These two effects were assessed by fitting a reduced model. The reduced model was the full model without the herd year effect.

range of variation in milk yield at 100 d for classes of breeds, herd milk yield, and heifer milk yield was 541.0, 517.8, and 985.9 kg, respectively (Table 2). These values indicate that variation is high not only between herds but also among heifers within herds. This large variation is likely due to the great diversity in feeding regimens, climatic conditions, and genetic composition that characterizes dairy farming in Costa Rica (24, 25, 26, 27).

Factors that had a significant effect on the continuous variable age at first calving (Table 3) were herd-year, year-season, and heifer weight category. Breed type was not significant. Effect of herd weight category, assessed by the reduced model, was significant. Two-way interaction effects were not significant.

Estimates of hazard ratios for breed type, although not significant, indicated that Jersey heifers were 1.18 times more likely to calve than were Holstein heifers (Table 4). The third breed category, mainly Brown Swiss crosses, was also 1.10 times more likely to calve than were Holstein heifers. These differences in the hazard ratios might be because Holstein cows in the tropics are more likely to present fertility problems, and, therefore, a higher proportion do not achieve a first calving (20).

According to the reduced model, effect of herd weight on age to first calving was significant (Table 3), which illustrates that herd weight explains a significant proportion of the variation between herds. The hazard ratios suggest that the probability of calving is higher for heifers from herds in a higher herd weight category. For example, heifers from herds in class H_WE1 were 1.18 times more likely to calve than were heifers from herds in class H_WE2; heifers from herds in class H_WE3 were only 0.91 times as likely to calve as heifers in H_WE2 (Table 4). It is likely that heifers from herds in the top weight categories are reared more intensively and that more attention is dedicated to feeding, disease control, and breeding. Substantial differences in the feeding systems within the population under analysis have been documented (24). It has been demonstrated that the effect of environmental factors on the survival rate of European breeds raised in the tropics is a factor of major importance (20). Differences in genetic level and breeding policies for the herds included in this study have also been documented (27).

The most important finding from this analysis was the significant difference in the chance of parturition for heifers in different heifer weight categories (Table 3). The trend suggests that the probability of calving becomes higher for heifers with a higher body weight at 390 d. For heifers in class C_WE1, the chance of calving was 1.25 times higher than for heifers in class C_WE2 (Table 4); heifers in classes C_WE3 and

TABLE 4. Estimates of hazard ratios for age at first calving for classes within factors.

Factor	Class	β[1]	SED[2]	Hazard ratio[3]	Uncensored failure
Breed	Holstein	0.00	...	1.00	1976
	Jersey	0.16	0.08	1.18	952
	Others[4]	0.10	0.16	1.10	616
Herd weight	H_WE1	0.17	0.17	1.18	1208
	H_WE2	0.00	...	1.00	1806
	H_WE3	–0.09	0.17	0.91	530
Heifer weight	C_WE1	0.22	0.06	1.25	399
	C_WE2	0.00	...	1.00	1471
	C_WE3	–0.19	0.04	0.83	1324
	C_WE4	–0.35	0.06	0.70	350

[1]Regression parameter of the survivor function.

[2]Standard error of difference between β in this class and the largest class.

[3]Hazard ratios within factor are given relative to the hazard for the largest class, which is set to 1.0.

[4]Approximately 80% of the heifers included in this class were Brown Swiss crosses.

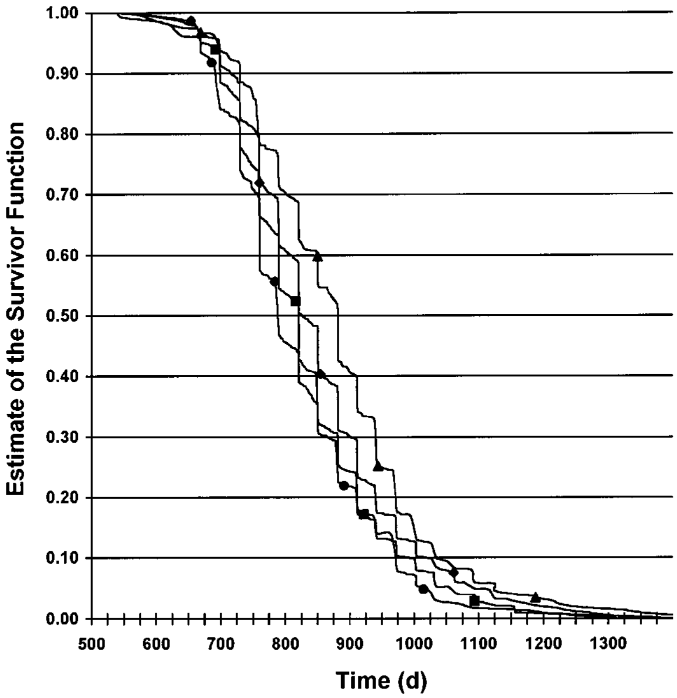

Figure 1. Kaplan-Meier estimates of the survivor function for trait age at first calving within heifer weight strata: C_WE1 (●), C_WE2 (■), C_WE3 (▲), and C_WE4 (♦).

C_WE4 were only 0.83 and 0.70 times as likely to calve as heifers in C_WE2. Other studies (2, 9, 16, 17, 21), using different techniques, have also shown that growth parameters are inversely related to age at puberty or age at first calving. Our study showed that the body weight of heifers also had an effect on the chance of the heifer to have a subsequent parturition. It is likely that onset of puberty could be delayed and that fertility could be reduced in underfed heifers.

The plot of the survivor function (Figure 1) within heifer weight category shows that the survival curves for heifers in the third and fourth quartiles are higher than those for heifers in first and second quartiles. For almost any age, the survival probability (i.e., the heifer does not have a record of first calving) is higher for heifers with lower body weight. In other words, the chance of a failure (i.e., the heifer reaches parturition) is lower for heifers with lower body weight. This result is in agreement with the results obtained with the hazard ratios.

The irregular shape of the curves (Figure 1) is due to the tendency of censoring times to be grouped. As stated previously, censoring dates were defined on the basis of the last recorded event for the heifer. Further analysis of the data set showed that, for a large proportion of the heifers, this event corresponded to the measurement of the body weight, which was predicted by interpolation at 5-mo intervals; therefore, the stepwise pattern arises.

Days to First Breeding and Days Open

The unadjusted mean for days to first breeding and for days open was 76.5 and 109.8 d, respectively (Table 1). The number of records was low because heifers included in this analysis were required to have information on 390-d body weight and 100-d milk yield. The number of heifers that did not have a first service was 45 for Holsteins, 12 for Jerseys, and 12 for other breeds. According to the full model, factors with a significant effect on both continuous traits (Table 3) were herd-year, breed type, and heifer milk yield category. The effect of heifer weight was not significant. The effect of herd weight, assessed by fitting the reduced model, was significant. The effect of herd milk yield, also assessed by fitting the reduced model, was significant only for the variable days to first breeding. Two-way interaction effects were not significant.

Estimates of hazard ratios (Table 5) indicated that Jersey heifers and heifers in the third breed class were 1.64 and 1.73 times, respectively, more likely to have a first service than Holstein heifers. The ratios obtained for days open for the same breed types were 1.52 and 1.42, respectively. This result seems to indicate, as found with age at first calving, that Holstein heifers have a lower chance of getting pregnant and also a lower chance to be bred. The relatively low reproductive performance of European breeds in the tropics has also been documented in previous research (20).

According to the analysis of days to first breeding (Table 5), heifers from herds classified in H_WE1 had a lower chance of being bred. In contrast, results for days open indicate that heifers in H_WE3 were only 0.68 times as likely to become pregnant as were heifers in H_WE2; thus, heifers from herds with higher body weight at 390 d have more chance of getting pregnant. This contradictory result could be explained by differences in breeding policies before and after first breeding. It seems necessary to confirm this result by characterizing breeding policies within herd categories, which was not possible with the available data set.

For heifer weight categories, the values of hazard ratios tended to be linear for days to first breeding, but not significantly (Table 5). The ratios indicate that heifers with a higher body weight at 390 d of age

TABLE 5. Estimates of hazard ratios for classes within factors for the traits days to first breeding and days open.

		Days to first breeding				Days open			
Factor	Class	n[1]	β[2]	SED[3]	HR[4]	n	β	SED	HR
Breed	Holstein	1066	0.00	. . .	1.00	1007	0.00	. . .	1.00
	Jersey	581	0.49	0.11	1.64	562	0.42	0.11	1.52
	Others[5]	276	0.55	0.21	1.73	240	0.35	0.22	1.42
Herd weight	H_WE1	575	–0.42	0.21	0.66	525	–0.03	0.21	0.98
	H_WE2	1052	0.00	. . .	1.00	1004	0.00	. . .	1.00
	H_WE3	296	–0.10	0.27	0.91	280	–0.39	0.27	0.68
Heifer weight	C_WE1	990	0.07	0.08	1.07	943	0.10	0.08	1.11
	C_WE2	933	0.00	. . .	1.00	866	0.00	. . .	1.00
	C_WE3	243	–0.01	0.06	0.99	223	0.09	0.06	1.10
	C_WE4	759	–0.08	0.08	0.93	715	0.11	0.08	1.12
Herd milk yield	H_MY1	665	0.00	. . .	1.00	631	0.00	. . .	1.00
	H_MY2	256	0.27	0.37	1.31	240	0.15	0.39	1.15
Heifer milk yield	C_MY1	278	–0.13	0.08	0.88	259	–0.08	0.08	0.92
	C_MY2	717	0.00	. . .	1.00	678	0.00	. . .	1.00
	C_MY3	678	–0.09	0.06	0.92	638	–0.05	0.06	0.95
	C_MY4	250	–0.37	0.08	0.69	234	–0.25	0.08	0.78

[1]Uncensored failure.

[2]Regression parameter of the survivor function.

[3]Standard error of difference between β in this class and the largest class.

[4]Hazard ratios within factor are given relative to the hazard for the largest class, which is set to 1.0.

[5]Approximately 80% of the heifers included in this class were Brown Swiss crosses.

had a slightly higher chance of being bred after the first calving. For days open, the estimates did not follow the same linear trend and were not significant. These estimates seem to indicate that differences in body weight at 390 d do not have a large effect on reproductive performance after calving.

Estimates of hazard ratios for herd milk yield indicate that heifers in the low category were 1.31 times more likely to be bred than were heifers from herds in the high category. The respective value for days open decreased to 1.15 and was not significant (Table 3). Another study (12) showed a maximum range of 5% for heifers and 13% for heifers from herds classified in four categories of milk yield and a higher chance of conception for heifers from herds with lower milk yield. This result was similar to the estimates found in the present study and might indicate that herds with higher milk yield also have a higher incidence of reproductive problems and, therefore, longer days open.

Significant differences were detected among heifer 100-d milk yield categories (Table 3). The estimated hazard ratios (Table 5) show a nonlinear effect of milk yield on days to first breeding and days open. Heifers in the top three classes had a similar probability of being bred or becoming pregnant; the chance was much lower for heifers with the lowest milk yield (i.e., C_MY4). To confirm these results, the survivor function for days open was plotted for heifers stratified by milk yield categories (Figure 2). This plot shows that the survival curve for heifers in the fourth quartile (i.e., C_MY4) is consistently higher than survival curves for heifers in the third, second, and first quartiles, in the same order. It is important that the main differences are for heifers with the lowest milk yield, as found with the hazard ratios. The main differences appear only after 100 d from the calving date, which might reflect that these heifers were probably no longer being inseminated.

An earlier study (8) has shown that the effect of milk yield on conception rate is minimal. Another study (12) has found a lower conception rate for high yielding heifers but not for cows. In theory, cows with a high milk yield are expected to have more days open because of the negative effect of milk yield on energy balance and reproductive performance. Our analysis does not fully support this effect because heifers in the highest milk yield category showed only a slightly lower chance to be bred and to become pregnant, and the difference among the survival curves for the three first categories was not clear. In contrast to some results of previous research (12), the chance of calving was the lowest for heifers with the lowest milk yield, which could be the result of an unidentified management practice rather than a result of genetic factors. The effects of management strategies on days open have been previously documented (9, 23). Farmers likely do not show the same interest in breeding low yielding heifers.

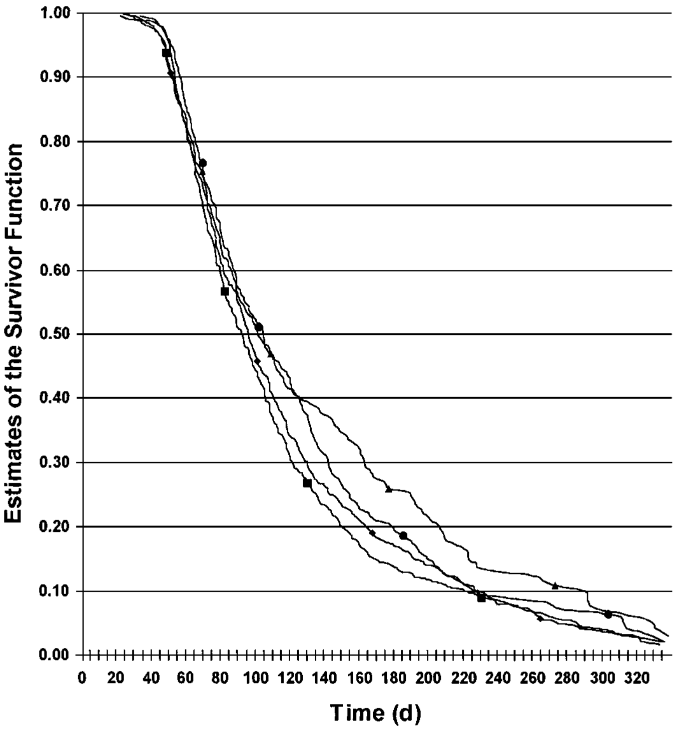

Figure 2. Kaplan-Meier estimates of the survivor function for trait days open within heifer milk yield strata: C_MY1 (■), C_MY2 (♦), C_MY3 (●), and C_MY4 (▲).

CONCLUSIONS

Herd differences in body weight appear to have a significant effect on age at first calving. There is also a significant effect of body weight of individual heifers at 390 d on age at first calving. An increment in body weight increases the probability that a heifer will reach a first calving. Body weight at 390 d seems not to have a large impact on days to first breeding or days open.

Heifers from herds with higher average body weight at 390 d appeared to have a lower probability of being bred after calving, but the contrary was demonstrated for days open. Further analysis is needed to identify management practices before and after breeding that could cause this effect. Body weight of heifers at 390 d appeared not to have an important effect on reproductive performance after first calving. Heifer milk yield seemed to have a nonlinear effect on days open. Heifers with higher milk yield had a slightly lower chance of being bred; however, management practices seem to be more important for the situation analyzed here because the heifers with the lowest yield had the lowest chance of being bred and getting pregnant. Days open and days to first breeding in Costa Rica are closer to the goals than in most US dairies. Management practices and production level might explain these phenomena. The differences in reproduction and performance levels are expected to have a small effect on the results of this study.

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