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Productive and reproductive losses associated with abortion in specialized dairy cattle from Costa Rica

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ABSTRACT

Abortions can negatively affect a dairy farm's milk yield, reproductive efficiency, and profitability. Despite the recognized economic losses associated with abortions, the reproductive and productive detriments caused by abortion have not been estimated in dairy cattle in tropical productive conditions such as those in Costa Rica. Therefore, this study aimed to evaluate the potential productive and reproductive losses caused by abortions in dairy cattle from Costa Rica. The reproductive and productive losses caused by abortion were estimated using a dataset with 953,181 complete lactations from 322,873 cows belonging to 1,133 Costa Rican specialized dairy herds. Abortions were classified as early fetal mortality (EFM) and late fetal mortality (LFM). The number of services per conception (NSPC) and calving to effective conception interval (CECI) indicated the reproductive losses. The productive losses were indicated by the DIM per lactation and per cow, productive lifetime, 305-d milk yield per lactation (305-d MY), total milk yield per lactation (TMYPL), and total lifetime milk yield per cow (LTMY). Generalized linear mixed models were adjusted by cow breed, parity, and ecozone, using farm and cow as random effects. Cows that experienced an EFM during the lactation had NSPC increase by 1.61, CECI by 8 d, DIM per lactation by 11 d, 305-d kg by 283 kg, and TMYPL by 297 kg. Cows that experienced a LFM during the lactation had an increase of 0.22 NSPC and a reduction of 33 DIM per lactation, 201 d of productive lifetime, 1,006 kg of 305-d MY, and 1,518 kg of TMYPL. Furthermore, as the parity with abortions increased from 0 to 3 or more, the DIM per cow increased. Still, we found no significant difference in the LTMY when the number of lactations with abortions increased. These results illustrate the impact of abortions on the reproductive and productive performance of cows and, consequently, on the profitability of dairy herds from a tropical country like Costa Rica.

Key words: bovine, abortion, economic impact, productive losses

INTRODUCTION

Reproductive indices are one of the most important factors influencing the profitability of a dairy farm because they affect milk production, breeding costs, culling rates and genetic progress. Breeding efficiency is strongly influenced by the general management of the farm and the personnel involved in herd health, feeding, and insemination (De Vries, 2006). Specifically, poor reproductive performance may be due to poor heat detection, fertility problems, or pregnancy losses (Melendez and Pinedo, 2007).

Pregnancy losses in cattle, such as abortions (defined as a pregnancy loss between 42 and 260 d after conception; Markusfeld-Nir, 1997), may negatively affect a dairy farm's profitability by reducing milk yield and the number of herd replacements. Furthermore, abortions can cause an increase in the number of services per conception (**NSPC**) for the next successful conception and the proportion of involuntary culling of the herd (Lee and Kim, 2007; Gädicke et al., 2010; El-Tarabany, 2015).

Due to their different economic implications, it is essential to distinguish bovine abortions on whether or not they were observed by the farmer (Gädicke and Monti, 2013), if the cow had suffered a previous abortion (Keshavarzi et al., 2017), and if the abortion originated a new lactation (Keshavarzi et al., 2020). Observed abortions usually occur when the fetus is between 120 and 260 d of pregnancy; on d 42 to 120, the fetus is generally so small that the farmer does not observe it, or the fetus is reabsorbed by the cow (Mee, 2020). When the fetus is reabsorbed, the only evident indirect sign of abortion is the cow's return to service; hence, it can be referred to as inferred abortion (Mee, 2020). The incidence rate of inferred abortions can be greater than observed abortions (Gädicke and Monti, 2013) and should therefore not be

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ignored. In addition, cows with a previous abortion have an increased risk of a new abortion (Rafati et al., 2010), and cows that undergo an abortion that starts a new lactation have a more significant decrease in milk yield and, consequently, a larger economic loss than cows that suffer an abortion and do not start a new lactation (Keshavarzi et al., 2020). Furthermore, cows that undergo an abortion have an increased risk of being culled (Bell et al., 2010; Keshavarzi et al., 2020).

Estimations of financial loss associated with abortion range from US$143 per abortion (Gädicke et al., 2010) based on Holstein cows in Chile to US$2,333 per abortion in the United States (De Vries, 2006; Lee and Kim, 2007). These estimations include cost for treatment, feeding, labor, replacement heifers, loss of the calf, NSPC, and premature culling (Lee and Kim, 2007; Gädicke et al., 2010; El-Tarabany, 2015), which can be very different between countries. Although the direct consequence of abortion is producing fewer calves, other indirect effects lead to further loss. A single abortion case can extend the calving interval by 46 to 120 d and the NSPC by 1.0 to 1.6 units (Gädicke et al., 2010; El-Tarabany, 2015; Keshavarzi et al., 2020). Additionally, it can diminish milk production performance with estimates ranging from 894 to 950 kg for 305-d MY, 0.8 L/d for average milk yield, and 0.5 yr for the productive lifetime of the cow (Gädicke et al., 2010).

Although it is well known that abortions are a major cause of financial losses in the dairy industry, the extent of these losses varies widely depending on several factors, including management practices, herd size, and environmental conditions. However, most of the available research and reports on this topic are from temperate regions, where the dynamics of cattle production and disease prevalence may differ substantially from those in tropical areas such as Costa Rica. These knowledge gaps limit our understanding of the economic and biological impact of abortion under different production conditions. Addressing this knowledge gap is essential for developing targeted strategies to improve herd health and productivity in tropical dairy systems.

Therefore, this study aimed to estimate the potential productive and reproductive losses caused by bovine abortions considering the production conditions of specialized dairy cattle from Costa Rica.

MATERIALS AND METHODS

Herds and Management

A retrospective study using data from January 1, 2010 to December 31, 2022, gathered information from all lactations of the cows being present during those years. Initially, the dataset included 1,032,457 lactations from 330,265 cows. After checking for the inclusion criteria (described in the next section) the dataset used in this study included 953,181 lactations from 322,873 cows belonging to 1,133 Costa Rican dairy herds in 10 ecozones. These herds were classified according to Holdridge's life zone system (Holdridge, 1978), considering factors such as temperature, precipitation levels, altitude, and latitude. Dairy farms in each ecozone typically exhibit similar grazing pastures, management practices, breeds, and endemic diseases, with multiple ecozones distributed throughout the country.

Dairy farms in Costa Rica are mainly located at altitudes between 500 and 2,500 m above sea level (Vargas-Leitón et al., 2013), with the majority (79.4%) relying on pasture-based systems (INEC, 2022). The cow breeds in this study included Holstein (28.9%), Jersey (30.9%), Holstein × Jersey crossbred (10.7%), and other breeds, such as Gyr, Brown Swiss, and their crosses (29.5%). They were bred using artificial insemination (53.6%), natural mating (46.1%), and embryo transfer (0.3%). The infection and vaccination status of the cows were unspecified.

The culling rate in milking cows in the studied farms ranged between 25% and 35% yearly, with 51% to 83% of culling incidences being due to involuntary causes such as reproductive disorders, subfertility, mastitis, lameness, and metabolic disorders, among others.

All herds were free of brucellosis, and most of them were vaccinated against *Leptospira* spp. infections and respiratory and reproductive viral diseases such as bovine respiratory syncytial virus, bovine viral diarrhea, infectious bovine rhinotracheitis, and bovine parainfluenza-3 viruses.

Data Collection

The database was compiled by retrieving information from the Veterinary Automated Management and Production Control Program (**VAMPP**) at the Centro Regional de Informática para la Producción Animal Sostenible at the Escuela de Medicina Veterinaria of the Universidad Nacional de Costa Rica (Heredia, Costa Rica; Romero-Zúñiga et al., 2019).

The criteria for including a dairy herd in the study were as follows: (1) Use of VAMPP (Noordhuizen and Buurman, 1984) as the herd management information system. (2) Veterinarian visits at regular intervals (at least once a month). (3) Maintaining complete records spanning a minimum of 4 yr within the study period. (4) Confirmation of pregnancy through transrectal ultrasonography or palpation at 35 and 60 d, as well as at 4 and 7 mo after service.

In all farms, veterinarians assessed the pregnancy status. The date of abortion was documented either by farm workers or farmers when it was observed.

Case Definitions

Abortion was defined as the disruption of gestation between 42 and 260 d after conception (Markusfeld-Nir, 1997; Mee, 2020), which could be either observed or inferred. Inferred abortion occurred when a cow received a nonpregnant diagnosis or underwent a new service following a confirmed pregnancy (Markusfeld-Nir, 1997). In such cases, VAMPP calculated the abortion date as half the interval between the last positive pregnancy diagnosis and the date of recording a nonpregnant diagnosis or a new service.

Abortions were classified as early fetal mortality (**EFM**) when the cow aborted between 42 and 120 d of pregnancy (Mee, 2020) and late fetal mortality (**LFM**) when the abortion occurred between 121 and 260 d of pregnancy.

The NSPC represents the number of services, either by artificial insemination or natural mating, needed for a conception that begins a new lactation, ending with a calving or an abortion beyond 7 mo of pregnancy. The calving to effective conception interval (**CECI**) represents the number of days between a cow's calving and the conception that began a new lactation, either ending with a calving or an abortion beyond 7 mo of pregnancy.

The VAMPP estimated each lactation's 305-d MY with records of at least 200 DIM. Therefore, the analysis did not include lactations shorter than 200 DIM. For lactations between 200 and 304 DIM, the 305-d MY was estimated by VAMPP using extrapolation based on an expected lactation curve and the cow's test-day milk records for the current lactation. In cows with lactations exceeding 305 d, the 305-d MY was capped at 305 DIM (Romero et al., 2005).

Total milk yield per lactation (**TMYPL**) represents a cow's cumulative milk output (in kg) throughout the entire lactation period. The total lifetime milk yield per cow (**LTMY**) is the sum of the TMYPL across all lactations. The DIM per lactation indicates the duration of the lactation, considering lactations initiated postcalving or post-abortion beyond 7 mo of pregnancy. The DIM per cow was computed by adding the DIM per lactation across all lactations. The productive lifetime of a cow encompasses the period from its first calving to the date it exits the herd (due to culling, death, or sale).

Statistical Analysis

The biological plausibility of all records was validated. After editing, a descriptive analysis regarding the general characteristics of the farms and animals was performed. However, the number of observations per variable or category differs because farm records vary in periodicity and completeness of the data collection and recordkeeping.

We estimated the reproductive losses expressed by the NSPC and CECI, and productive losses represented by the DIM per lactation, DIM per cow, productive lifetime, 305-d MY, TMYPL, and LTMY caused by the first abortion event, using various models, based on the nature of the response variables. Because no censored lactations were included and given the hierarchical structure of the data, generalized linear mixed models were employed to estimate reproductive losses.

A model with Poisson distribution was fitted for losses related to the additional NSPC. A normal distribution was fitted for the effect of abortion on the CECI, DIM per lactation, productive lifetime 305-d MY, and TMYPL. Farm and cow were treated as random effects in all these models. The final model's estimations were adjusted for fixed effects such as breed, parity, and the ecozone to which the farm belonged. The general statistical model was as follows:

$$y_{ijklm} = m_0 + \text{fmclas}_i + \text{breed}_j + \text{parity} + \text{eco}_l + a_m + e_{ijklm},$$

where y_{ijklm} is the dependent variable (NSPC, CECI, DIM per lactation, productive lifetime, 305-d MY, TMYPL); m_0 is the general mean; fmclas_i is the fixed effect of ith abortion in the lactation (i = 0 = no, 1 = early fetal mortality, 2 = late fetal mortality); breed_j is the fixed effect of jth breed (j = 0 = Holstein, 1 = Jersey, 2 = Holstein × Jersey, 3 = others); parity_k is the fixed effect of the kth parity (k = 1 = first, 2 = second, 3 = third, 4 = fourth or greater); eco_l is the fixed effect of the lth ecozone (l = 1–10); a_m is the random effect of the mth cow (m = 1–322,873) nested within herd; and e_{ijklm} is the random residual effect.

The effects of having a case of abortion per parity and the number of lactations with a case of abortion on LTMY and DIM per cow were evaluated using generalized linear mixed models with normal distribution. To account for extra variation, farm and cow were used as random effects. The models were adjusted for fixed effects such as cow breed, total calving number, and ecozone to which the farm belongs. The general statistical models were

$$y_{ijklm} = m_0 + \text{abortion} \times \text{parity}_i + \text{breed}_j + \text{calving}_k + \text{eco}_l + a_m + e_{ijklm},$$

where y_{ijklm} is the dependent variable (DIM per cow, LTMY); m_0 is the general mean; abortion × parity_i is the

fixed effect of ith parity where the abortion occurred (i = 0 = no abortion, 1 = abortion in first parity, 2 = abortion in second parity, 3 = abortion in third parity, 4 = abortion in fourth parity or more); breed_j is the fixed effect of the jth breed (j = 0 = Holstein, 1 = Jersey, 2 = Holstein × Jersey, 3 = Others); calving_k is the fixed effect of the kth parity (k = 1 = one, 2 = 2, 3 = 3, 4 = 4 or greater); eco_l is the fixed effect of the lth ecozone (l = 1–10); a_m is the random effect of the mth herd (m = 1–1,133); and e_{ijklm} is the random residual effect.

Additionally,

$$y_{ijklm} = m_0 + \text{nabortion}_i + \text{breed}_j + \text{calving}_k + \text{eco}_l + a_m + e_{ijklm},$$

where y_{ijklm} is the dependent variable (DIM per cow, LTMY); m_0 is the general mean; nabortion_i is the fixed effect of ith number of lactations with abortion (i = 0 = no abortion, 1 = one lactation with abortion, 2 = 2 lactations with abortion, 3 = 3 or more lactations with abortions); breed_j is the fixed effect of jth breed (j = 0 = Holstein, 1 = Jersey, 2 = Holstein × Jersey, 3 = others); calving_k is the fixed effect of the kth parity (k = 1 = one, 2 = 2, 3 = 3, 4 = 4 or greater); eco_l is the fixed effect of the lth ecozone (l = 1–10); a_m is the random effect of the mth herd (m = 1–1,133); and e_{ijklm} is the random residual effect.

The final model considered only statistically significant 2-way interactions between the variables. The optimal models were determined using a backward model-building strategy. The goodness of fit of various fitted models was evaluated using the Akaike information criterion and the quasi-information criterion.

The data were processed and analyzed using SAS On-Demand for Academics (SAS Institute Inc., Cary, NC) using the procedures PROC FREQ, PROC MEANS, PROC GLIMMIX, AND PROC GENMOD, with a P-value <0.05 indicating statistical significance.

RESULTS

Frequency of Abortion Cases

After the inclusion criteria were applied, the final dataset consisted of 953,181 lactations. Of these, 57,353 lactations (6.0%, 95% CI = 5.9%–6.2%) had at least one case of abortion, and of these, 20,617 (36.0%) were classified as EFM and 36,736 (64.0%) as LFM (Table 1). Furthermore, out of the lactations with at least one case of abortion, the number of abortions per parity ranged from 1 (95.2%) to 5 (0.01%) cases of abortion.

Effect of Abortion on Reproductive Parameters

Number of Services per Conception. For the losses related to the additional NSPC, the final model included 5 variables and 6 interaction terms (Supplemental Table S1, see Notes). In general, a lactation with a case of abortion (2.43 ± 0.02) needed 0.72 more services per conception than a lactation without an abortion (1.71 ± 0.004; Table 2). Supplemental Table S2 (see Notes) resumes the effects of the other factors that also correlate with NSPC. Moreover, a lactation with a case of EFM needed 1.61 more services per conception than a lactation without it, and a lactation with a case of LFM needed 0.22 more services per conception than a lactation without it (Table 2).

Holstein cows had the highest NSPC for the 3 categories of abortion (no abortion, EFM, LFM). The difference in NSPC between lactations with EFM and without abortion among breeds ranged from 1.52 to 1.64, with the lactations from Holstein × Jersey cows having the least difference, and those from other crossbred cows having the largest difference (Supplemental Table S2). Furthermore, the difference in NSPC between lactations with LFM and without abortion among breeds ranged from 0.16 to 0.32, with Holstein cows having the least difference and other crossbred cows having the most. For the 3 categories of abortion, primiparous cows had the lowest NSPC.

Table 1. Frequency of abortion overall and according to early fetal mortality (EFM), late fetal mortality (LFM), trimester of gestation, and recurrence within a lactation

Variable	Category	Abortions (n)	Total lactations (n)
Type of abortion	Overall	57,353	953,181
	EFM	20,617	953,181
	LFM	36,736	953,181
Pregnancy trimester	1	16,402	953,181
	2	15,489	953,181
	3	25,462	953,181
Recurrence	First recurrence[1]	2,736	57,353
	Second recurrence[2]	163	2,736

[1]Second abortion case in a single lactation.

[2]Third abortion case in a single lactation.

Table 2. Estimated effects on a given lactation of having or not having an abortion, early fetal mortality (EFM), and late fetal mortality (LFM) on reproductive and productive variables in dairy cows from herds in Costa Rica, adjusted for breed, parity, ecozone, and significant interactions with farm and cow as random effects (LSM ± SE)

Variable	Lactation without abortion	Lactation with abortion	Lactation with EFM	Lactation with LFM
Services per conception (n)	1.71 ± 0.004 (n = 895,828)	2.43 ± 0.02* (n = 57,353)	3.32 ± 0.03* (n = 20,617)	1.93 ± 0.01* (n = 36,736)
Calving to effective conception interval (d)	130.1 ± 0.2 (n = 895,828)	114.9 ± 1.8* (n = 57,353)	137.8 ± 0.7* (n = 20,617)	112.6 ± 0.6* (n = 36,736)
DIM per lactation (d)	205.5 ± 0.3 (n = 895,828)	188.0 ± 0.6* (n = 57,353)	216.1 ± 1.0* (n = 20,617)	172.3 ± 0.8* (n = 36,736)
DIM per cow (d)	491.0 ± 2.2 (n = 275,829)	599.0 ± 3.3* (n = 56,242)	642.7 ± 4.9* (n = 17,938)	560.9 ± 3.8* (n = 33,725)
305-d milk yield per lactation (kg)	5,587.8 ± 9.0 (n = 388,680)	5,160.2 ± 14.2* (n = 21,725)	5,870.8 ± 18.9* (n = 9,733)	4,581.4 ± 17.5* (n = 11,992)
Total milk yield per lactation (kg)	5,053.9 ± 11.2 (n = 519,520)	4,263.4 ± 18.0* (n = 32,543)	5,350.7 ± 25.3* (n = 13,017)	3,535.9 ± 21.6* (n = 19,526)
Lifetime milk yield per cow (kg)	10,217 ± 32.7 (n = 190,248)	10,517 ± 98.6** (n = 43,433)	12,021 ± 184* (n = 14,523)	9,530 ± 121* (n = 25,108)
Productive lifetime (d)	1,733.8 ± 2.4 (n = 569,888)	1,608.1 ± 4.5* (n = 38,629)	1,746.6 ± 6.9 (n = 13,584)	1,532.8 ± 5.3* (n = 25,045)

*$P < 0.0001$; **$P < 0.01$; Tukey-Kramer adjustment for multiple comparisons.

The difference in NSPC between lactations with EFM and without abortions among parities ranged from 1.47 to 1.68, with primiparous cows having the slightest difference. Similarly, the difference in NSPC between lactations with LFM and without abortions among parities ranged from 0.17 to 0.32, with primiparous cows having the greatest difference. Finally, the difference in NSPC between lactations with EFM and without abortions and between LFM and without abortions among ecozones ranged from 1.49 to 1.86 and from 0.04 to 0.39, respectively (Supplemental Table S2).

Calving to Effective Conception Interval. In general, a lactation with a case of abortion has a CECI longer (130.1 ± 0.2 d) than a lactation without it (114.9 ± 1.8; Table 2). In addition, when a lactation experimented an EFM case, the CECI increased by 7.7 d (± 0.7), whereas with a case of LFM during lactation, it decreased by 17.5 d (± 0.7; Table 2). Furthermore, the CECI was also significantly ($P < 0.05$) affected by cow breed, parity, and ecozone (Supplemental Table S3, see Notes). Holstein cows had the longest CECI (136.4 d ± 0.4) and Jersey cows had the shortest (119.2 ± 0.4). Furthermore, primiparous cows had the longest CECI (134.7 d ± 0.6) and cows in their fourth parity or greater had the shortest (117.8 d ± 0.4). Finally, the CECI ranged from 108.8 to 147.6 d among ecozones (Supplemental Table S3).

Effect of Abortion on Productive Parameters

Productive Lifetime. For the losses related to the productive lifetime, the final model included 4 variables and 5 interaction terms (Supplemental Table S1). The overall mean productive lifetime of the cows in this study was 1,843.9 d (± 965.2). The productive lifetime of cows without abortion was 1,733.8 d (± 2.4); with an EFM case, it was 1,746.6 d (± 6.9), and with an LFM case, it was 1,532.8 d (± 5.3; Table 2). Moreover, breed, parity, and ecozone significantly ($P < 0.05$) affected the productive lifetime. Jersey cows had the shortest productive lifetime (1,639.3 d ± 3.7), whereas Holstein × Jersey crossbred cows and other breeds and their crosses spent the longest in production (1,693.7–1,697.6 d). Finally, the productive lifetime ranged from 1,604.3 to 1,780.4 d among ecozones (Supplemental Table S3).

Days in Milk per Lactation. For the losses related to the DIM per lactation, the final model included 5 variables and 2 interaction terms (Supplemental Table S1). Cows without abortion showed a significantly ($P < 0.05$) longer DIM per lactation (205.5 ± 0.3 d) compared with those with an abortion case (188.0 ± 0.6 d; Table 2). In addition, a case of EFM during lactation resulted in an average of 10.6 d (± 1.0) increase in the DIM per lactation compared with a lactation without abortion, whereas a case of LFM during lactation resulted in a 33.2 d (± 0.7) decrease (Table 2). Moreover, cow breed, parity, and ecozone also had a significant ($P < 0.05$) effect on the DIM per lactation (Supplemental Table S3). Holstein cows had the longest DIM per lactation at 217.5 d ± 0.5, whereas other breeds and crossbred breeds spent the shortest at 166.7 d ± 0.5. Cows in the second and third parity had the longest DIM per lactation at 200.6 to 201.9 d, whereas cows in the first and fourth parity or more had the shortest at 194.4 to 195.0 d. Furthermore, the DIM per lactation varied among ecozones, ranging from 121.5 to 249.7 DIM per lactation.

Days in Milk per Cow. For the losses related to the DIM per cow, the final model included 5 variables and 5 interaction terms (Supplemental Table S1). Overall,

Table 3. Estimated effects of the first abortion on the parity that occurred on the total DIM in a cow's productive lifetime and the lifetime milk yield per cow in dairy herds from Costa Rica, adjusted for breed, parity, ecozone, and significant interactions with farm as a random effect (LSM ± SE)

		Abortion parity			
Variable	No abortion	1	2	3	≥4
DIM per cow (d; n = 332,071)	490.8 ± 2.2 (n = 275,829)	631.5 ± 5.3* (n = 12,309)	726.2 ± 17.6* (n = 13,988)	971.4 ± 32.4* (n = 10,137)	1,313.2 ± 38.6* (n = 19,808)
Lifetime milk yield per cow (kg; n = 233,681)	10,546 ± 53 (n = 190,248)	10,949 ± 155 (n = 8,801)	10,489 ± 212 (n = 10,450)	10,881 ± 346 (n = 7,921)	11,321 ± 374 (n = 16,261)

*$P < 0.0001$; Tukey-Kramer adjustment for multiple comparisons.

cows with abortions had greater DIM per cow compared with those without (Tables 2 and 3). However, the number of days the lactation was extended differed based on the lactation in which the first abortion occurred. When the abortion occurred on the fourth lactation or greater (1,313.2 d ± 65.6), the DIM per cow was greater by 681.7 d ± 57.5 ($P < 0.0001$) than when the abortion occurred in the first lactation (631.5 d ± 16.1). This pattern was evident among the breeds (Supplemental Table S4, see Notes). However, the effect of abortion per parity on the total DIM per cow is also influenced by parity. Cows had greater DIM when they had undergone an abortion in any parity than when they did not have an abortion during their productive lifetime (Supplemental Table S4). We found no statistically significant differences in the total DIM per cow for breeds ($P = 0.06$–1.00) for any parity.

Overall, the number of lactations with abortions that a cow has experienced had an important effect on the total DIM per cow in their productive lifetime. As the number of lactations with abortions increases from 0 to 3 or more, the DIM per cow also increases (Table 4). This increase was evident in all the cow breeds studied and all parities (Supplemental Table S5, see Notes).

305-d Milk Yield. For the losses related to the 305-d MY, the final model included 4 variables and 2 interaction terms (Supplemental Table S1). Cows with abortions produced significantly ($P < 0.05$) less 305-d MY (5,160.2 kg ± 14.2) compared with those without (5,587.8 kg ± 9.0; Table 2). However, for lactations with a case of EFM, the 305-d MY increased by 283.1 kg (± 17.0) on average compared with those without abortion, whereas for lactations with an LFM case, it decreased by 1,006.4 kg (± 15.4) on average (Table 2). Additionally, cow breed, parity, and ecozone significantly ($P < 0.05$) affected the 305-d MY. Holstein cows had the greatest (6,443.6 kg ± 12.0), and other crossbred cows had the least (4,752.5 kg ± 12.6; Supplemental Table S6, see Notes). Cows in their third or fourth or greater lactation had the greatest 305-d MY (5,704.0–5,749.6 kg), and primiparous cows had the least (4,593.4 kg ± 21.9). The 305-d MY varied from 4,555.7 to 6,559.8 kg among ecozones (Supplemental Table S6). Finally, for all parities, Holstein cows had the greatest 305-d MY per lactation (5,507.2–6,943.9 kg), whereas other breeds and crossbred cows had the lowest (4,116.2–5,113.5 kg).

Total Milk Yield per Lactation. For the losses related to the TMYPL, the final model included 4 variables and 1 interaction term (Supplemental Table S1). Cows with abortions produced significantly ($P < 0.05$) less TMYPL (4,263.3.7 ± 18.0.3) in comparison with those without (5,053.9 ± 11.2; Table 2). However, this effect is different for lactations with a case of EFM, where the TMYPL exhibited a significant increase (5,350.7 ± 25.3; $P < 0.05$), whereas for lactations with an LFM case, the TMYPL decreased by 1,518.1 kg (± 19.1) on average (Table 2). Furthermore, breed and parity significantly ($P < 0.05$) affected the TMYPL (Supplemental Table S7, see Notes). Holstein cows had the greatest (5,782.0 kg ± 15.3), whereas other breeds and crossbred cows had the least (3,919.1 kg ± 15.9). In addition, cows in their third

Table 4. Estimated effects of the number of lactations with abortions on the total DIM in a cow's productive lifetime (DIM per cow) and the lifetime milk yield per cow in dairy herds from Costa Rica, adjusted for cow breed, parity, ecozone, and significant interactions with farm as a random effect (LSM ± SE)

		Number of lactations with abortions		
Variable	No abortion	1	2	≥3
DIM per cow (d; n = 332,071)	491.1 ± 2.2 (n = 275,829)	581.5 ± 3.4* (n = 45,750)	786.6 ± 28.7* (n = 8,980)	1,091.3 ± 126.1* (n = 1,512)
Lifetime milk yield per cow (kg; n = 233,681)	10,565 ± 51.6 (n = 190,248)	10,722 ± 69.0 (n = 34,828)	11,071 ± 272 (n = 7,300)	12,191 ± 944 (n = 1,305)

*$P < 0.0001$; Tukey-Kramer adjustment for multiple comparisons.

lactation had the greatest TMYPL (5,041.7 kg ± 25.4), and primiparous cows had the least (4,047.4 kg ± 26.8; Supplemental Table S7).

Lifetime Milk Yield. For the losses related to the LTMY, the final model included 4 variables and 5 interaction terms (Supplemental Table S1). Significant ($P < 0.05$) differences were found in the LTMY per cow when comparing cows with no abortion (10,217 ± 32.7) and cows with an abortion (10,517 ± 98.6). We also found significant ($P < 0.05$) differences when comparing cows with no abortion and cows with a case of EFM (12,021 kg ± 184), as well as when comparing cows with a case of LFM (9,530 kg ± 121; Table 2). We found no differences ($P = 0.07$–1.00) in the total LTMY when comparing cows with no abortion and cows with an abortion occurring on varying parities (Table 3). For cows with 4 or more parities, the LTMY was 1,812 kg (± 196) greater for cows with an abortion in the fourth or later parities than cows with no abortions (Supplemental Table S8, see Notes). For the effect of the number of lactations with abortions on the LTMY of a cow, overall, we observed no differences ($P = 0.19$–0.42) in the LTMY as the number of lactations with abortions increased from 0 to 3 or more (Table 4).

DISCUSSION

Our study found that a lactation with a case of LFM requires 0.22 additional services per conception than a lactation without an abortion. This result is lower than the difference in the number of inseminations per lactation between cows with and without a case of abortion in Chilean (0.97; Gädicke et al., 2010) and Iranian dairy herds (1.57; Keshavarzi et al., 2020). However, this difference could arise due to the different definitions and calculations of the variables in the studies. In our study, the NSPC considered a conception when the pregnancy began a new lactation, even if the pregnancy ended in a late abortion. Nevertheless, the increase of 1.61 in NSPC with a case of EFM compared with a lactation without an abortion in our study is consistent with the results of these previous reports.

Furthermore, the difference in NSPC was also due to the breed of the cow, the parity, and the ecozone. Regarding the EFM cases, Holstein × Jersey cows had the slightest difference in NSPC, which is in line with other studies (Auldist et al., 2007; Coffey et al., 2016) that have concluded that Holstein × Jersey crossbred cows have increased fertility compared with Holstein and Jersey purebred cows.

Additionally, primiparous cows exhibited the slightest difference in NSPC, which could be attributed to the decreased reproductive performance of lactating cows (Nebel and McGilliard, 1993; Lucy, 2001). Any additional NSPC increases the costs related to the inseminations and labor, as well as causes an increase in the days open and productive time lost. However, the NSPC is a measure that depends on other factors, including the estrus detection efficiency and the quality of the semen used (Tadesse et al., 2022).

In our study, we found that in a lactation with a case of EFM, the CECI was increased compared with a lactation without an abortion. This result is consistent with previous studies that have found an increase in the calving interval in cows that suffered an abortion (Gädicke et al., 2010; El-Tarabany, 2015). It is expected for the CECI and the calving interval to increase with a case of abortion because a new conception is needed to obtain a pregnancy that ends with a calving, thus increasing the time between effective calvings. However, our study found that a lactation with a case of LFM caused the CECI to decrease compared with a lactation without an abortion. This could be explained because the CECI was calculated as the days between a calving and the conception of a pregnancy that caused the beginning of a new lactation, including late abortions. Therefore, these results underestimate the lost productive time caused by the LFM cases. Greater losses may be evident when calculating the CECI as the interval between a calving and the beginning of a pregnancy that ends with a calving, not including the lactations that started with a late abortion. Nevertheless, an increase in the CECI and the calving interval could represent an increase in the cow's dry period (Dijkhuizen et al., 1985) and, therefore, in the cow's nonproductive period, causing economic losses to the dairy production systems.

Our findings indicate that a lactation with an LFM case results in a decreased 305-d MY per lactation of, on average, 1,006 kg. This exceeds the decrease reported in other studies (894 to 950 kg; El-Tarabany, 2015; Keshavarzi et al., 2020). The decrease in milk yield could be explained by the duration of the lactation being shortened due to the premature beginning of the new lactation caused by the abortion. This is also evidenced in the DIM per lactation; a lactation with a case of LFM has a decrease of 33 DIM per lactation compared with a lactation without an abortion. However, milk yield is affected by many factors, including cow breed, parity number, genetic factors, nutrition, and climatic conditions (Ramírez-Rivera et al., 2019). It is clear that milk yield in a lactation with abortion is decreased due to the mammary glands' reduced development and because the aged or damaged mammary epithelial cells were not replaced in time for the start of the next lactation (Capuco et al., 1997). This also explains the reduction in TMYPL observed in our study in a cow with a case of LFM (−1,518 kg). These results align with previous studies that have demonstrated that milk yield in cows with

abortion decreases (Gädicke et al., 2010; El-Tarabany, 2015; Keshavarzi et al., 2020).

In contrast to the LFM cases, our study found that a lactation with a case of EFM resulted in an increased 305-d MY (283 kg), TMYPL (297 kg), and DIM per lactation (11 d). A possible explanation could be that because an EFM does not cause the start of a new lactation, unlike in some cases of LFM, the current lactation is extended, thus causing an increase in DIM per lactation and the increase in milk yield per lactation. This aligns with the results of previous studies that have found that cows with abortion that start a new lactation have a greater decrease in milk yield compared with cows with abortion that do not start a new lactation (Keshavarzi et al., 2020).

The results of our study show that cows that undergo cases of LFM have a decreased productive lifetime of approximately half a year (0.55 yr). This result is consistent with previous studies, which concluded that dairy cows from Chile that have suffered an abortion have a decreased productive lifetime of 0.46 yr compared with cows without an abortion (Gädicke et al., 2010) and that cows with abortion have an increased culling risk (Bell et al., 2010; Keshavarzi et al., 2020). This could be explained because cows with abortion are more likely to suffer from reproductive disorders like retained placenta and metritis (Keshavarzi et al., 2020). These disorders can cause a decrease in the cow's overall health, affecting milk yield or causing the cow to be involuntarily culled.

Our study found significant differences in LTMY between cows with and without abortion. Similar to the 305-d MY and TMYPL, the LTMY decreased with a case of LFM, despite the milk yield in Costa Rican cows (305-d MY = 5,562 kg) being lower than that of other countries (Romero et al., 2005), such as Ireland (second lactation milk yield at 304 d = 6,550–6,789 kg; Ferris et al., 2014) and Iran (305-d MY = 11,556–11,608 kg; Keshavarzi et al., 2020), which could make the milk yield reduction less noticeable than in high-producing cows. In addition, the lactation after an abortion can have a higher milk yield (Dijkhuizen et al., 1985) because the dry period of the cow is more extended and the mammary gland has more time to recuperate for the next lactation (Capuco et al., 1997). This increase in milk yield, and possibly DIM, on the lactation after the abortion is the most likely explanation for the effect of abortion on the DIM per cow observed in our study; a case of abortion caused an increased total DIM per cow. However, a matched pairs design study could provide more specific information about the effect of abortion on the cows' LTMY and DIM per cow. This would allow us to more accurately consider the number of abortions per lactation, the number of lactations with abortions per cow, and the parity when the abortion(s) occurred.

CONCLUSIONS

This study provides a precise estimation of the reproductive and productive losses caused by abortion in dairy cattle from tropical areas like Costa Rica, offering valuable results for Costa Rican dairy producers and others facing comparable conditions. The results of this study demonstrate the significant impact of abortions in dairy production systems and reinforce the notion that the loss associated with an abortion goes beyond the loss of a calf. It includes increased NSPC and CECI for EFM cases and decreased DIM and MY per lactation for LFM cases.

NOTES

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Nonstandard abbreviations used: 305-d MY = 305-d milk yield; CECI = calving to effective conception interval; EFM = early fetal mortality; LFM = late fetal mortality; LTMY = total lifetime milk yield per cow; NSPC = number of services per conception; TMYPL = total milk yield per lactation; VAMPP = Veterinary Automated Management and Production Control Program.

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