THE ASSOCIATION BETWEEN CALFHOOD BRDC AND SUBSEQUENT DEPARTURE FROM THE HERD, MILK PRODUCTION, AND REPRODUCTION: AN OBSERVATIONAL, RETROSPECTIVE STUDY

by

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ABSTRACT

Bovine respiratory disease (BRDC) is a multifaceted disease that causes considerable economic loss in both the beef and dairy industry. However, because there may be lingering effects of BRDC in the dairy industry, the full economic costs of the disease may not be realized. These lingering effects may include an increased departure from the herd, decreased milk production, and decreased reproductive performance. All of these outcomes are affected by multiple variables, but proper statistical modeling can control for many of the different influences. Few studies have attempted to look at the long term effects of calfhood BRDC but consistent associations have not been identified. The objective of this observational, retrospective study was to determine the association between calfhood BRDC prior to 120 d of age and departure from the herd, milk production, and reproductive performance. The association between the occurrence of BRDC with departure from the herd prior to first calving depended on the birth year, but for 5 of the 6 years, animals that contracted BRDC were 1.62 to 4.98 times more likely to leave the herd than animals that did not contract BRDC. In addition, animals that contracted BRDC were also 1.28 times more likely to leave the herd between first and second calving than animals that did not contract BRDC. Furthermore, the age at BRDC occurrence was associated with departure from the herd. Animals that contracted BRDC pre-weaning were 2.62 times more likely to leave the herd prior to first calving than animals that contracted BRDC post-weaning. However, age of BRDC occurrence was not significantly associated with departure from the herd between first and second calving. The occurrence of BRDC during the first 120 d of life was associated with a 233 kg decrease in lactation-one production, but was not significantly associated with production in subsequent lactations. Finally, calfhood BRDC was not significantly associated with a decreased reproductive performance measured by calving interval. In conclusion, calfhood BRDC negatively impacts productivity both prior to and after first calving.

Key words: bovine respiratory disease, dairy calf, departure from the herd, milk production

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Chapter 1 – LITERATURE REVIEW

Bovine Respiratory Disease

Bovine respiratory disease complex (BRDC) is a common, multifaceted disease that causes considerable economic loss in both the beef and dairy industries. The major bacterial pathogens associated with BRDC are *Mannheimia haemolytica, Pasteurella multocida, Histophilus somni,* and *Mycoplasma bovis,* and the most common viral pathogens include infectious bovine rhinotracheitis virus (IBR), bovine viral diarrhea virus (BVDV), para-influenza-3 virus (PI3), and bovine respiratory coronavirus (BRCV; Kapil and Basaraba, 1997; Martin and Bohac, 1986; Griffin et al., 2010). However, Dabo et al. (2007) discussed that, although *M. haemolytica* is the most commonly associated bacterial pathogen of BRDC in feedlot cattle, *P. multocida* is the most common bacteria associated with BRDC in diary calves. In addition, they reported that *P. multocida* is more commonly isolated in younger animals with the peak occurrence of BRDC in dairy calves being from 28 to 42 d of age. This age at peak occurrence is much younger than the age of 202 d that Snowder et al. (2006) reported as the average age of treatment for BRDC in feedlot cattle. Thus, the difference in age at BRDC occurrence between cattle in the two industries may explain the difference in the most commonly isolated pathogen.

It is well known that the common bacterial pathogens of BRDC are all commensal organisms in calves and that BRDC infections often occur secondary to stressful situations or viral infections that suppress the immune system. Mosier (1997) states that in a feedlot animal, transportation, temperature extremes, processing, commingling and marketing can all inhibit the immune defenses propitiating an increase in bacterial pathogen proliferation leading to BRDC in cattle. Because the age of transportation and commingling of calves is different in the beef and dairy industries, the age at which immunosuppression and secondary BRDC infections most likely occur are also different. In the dairy industry, calves are commonly weaned and commingled at 6 to 8 wkof age, whereas in the beef industry calves are commonly commingled and placed into feedlots at 5 to 7 months of age (Snowder et al., 2006; Gorden and Plummer, 2010). Furthermore, the additional stress of poorly ventilated indoor housing has been reported to be associated with BRDC occurrence in the dairy industry unlike the open air feedlot production sites predominant in the beef industry (Mosier, 1997). These and other production and environmental differences between the dairy and beef industries may explain the difference in the epidemiology of BRDC observed in beef and dairy calves.

Although the epidemiology of BRDC occurrence may be different between the cattle in the beef and dairy industries, the clinical signs of BRDC in beef and dairy cattle are similar. The initial clinical signs of BRDC in cattle include: nasal and ocular discharge, depression, anorexia, fever, and a moist cough. These signs may progress to respiratory distress, an encrusted muzzle, excessive tear production and dyspnea (Edwards, 2010; Griffin et al., 2010). Griffin et al. (2010) also reports that lung lesions associated with BRDC include: bilateral lung consolidation, lobules with a marbled appearance and sheets of fibrin attached to the parietal and visceral pleura. In severe BRDC cases, light yellow thoracic fluid, coagulation necrosis and extensive adhesions may be seen. Histologically, potential findings during the early stages of BRDC include edema, fibrin, and congestion or hemorrhage within the alveoli, and, in later stages, dark, oat shaped neutrophils with pyknotic and hyperchromic nuclei (Griffin et al., 2010).

In cattle from both the beef and dairy industries, the predator-prey behavior often masks the early clinical signs of BRDC and makes accurate diagnoses difficult (Griffin et al., 2010). The difficulty of field diagnosis of BRDC is likely to increase variation between studies estimating the frequency of BRDC, especially in dairy calves. Sivula et al. (1996) reported the cumulative incidence of BRDC in dairy calves from birth to 16 wk of age on 30 Minnesota dairy farms to be 7.6% (64/845 calves), whereas the 2011 US National Animal Health Monitoring Survey (NAHMS) reported the cumulative incidence of BRDC on commercial heifer raising operations to be 18.1% and 11.2%, for unweaned and weaned dairy heifers, respectively (USDA, 2012). Similarly, the case fatality risk varies among studies. Sivula et al. (1996) reported that the case fatality risk of BRDC was 9.4% in dairy calves, however, Virtala et al. (1996a) reported that, in a convenience sample of 410 dairy calves from 18 dairy farms in New York, the case fatality risk was 4.2%. Accurately and consistently diagnosing BRDC is one of the many challenges that BRDC presents to beef and dairy caregivers.

Implications of Bovine Respiratory Disease on Growth and Performance in the Dairy Industry

The implications of BRDC to cattle health, performance and carcass characteristics in the feedlot industry are well documented. In a review article, Smith (1998) reported that BRDC decreased average daily gain (ADG) by 0.14 to 0.23 kg in beef cattle during the feedlot receiving period. He also reported that the difference in ADG between cattle treated and cattle not treated for BRDC can persist for the entire feeding period. A study by D.J. Rezac (personal communication) reported that severe lung lesions in feedlot cattle were associated with a decreased ADG of 0.07 kg and a hot carcass weight of 7.1 kg less than cohorts with no pulmonary lesions. In the dairy industry, there are also data that supports the decreased growth and performance of dairy calves treated for BRDC. However, because the lifespan of a dairy animal is considerably longer than the lifespan of a feedlot animal and because of early occurrence of peak BRDC risk in the life of dairy cattle, there may be additional lingering implications of BRDC for cows in the dairy industry.

Waltner-Toews et al. (1986) investigated long term effects of BRDC on dairy cow performance in commercial dairy farms. They investigated the effects of calfhood health on dairy heifer survival and age at first calving (AFC) in 808 dairy calves from 34 randomly selected farms in southwestern Ontario.the effect of BRDC. In this study, heifers with BRDC were 2.45 times more likely to die after 90 d of age than those without BRDC. However, BRDC did not affect AFC in diary heifers.

Warnick et al. (1995) investigated the effects of calfhood morbidity during the first 90 d of life on first lactation milk production in 24 herds near Ithaca, NY. The occurrence of respiratory disease had no effect on future milk production of heifers that survived the BRDC illness, were kept as replacements, and remained in the herd. However, the authors did comment that the percentage of heifers that survived and were kept as replacements tended to be lower for heifers affected by calfhood BRDC, and to consider heifers that were lost from the study when analyzing the true effect of calfhood BRDC on subsequent milk production. These researchers also investigated the effects of calfhood morbidity on survival after calving. Using data from the same 24 herds, the crude survival function for productive life was used to estimate the simultaneous effects of calfhood diseases on longevity after calving. In this study, dairy calfhood morbidity was not significantly associated with decreased survival of the heifer/cow in the milking herd (Warnick et al. 1997).

In a dairy replacement heifer growth study, Virtala et al. (1996b) observed the effect of calfhood disease on growth during the first 3 mo of life in 410 female dairy calves originating from 18 commercial farms in New York State. Calves that required treatment of BRDC during the first month of life had a reduced ADG gain of 66 g during the first month of life compared to calves that did not suffer from BRDC. Bovine respiratory disease complex in dairy calves during the second month of life was not associated with decreased ADG, but for each wk BRDC persisted during the third month of life, ADG decreased by 14 g in dairy calves compared to dairy calves that did not suffer from BRDC complex. Over the 3 mo of study, BRDC decreased dairy replacement heifer BW gain by 3.8 kg relative to heifers not suffering from BRDC. Also, the authors noted that the longer the duration of respiratory disease in the calf, the more BW was reduced.

A study conducted in a convenience sample of approximately 3,300 female Holstein calves born on 2 large Florida dairies investigated calf-level risk factors that affect performance between birth and 14 mo of age (Donovan et al., 1998). In this study, data were collected at birth, 6 mo and 14 mo of age. The data from this study indicated that there was a 10.6 kg and 3.1 kg decrease in BW gain from birth to 6 mo age and from 6 mo to 14 mo of age, respectively, for a dairy calf that was treated for BRDC for the average number of days (5.63 d) compared to a calf that was not treated for BRDC. Also, BRDC was associated with a decreased rate of pelvic growth by 4.4% during the first 6 mo of life, but it did not affect hip height from 6 to 14 mo of age in dairy calves treated for BRDC compared to calves that were not.

A randomized clinical control trial comparing the effects of tulathromycin and oxytetracycline treatment of BRDC on calf health and performance, conducted at a single commercial heifer raising facility in New York, found that calves that had BRDC prior to the start of the study had an exit weight 2.9 ± 0.6 kg lower than calves that did not have BRDC prior to the start of the study (Stanton et al., 2010). In addition, calves that suffered from BRDC during the study had an exit BW that was 7.9 ± 0.6 kg less than calves that did not suffer from BRDC. Being diagnosed with BRDC as calves was also associated with decreased withers height at the end of the study. Moreover, Stanton et al. (2012)evaluated the long term effects of BRDC treatment on dairy heifer performance and found that BRDC occurrence prior to 2 mo of age decreased body weight at 3, 6, 9, and 13 mo by 7.1, 11.4, 15.4 and 14.4 kg respectively, and it also decreased withers height at 13 months by 1.7 cm . In addition, BRDC in dairy heifers decreased odds of survival to first calving, and it also decreased odds of calving by 25 mo of age compared to heifers not diagnosed with BRDC at a young age. However, BRDC did not affect milk production or survival to 120 d in milk.

Bach (2011) conducted an observational study to evaluate the potential association between development characteristics, health, and reproductive performance of replacement heifers with the odds of completing their first lactation as cows. This study utilized data from 133 different source dairy farms (7,992 dairy heifers) located in Zaragoza province, Spain. In this model, incidence of BRDC in dairy calves was not associated with the odds of finishing first lactation, but heifers that experienced 4 or more occurrences of BRDC before first calving had a 1.87 ± 0.14 greater odds of not completing first lactation than those that had not had BRDC. In addition, accumulated days in milk of cows throughout the recorded productive life decreased linearly as the number of BRDC cases increased.

Economic Implications of Bovine Respiratory Disease in the Dairy Industry

Direct costs of BRDC in cattle from both the feedlot and dairy industries include increased mortality, veterinary services, treatment costs, and labor. In addition, decreased growth performance and efficiency incur indirect costs in both industries. In the feedlot industry it is estimated that BRDC costs $20.76 to $37.90 per animal treated (Smith, 1998). Because additional costs of BRDC in the dairy industry may include increased culling, decreased fertility, and decreased milk production, the cost of BRDC to the dairy industry may be even higher than the cost to the feedlot industry. Kaneene and Hurd (1990) attempted to estimate the cost of preventing and treating calfhood BRDC on Michigan dairies. They estimated the cost of BRDC treatment in dairy calves to be $14.71 (range: $0 to $119) per calf per year. This estimate included drug cost, veterinary costs, labor, mortality, and replacement costs; it did not include the cost of lost potential genetic improvement. More recently, a model constructed by van der Fels-Klerx et al. (2001) of a Dutch dairy considered BRDC costs to include: drug and veterinary cost, labor, and mortality, as well as increased premature culling, reduced growth, reduced fertility, and reduce milk production during the first lactation. Their estimated cost of BRDC in dairy heifers was 31.2 euros ($26.86 U.S.) per heifer present on a dairy. Although, the model by Kaneene and Hurd (1990) is somewhat dated and the model by van der Fels-Kerx is not based on U.S. dairy production systems, but both studies demonstrate that BRDC in dairy cattle can be a very costly disease.

Survival of Animals in the Dairy Industry

Culling and replacement costs are directly related to the survival and productive life of cows in the dairy industry as evidenced by the model by van der Fels-Klerx et al. (2001). Congelton and King (1984) modeled the effect of herd life on profitability of the dairyman. Their model found a linear increase in net income when dairy herd life was increased from 2.6 to 4 lactations per cow. When the herd life increased from 4 to 5.5 lactations, net income per cow did not change, and when herd life was extended beyond 5.5 lactations net income decreased. They estimated that an increase in herd life from 2.8 to 3.3 lactations increased the annual income by $29.92 per cow per year. Using an inflation calculator, today, this value would be roughly equal to $65 (Manuel, 2013). This potential increase in economic return validates the importance of understanding how BRDC affects survival and herd life of cattle in the dairy industry.

An increase in survival can be defined as a decrease in the rate of departure from the herd or an increase in productive life. Although it is important to note that the rate of departure from the herd may be influenced in part by BRDC, it can also be affected by a multitude of genetic and management factors. Weigel et al. (2003) reported that the rolling herd average, the number of cows per employee, and the number of times the herd is milked per day can all influence culling in expanding herds. Also, Hadley et al. (2006) reported that the most common causes for culling were: injury or other, reproduction, production, and mastitis. In 2008, the NAHMS study reported that approximately one-third of the dairy cow inventory (36.2%) is replaced every year (USDA, 2008). Therefore, when modeling an association between BRDC cases in cattle and herd life, it is important to remember that there are many biologically significant variables that affect dairy herd life and care should be taken to avoid making incorrect conclusions about potential associations.

Factors Affecting Milk Production

There are also many factors that directly impact future milk production in dairy cows. Many of these factors occur long before the animal even enters the milking herd. One of those factors is age at first calving (AFC). A study by Curran et al. (2013) reported that lifetime milk yield increased in cows with decreasing AFC in herds milking 3 times a day with the maximum response occurring when AFC was 20 mo. The same study also reported that first lactation milk yields were decreased by 166, 369, and 654 kg for heifers that calved at 22, 21, or 20 mo respectively when compared to heifers that calved at 24 mo. Because of this association, it is important to control for AFC when modeling the effect of BRDC on milk production in dairy cattle. Furthermore, there are many other variables that may affect milk production, so caution must be taken when interpreting the associations between independent variables and milk production.

Reproductive Performance of Dairy Cattle

Similarly, there are several factors that affect the reproductive performance of dairy cattle and there are many different methods to measure fertility and reproductive performance. The NAHMS study (2009) reported that the most common parameter used to measure reproductive performance in dairy cows was pregnancy rate. Pregnancy rate in dairy cows is calculated as the product of the conception rate times the heat detection rate. Across all sizes of dairy operations surveyed, 84.4% of operations considered pregnancy rate to be important or very important for monitoring reproductive performance (USDA, 2009).

Although not considered as important, calving interval was another parameter that was used to monitor reproductive performance (USDA, 2009). Calving interval in dairy cows is defined as the time from one calving to the next and is dependent on how quickly a cow conceives after calving. Plaizier et al. (1997) estimated losses of net revenue to be $4.70 per cow per year per dairy farm due to a 1 d increase in average calving interval. In addition, if reduced fertility and poor reproductive performance was considered a disease, it would be the second most costly disease in the dairy industry. In a study of Michigan dairies, Kaneene and Hurd (1990) estimated that breeding problems cost an average of $21.25 to 26.46 per cow per year depending on farm size. Although poor reproductive performance is economically important and can be affected by BRDC, there are also many other biologically significant variables that affect reproductive performance in dairy cows. Therefore, like survival and milk production, care must be taken when interpreting associations with reproductive performance.

Statistical Modeling of Survival, Production, and Calving Interval Data

There are many types of statistical modeling techniques that can be used to describe and analyze data. When modeling time-to-an-event data such as cow's departure from a dairy herd, survival approaches can be employed. One key aspect to survival modeling is that through censoring it is able to control for animals that do not have the event of interest during the study. Dohoo et al. (2003) describe censoring as the occurrence of the event of interest when an animal is not under observation. This may occur prior to the study period (left censoring), during the study period (interval censoring), or after the study period (right censoring).

There are multiple approaches to survival analysis including semi-parametric analysis used to evaluate the probability of the event of interest occurring at a point in time as a function of multiple continuous or categorical predictor variables (Dohoo et al., 2003). The most commonly used method of semi-parametric analysis is the proportional hazards model which is also known as the Cox regression model (Dohoo et al., 2003). The Cox regression model is based on the assumption that the hazard for an individual is always a multiple of a baseline hazard that is constant over time, but no assumptions are made about the baseline hazards and the model has no intercept (Dohoo et al., 2003). This model produces a hazard ratio that can be interpreted similar to an odds ratio or other risk ratios. Hazard ratios represent the effect of a unit of change in the predictor frequency on the frequency of outcome. For example, if a variable has a hazard ratio of two, then for every unit of increase in the variable, the hazard of the outcome will double.

When modeling an outcome that is measured on a continuous scale, linear regression modeling can be used. According to Dohoo et al. (2003), regression analysis is a statistical way of describing how the value of an outcome is influenced by a predictor value, after the assumptions of homoscedasticity, normality, linearity, and independence are met. In order for the model to have homoscedasticity, the variance of the outcome should be the same at all levels of the predictor variables and within all combinations of the values of the predictor variables (Dohoo et al., 2003). The assumption of normality is that the errors are normally distributed at all levels of the predictors or at all combinations of predictors in the model (Dohoo et al., 2003). Linearity refers to the association between the outcomes and continuous predictors being a straight-line relationship; for a dichotomous variable there is no assumption of linearity because two points can always be connected by a straight line (Dohoo et al., 2003). Independence refers to the fact that the values of the dependent variables are statistically independent from one another (Dohoo et al., 2003).

When an outcome of interest is categorical rather than linear, a multinomial regression model can be used. Although there are a variety of multinomial regressions models that can be used, only the multinomial logistic regression model will be discussed in more detail. This model is used to model nominal data by comparing the probability of being in category "x" to the probability of being in a base line category (Dohoo et al., 2003). This model can be used to simultaneously analyze multiple predictor variables, and displays an odds ratio as an output.

Each of these models can incorporate random effects in addition to fixed effects. A random effect is included in a model to account for data that may have a nested structure and helps to explain some of the extra variability about the fixed effect (Dohoo et al., 2003). Because these models contain both fixed effect and random effect, they are often referred to as mixed models.

Summary of Chapter 1

Although many of the same pathogens associated with BRDC in beef cattle in a feedlot setting are associated with BRDC in dairy cattle, the disease affects cattle at different ages and immune status due to differences in animal housing and management.   Bovine respiratory disease complex is costly to both industries, but because dairy animals have a longer productive life, there may be lingering longer-term effects of BRDC that are not seen in the feedlot industry. These long-term effects may include an increased rate of departure of cows from the herd, decreased milk production, and/or decreased reproductive performance of dairy cows. However, very few studies have attempted to examine these long-term effects of calfhood BRDC on subsequent dairy cow performance.

Study Objectives

The objectives of this study were to describe the frequency of BRDC occurrence in Holstein dairy calves and to determine the associations between BRDC occurrence in Holstein heifer calves during the first 120 d of age with the subsequent rate of departure from the herd, milk yield, and reproductive performance a single 5,000 cow dairy located in central Utah.

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Chapter 2 - The association between calfhood BRDC and subsequent departure from the herd, milk production, and reproduction: an observational, retrospective, study

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Interpretative summary

Bovine respiratory disease complex (BRDC) is associated with considerable economic cost to the dairy industry. Direct, short-term costs of BRDC are commonly recognized near the time of treatment for dairy cattle, but there may also be long-term effects of BRDC in the dairy industry that are difficult to assess. This study was designed to evaluate the effects of BRDC during the first 120 days of life on longer-term outcomes important to the economic viability of dairies. This study concluded that calfhood BRDC in dairy heifers is associated with increased cow departure from the herd and decreased first lactation milk production, but not calving interval.

ABSTRACT

Several studies have determined that calfhood bovine respiratory disease complex (BRDC) is associated with decreased growth performance and increased departure from the herd prior to first calving. However, few studies have looked at longer-term effects of calfhood BRDC. The objective of this observational, retrospective study was to describe the frequency of calfhood BRDC cases in dairy calves and to determine the association between BRDC prior to 120 d of age with the risk of cow departure from the herd, milk production and calving interval on a single dairy herd located in central Utah. All animals in this study were born and raised on the dairy, and all records were maintained using DHI-plus software. The association between the occurrence of BRDC prior to 120 d of age with the risk of an animal departing from the herd prior to first calving depended on birth year. For 5 of the 6 yrs of this study, calves that became infected with calfhood BRDC were 1.62 to 4.98 times more likely to depart from the herd at some point prior to first calving than those not diagnosed with BRDC. Furthermore, the age at BRDC occurrence was associated with heifer departure from the herd. Heifers that contracted BRDC pre-weaning were 2.62 times more likely to leave the herd prior to first calving than heifers that contracted BRDC post-weaning. In addition, calves that contracted BRDC during the first 120 d of age were 1.28 times (*P*-value) more likely to leave the herd between first and second calving than those calves that did not suffer from BRDC. Unlike heifer departure from the herd prior to first calving, cow departure from the herd between first and second calving was not associated with the age at BRDC occurrence in dairy calves. The occurrence of BRDC before 120 days of age in dairy replacement heifers was associated with a 233 kg decrease in 305 day mature equivalent first lactation milk production, but was not was not associated with production decreases in subsequent lactations. Finally, calfhood BRDC in replacement dairy heifers was not associated with a decreased cow reproductive performance measured by calving interval. In conclusion, based on the results of this study calfhood BRDC in replacement dairy heifers negatively impacts cow productivity prior to and after first calving by increasing the risk of departure from the herd and decreasing milk production during the first lactation.

Key words: bovine respiratory disease, dairy calf, departure from the herd, milk production

INTRODUCTION

Bovine respiratory disease complex (BRDC) is a multifaceted disease caused by a combination of viral and bacterial pathogens that take advantage of an immunosuppressed calf to cause disease. In dairy cattle, *Pasteurella multocida* is the most common bacterial pathogen, but *Mannheimia haemolytica*, *Histophilus somni*, and *Mycoplasma bovis* are also implicated (Dabo et al., 2007; Griffin et al., 2010). Viruses commonly associated with BRDC in cattle include Bovine Viral Diarrhea Virus (BVDV), Bovine Respiratory Syncytial Virus (BRSV), Bovine Herpes Virus-1 (BHV-1), and Para-influenza type 3 (PI-3; (Griffin et al., 2010).

Bovine respiratory disease complex is a common disease in the dairy industry that is associated with considerable economic costs. A model of Dutch dairy farms estimated the cost of BRDC to be between €18 and € 57 (US 2012 dollars: $19 to $63) per heifer present on the dairy (van der Fels-Klerx et al., 2001). However, it is difficult to determine a true cost of calfhood BRDC in dairy cattle as little is known about the long term implications on subsequent cow productivity. Studies have found that calfhood BRDC decreased survival in the herd prior to first calving, but these same studies show conflicting results about the association between calfhood BRDC and age at first calving (AFC) (Waltner-Toews et al., 1986; Stanton et al., 2012). Other studies have also failed to find an association between calfhood BRDC and decreased survival in the herd after calving or an association between calfhood BRDC and first lactation production (Warnick et al., 1995; Warnick et al., 1997; Stanton et al., 2012).

With the exception of these few studies, minimal research has been conducted to examine the effects of calfhood BRDC in dairy replacement heifers on subsequent performance and reproductive parameters after first calving. Nonetheless, because of the excellent health and production records kept by the dairy industry and by individual dairies, there is opportunity to evaluate existing data sets. Such evaluation could provide dairy managers with valuable information to assist key management decisions. Therefore a retrospective, observational study was conducted to evaluate the effects of calfhood BRDC in replacement dairy heifers on subsequent cow departure from the herd, milk production and cow reproductive performance. The objectives of this study were to describe the frequency of calfhood BRDC occurrence in Holstein replacement dairy heifers and to determine the association between BRDC occurrence in Holstein heifer calves during the first 120 d of age with the subsequent rate of cow departure from the herd, milk yield, and calving interval on a single 5,000 cow dairy located in central Utah.

MATERIALS AND METHODS

Study Population

The data for this study were collected from January 1, 2007 to November 11, 2012 from a single, 5,000 cow dairy located near Provo, Utah using DHI-plus records (DHI-Provo, Provo, UT). All calves were born on the farm and raised according to current industry standards. Calves were housed in individual hutches from shortly after birth until they were weaned and moved into group housing at approximately 60 d of age. At approximately 120 days of age the calves were moved into open-lot grower pens. A calf was determined to have BRDC if it had been treated once for respiratory disease by the farm personnel during the first 120 d of age. All animals under 120 d of age at the time of record collection were excluded from the analysis (927/14,969 calves) because they were still at risk for developing calfhood BRDC. In addition, 18 animals were excluded from this study because dates of BRDC occurrence or calving did not align with the date of departure from the herd. All other heifer calves born on this farm during the study period were included in the data.

Description of Variables

Calves on this farm were managed as weekly groups. To control for this, a variable pertaining to weekly cohorts was created within the data set based on date of birth. Animals born during the first wk of the study were assigned to cohort 1, animals born during the second wk were assigned to cohort 2, animals born the third wk were assigned to cohort 3, and so forth to cohort 288. The variable corresponding to weekly cohorts was included in the model as a random intercept. In addition, the season of birth, season of BRDC occurrence, and season of calving were also created. Based off of temperatures recorded for Provo, UT (Weather Underground, 2013), season was defined as: winter (temperature consistently below 4˚C) was defined as

December to February, spring (temperature increasing from 4˚C to 16˚C) as March to May, summer (temperature consistently above 16˚C) as June to September, and fall (temperature decreasing from 16˚C to 4 ˚C) as October to November.

The days at risk for BRDC were calculated as the number of days from birth until the animal was either treated for BRDC for the first time or left the herd, and if neither of those occurred, the days at risk were set to 120 d. Furthermore, the number of days in the youngstock herd (i.e., number of days prior to first calving) were calculated by subtracting the number of days since the date the animal died, was sold, or calved from the date the animal was born, and adding one, so that no animal left the herd at zero days of age. The number of days between first and second calving was calculated by subtracting the number of days since the date the animal died, was sold, or calved a second time from the date the animal calved the first time and adding one, so that no animal left the milking herd at zero days of age. The number of days between second and third calving was calculated in a similar manner. Finally, the calving intervals were calculated by subtracting dates of sequential calvings and dividing this number by 30 to give the calving interval on a monthly scale. After all data was aggregated, a computer generated random sample of 50 animals was used to validate accurate data aggregation.

Data from a total of 14,024 animals were used in the analysis of departure from the herd prior to first calving. To be included in the analysis of departure from the herd between first and second calving, an animal had to calve once and had to have a record for lactation-one milk production. To be included in the analysis of lactation-one milk production, an animal had to calve once, have a record for 305 d mature equivalent (305ME) lactation-one milk production, and have a record for first calving interval. To be included in the analysis of lactation-two production, an animal had to calve twice, have a record for 305ME lactation-two production, and have a record for second calving interval.

Descriptive Statistics

The incidence risk of BRDC was calculated by dividing the number of new cases of BRDC each year by the number of animals born that year. The case fatality risk was calculated by dividing the number of deaths attributed to BRDC each year by the number of new cases of BRDC each year. The incidence rate of BRDC occurrence by wk of age was calculated by dividing the number of new cases of BRDC per age group (in wk) by the number of animal days at risk in that age group.

Statistical Analysis

Independent variables included in the statistical models include: 1) birth year (modeled as a categorical variable with the following categories:2007, 2008, 2009, 2010, 2011, and 2012), 2) occurrence of BRDC (modeled as a dichotomous variable), 3) age at BRDC (modeled as a dichotomous variable: a calf that contracted BRDC either contracted it pre-weaning (prior to 60 d of age) or post-weaning (between 60 and 120 d of age)), 4) birth season, 5) season of BRDC occurrence, and 6) season of calving, all modeled as categorical variables with categories of winter, spring, summer, and fall. In addition, age at first calving (AFC) was also modeled a continuous variable ranging from 19.0 to 31.0 mo. When it was considered as an independent variable, milk production did not meet the assumption of linearity, and therefore, it was modeled as a categorical variable based on quartile of production. The categories for lactation-one milk production were 3,383 to 11, 885 kgs, 11,886 to 13, 224 kgs, 13,225 to 14,473 kgs, and 14,474 to 19,761 kgs. The categories for lactation-two milk production were 4,594 to 12,517 kgs, 12,518 to 13,855 kgs, 13,856 to 15,080 kgs, and 15,081 to 19,631 kgs. Calving interval was defined as the number of months between two sequential calvings and was also included as a categorical variable in the models. Categories were defined as < 12.0 mo, 12.0 to 13.4 mo, 13.5 to 15.0 mo, and > 15.0 mo based on previous research (Arbel et al., 2001).

The outcome variable of time to departure from the herd was modeled as a continuous variable. When evaluating the association of independent variables with time to departure from the herd prior to first calving, the days at risk were calculated as the total number of days between birth and either departure from the herd or first calving. The number of days at risk for departure from the herd between first and second calving was defined as the number of days between first calving and either departing from the herd or calving a second time, and the number of days at risk between second and third calving was defined as the number of days between second calving and either departing from the herd or calving a third time. For each of the three time intervals, animal departed from the herd by being sold or by dying. In addition, for each of the three time intervals, animals that had not departed from the herd nor reached the end of that respective time interval were censored. In addition, the outcome variable of milk production was modeled on a continuous scale. The outcome variable pertaining to calving interval, originally recorded on a continuous scale, was categorized due to convergence problems, as follows: < 12.0 mo, 12.0 to 13.4 mo, 13.5 to 15.0 mo, and > 15.0 mo.

All of the models were constructed using a similar technique. Initially a causal web diagram was constructed to visualize potential associations between independent variables and outcome variables. Next, a univariable analysis was performed modeling the association of each independent variable with the outcome. Any variable with a P-value ≤ 0.40 was kept to ensure that all potentially significant variables were considered for the multivariable analysis. Following the univariable analysis, both a Pearson and a Spearman correlation analyses of the variables were performed to ensure that if two variables were collinear, were not included in the multivariable analysis. After that, the linearity assumption for all continuous variables was evaluated, and if the linearity assumption was not met, transformations of the variables were performed.

Then, the main effects model was constructed based on variables that passed the univariable screen. After all main significant effects ($P < 0.05$) were included in the model, the model was assessed for confounding and all significant two-way interactions ($P < 0.05$) were included by adding one interaction at a time. Next, the final model was built including all significant main effects, two-way interactions, and a random intercept for weekly cohorts. Finally, the distribution of the best linear unbiased predictors (BLUPs) of the cohort variable was plotted to ensure they were normally distributed, and residuals at the lower level (i.e., calves) (e.g., Martingale and deviance residuals for Survival models) were also plotted to evaluate the functional form of the model and to check for potential outliers and influential observations

Departure from the herd was analyzed using a Cox proportional hazards analysis in PROC PHREG (SAS 9.3; SAS Institute Inc., Cary, NC), and a generalized liner mixed effects model with a Gaussian distribution, identity link, maximum likelihood estimation, and Kenward-Rogers degrees of freedom using PROC GLIMMIX (SAS 9.3; SAS Institute Inc., Cary, NC) was performed to assess the associations between independent variables with lactation-one and lactation-two milk production. Then, to analyze the association between independent variables and calving interval a mixed effects multinomial model with quadrature method and multinomial distribution in PROC GLIMMIX (SAS 9.3; SAS Institute Inc., Cary, NC) was used.

RESULTS

Descriptive Statistical Results

Of the 14,024 total animals in this study population, 6.20% (868 calves) contracted BRDC during their first 120 d of life (Table 2.1). Of those animals, 177 died, resulting in an overall mortality risk of 1.26% and a case fatality risk of 20.39%. The incidence rate was 0.056 cases per 100 animal-days at risk. The highest incidence rate of BRDC was during the first wk of life at 0.24 cases per 100 animal days and the lowest incidence rate of BRDC was during the ninth wk of age and 18th wk of age at zero cases per 100 animal days (Table 2.2).

Of the cattle observed, 868 calves contracted BRDC prior to 120 d of age. Of the 868 animals that contracted BRDC during the first 120 d of life, 454 (52.3%) became ill pre-weaning and 414 (47.7%) contracted BRDC post-weaning. Of the 7,287 animals that were included in the analysis of departure from the herd between first and second calving, 430 (5.9%) animals were diagnosed with BRDC. Of those 430 animals, 222 contracted BRDC prior to weaning and 208 contracted BRDC after weaning. Moreover, of the 4,005 animals that were included in the analysis of lactation 1 production, 261 (6.5%) experienced calfhood BRDC, however, from the 1,717 animals considered for the analysis of lactation 2 production, 126 (7.3%) contracted BRDC as calves.

Univariable Analysis Results

Departure from the herd. From the univariabe analysis of the association between independent variables with departure from the herd prior to first calving (Table 2.3), it was found that birth year, the occurrence of BRDC, and birth season were all significant ($P < 0.40$). Analysis of departure from the herd prior to first calving for only those animals that contracted BRDC (Table 2.4) indicated that birth year, birth season, season of BRDC and the age the animal contracted BRDC were significantly associated with the outcome at the 40% significance level ($P < 0.40$).

The analysis of the associations between independent variables with departure from the herd between first and second calving (Table 2.5) determined that birth year, season of birth, occurrence of BRDC, season of first calving, first lactation production, and AFC were all significant ($P < 0.40$). Moreover, analysis of departure from the herd between first and second calving for only those animals that contracted BRDC (Table 2.6) showed that birth year, the age the animals contracted BRDC, and the quartile of lactation one production were all significantly associated with departure from the herd ($P < 0.40$).

The analysis of the relationship between independent variables with departure from the herd between second and third calving (Table 2.7) determined that birth year, occurrence of BRDC, season of second calving, and quartile of lactation-two production were all associated with departure from the herd based on the univariable screen ($P < 0.40$).

Milk Production. The univariable analysis of associations between independent variables with mean lactation-one milk production (Table 2.8) indicated that birth year, the occurrence of BRDC, and calving interval were all associated with lactation-one production ($P < 0.40$). Likewise, birth year, occurrence of BRDC, and calving interval were also all significantly associated with lactation-two production ($P < 0.40$) (Table 2.9).

Calving Interval. When a univariable analysis of the relationship between independent variables and calving interval was performed (Table 2.10), no significant association between the occurrence of BRDC as calves and the category of calving interval as cows was observed at the 40% significance level. However, birth year, birth season, AFC, season of first calving and lactation-one production were all associated with a difference in calving interval ($P < 0.40$).

Multivariable Analysis Results

Departure from the herd. The multivariable model of the associations between independent variables with departure from the herd prior to first calving (Table 2.11) indicated that the birth year and an interaction between birth year and the occurrence of BRDC were significant ($P < 0.001$). Because the association between the occurrence of BRDC with departure from the herd prior to first calving depended on the birth year, the contrasts comparing the associations between occurrence of BRDC with departure from the herd within each birth year are presented (Table 2.12). These contrasts depicted that the occurrence of BRDC did have a significant effect on departure from the herd prior to first calving for all birth years except 2007. The hazard ratio for an animal that contracted BRDC departing from the herd was 1.62 ($P < 0.001$), 2.06 ($P < 0.001$), 2.58 ($P < 0.001$), 3.71 ($P < 0.001$), and 4.98 ($P < 0.001$) for years 2008, 2009, 2010, 2011, and 2012, respectively, when compared to an animal of the same birth year that did not contract BRDC.

The analysis of the relationship between independent variables with departure from the herd prior to first calving for those animals that contracted BRDC (Table 2.13) showed that the age at BRDC occurrence and the birth year both impacted the departure from the herd prior to calving. The hazard ratio for an animal departing from the herd prior to first calving if it contracted BRDC pre-weaning was 2.62 ($P < 0.001$) when compared to an animal contracting BRDC post-weaning. When compared to 2007, the hazard ratio for departure from the herd prior to first calving for animals born in 2008, 2009, 2010, 2011, and 2012 was 2.09 ($P < 0.001$), 3.56 ($P < 0.001$), 3.29 ($P < 0.001$), 5.5 ($P < 0.001$), and 8.91 ($P < 0.001$), respectively.

The model of the associations between independent variables with departure from the herd between first and second calving (Table 2.14) showed that the occurrence of BRDC, birth year, the quartile of lactation one production, and AFC were all significantly associated with departure between first and second calving ($P < 0.05$). When compared to animals that did not contract BRDC, animals that did contract BRDC were 1.28 ($P = 0.023$) times more likely to leave the herd between first and second calving. Furthermore, when compared to animals born in 2007, animals born in 2009 and 2010 were 1.67 ($P < 0.001$) and 1.56 ($P < 0.001$) times more likely to leave the herd, respectively. However, animals born in 2008 were not more likely to leave the herd than animals born in 2007. When compared to animals in the lowest quartile of lactation-one production, animals in the second, third, and fourth quartile had a hazard ratio of 0.23 ($P < 0.001$), 0.14 ($P < 0.001$), and 0.10 ($P < 0.001$), respectively, for departure from the herd. For every tenth of a month of increase in AFC, the hazard ratio for the departure from the herd between first and second calving increased 1.08 times ($P < 0.001$).

Age of BRDC occurrence was not significantly associated ($P = 0.760$) with departure from the herd between first and second calving if an animal contracted BRDC (Table 2.15). However, because this variable was considered a variable of interest and an *a priori* confounder, it was forced into this model. This model did show that lactation-one production was associated with departure from the herd ($P < 0.001$). Relative to the animals that were in the lowest quartile of production, animals that were in the second, third, and fourth quartile had a hazard ratio of 0.22 ($P < 0.001$), 0.17 ($P < 0.001$), and 0.05 ($P < 0.001$), respectively.

Finally, the multivariable model of the associations between independent variables with departure between second and third calving (Table 2.16) showed that birth year and the quartile of lactation-two production were significantly associated with the outcome ($P < 0.001$). However, the occurrence of BRDC was not significantly associated with departure from the herd ($P = 0.51$). When compared to 2007, animals born in 2008 had a hazard ratio for departure of

1.26 ($P < 0.01$) and animals born in 2009 had a hazard ratio of 2.09 ($P < 0.001$). When compared to animals in the lowest quartile of production, animals in the second, third, and fourth quartile had a hazard ratio for departure of 0.37 ($P < 0.001$), 0.23 ($P < 0.001$), and 0.15 ($P < 0.001$), respectively.

The multivariable analysis of the associations between independent variables with lactation-one production (Table 2.17) indicated that occurrence of BRDC, birth year and calving interval were statistically significant ($P < 0.05$). The occurrence of BRDC was associated with a 233 kg decrease in 305ME production ($P = 0.04$). In addition, there was a 1,085 kg decrease in 305ME production for animals born in 2008 ($P = 0.007$) compared to animals born in 2010. However, animals born in other years did not have a significant difference in milk production compared to animals born in 2010. Also, an increase in calving interval was associated with an increase in 305ME production. Animals that had a calving interval less than 12.0 mo, 12.0 to 13.4 mo, and 13.5 to 15.0 mo produced 814 kg ($P < 0.001$), 492 kg ($P < 0.001$), and 228 kg ($P = 0.032$) less in 305ME milk, respectively, compared to animals that had a calving interval of 15.0 m or greater.

There was not a significant association between the occurrence of BRDC and milk production in lactation-two ($P = 0.67$) (Table 2.18). However, birth year was significantly associated with lactation-two production. When compared to animals born in 2009, animals born in 2007 were associated with an 831 kg ($P < 0.014$) decrease in 305ME production and animals born in 2008 were associated with a 781 kg ($P < 0.020$) decrease in 305ME production. Similarly to first lactation production, an increase in calving interval was associated with increase in 305ME production in lactation-two. Animals with a calving interval less than 12.0 mo and 12.0 to 13.4 mo were associated with a 961 kg decrease ($P < 0.001$) and 415 kg decrease in 305ME production (*P* = 0.008), respectively, compared to animals with a calving interval of 15 mo or greater. However, animals with a calving interval of 13.5 to 15.0 mo were not associated with a difference in production (*P* = 0.388) compared to animals with a calving interval greater than or equal to 15 mo.

The variable pertaining to the occurrence of BRDC was not significantly associated with a difference in calving interval length (*P* = 0.53) (Table 2.19). This model did show that lactation-one production, season of first calving, and birth year were all associated with a difference in the first calving interval (*P* < 0.001). However, only lactation-one production had a trend between categories of production. As milk production decreased, the calving interval for cows in that production quartile also decreased. For example, cows from the highest quartile of production were 1.79 (95% CI: 1.43 to 2.24) times more likely to have a calving interval less than 12.0 mo rather than a calving interval of 12.0 to 13.4 mo. Compared to cows from the lowest quartile of production. It could also be said, that as one evaluated cows from the highest quartile of production compared to cows from the lowest quartile of production, it was 0.44 times as likely of having a calving interval greater than 15.0 mo (95% CI: 0.32 to 0.61) rather than a calving interval of 12.0 to 13.4 mo.

DISCUSSION

This study was consistent with previous studies that found the occurrence of BRDC in dairy cattle was associated with an increase in risk of calf departure from the herd prior to first calving. However, it differed from previous studies in that it found that BRDC in dairy cattle was associated with an increase in risk of cow departure from the herd between first and second calving. It also differed in that it found that the occurrence of BRDC in dairy cattle was associated with decreased milk production. This may be due to the current study including a larger population of dairy cows than previous studies.

However, one must use caution when interpreting the results of this study as this is an observational study of a single dairy located in central Utah. Observational studies should not be used to determine causality. In addition, care should be taken when extrapolating the result of this study to dairies in other geographical locations or with other management styles.

In this study, the overall incidence rate of BRDC was lower than the 0.1 cases per 100 head days at risk reported by Sivula et al. (1996). However, the peak incidence rate in the current study was higher than the peak rate (0.18 cases /100 animal days) reported by Sivula et al. (1996). Nonetheless, in both of these studies the peak incidence of BRDC occurred during the first wk of life. This is highly unexpected and raises the question of whether or not the dairy farms have recorded consistent case definitions for BRDC. In the current study, the incidence of BRDC decreased during the first few wk of age and then began to increase again after 9 wks of age. The dairy in the current study moved calves to group housing at 9 wks of age; this commingling may explain the increase in incidence of BRDC observed at this time.

Although the morbidity was lower in this study compared to some of the other published literature (Sivula et al., 1996; Virtala et al., 1996a), the case fatality risk in this study was higher than in previous studies. Sivula et al. (1996) reported a case fatality risk of 9.4% for BRDC, and

Virtala et al. (1996a) reported an even lower case fatality risk at 4.2%. Like the incidence rate, this variation in case fatality risk could be due to differences in the ability of calf-caregivers to diagnose and treat disease as differences in management strategies to diagnose BRDC in dairy calves can have a significant impact on case fatality risk. Emphasis on identifying animals with BRDC and therefore increasing the number of animals treated when risk of death remains the same lowers the case fatality risk within a herd. Likewise, treatment choices for treating cattle with BRDC can influence the success of the treatments therefore improving the case fatality risk by decreasing death loss at given morbidity risk within herds.

Similar to the overall incidence rate, the incidence risk of BRDC from birth to 120 d of age in this study was lower than in previous studies. Sivula et al. (1996) reported the risk of BRDC in calves from birth to 16 wk of age on 30 Minnesota dairy farms to be 7.6%, and Virtala et al. (1996a) reported the incidence risk on dairies in New York State to be 11% or 25.6% depending on whether the diagnosis was made by the caretaker or clinician, respectively. This raises the question of whether the variation in incidence is due to differences in geographical location, differences in the ability of the caretaker to diagnose BRDC, or if it is due to other management differences. In the current study it is interesting to note the high variability of risk of BRDC from a high of 13.0 in 2008 to a low of 1.9% in 2010 in the current study. This high variability may be due to changes that occurred within the dairy over time. When this was discussed with the dairy, they commented that they had had some employee compliance issues and had changed vaccines protocols.

In the current study, the occurrence of BRDC was associated with an increased departure from the herd prior to first calving. This association is consistent with previous studies (Waltner-Toews et al., 1986; Stanton et al., 2012). However, in the current study the association between the occurrence of BRDC with departure from the herd depended on the year of birth. The only birth year that BRDC was not associated with an increase in departure from the herd prior to first calving was 2007. During the birth years 2008 to 2012, occurrence of BRDC was associated with an increase in the hazard ratio for departure from the herd. This increase in the hazard ratio may reflect a change in culling practices over time. During the early years of the study period the dairy was expanding from within and was not aggressively culling. More recently, the dairy has begun to cull calves that do not have the growth performance of the other calves in their same age group, and it has been estimated in previous studies that BRDC decreases growth by as much as 10.6 kg from birth to 6 mo of age (Donovan et al., 1998). Therefore, in more recent years, calves that contracted BRDC may have been more likely to be culled because of decreased growth than they were earlier in the study.

In addition to BRDC occurrence being associated with the rate of departure from the herd prior to first calving, the age at BRDC occurrence also affected the rate of departure from the herd. Animals that contracted BRDC pre-weaning were more likely to leave the herd at some point prior to first calving compared to animals that contracted BRDC post-weaning. To the best of our knowledge, the association between age at BRDC occurrence and departure from the herd has not been reported in previous studies. However, the median age of death for calves has been reported to be within the first 60 d of life (Waltner-Toews et al., 1986; Curtis et al., 1988) and therefore, the increased departure from the herd associated with calves that contract BRDC pre-weaning that was seen in this study may be associated with the higher mortality often seen in younger calves.

The current study also found a significant difference in the departure from the herd between first and second calving associated with calfhood BRDC. This is different than the findings of Warnick et al. (1997) and Stanton et al. (2012). This study did include a larger sample of animals which may have increased the power to find an association between calfhood BRDC and the risk of departure between first and second calving. However, the age at BRDC occurrence was not associated with a difference in departure from the herd between first and second calving, nor was the occurrence of calfhood BRDC associated with departure from the herd between second and third calving.

The current study estimated a decrease in projected first lactation 305ME production if an animal contracted BRDC during the first 120 d of life compared to animals that did not contract BRDC. This is different than previous studies by Warnick et al. (1995) and Stanton et al. (2012) that did not find an association between calfhood BRDC and first lactation milk production. It is also interesting to note that animals born in 2008 had an estimated lower projected 305ME production than those animals born during 2010. However, when animals born during 2007 and 2009 were compared with animals born in 2010 there was no difference in first lactation 305ME production. This is pointed out because 2008 was the birth year that had the highest percentage BRDC occurrence. An association between calfhood BRDC and a difference in second lactation production was not noted.

The current study did not find an association between calfhood BRDC and a difference in the first calving interval. A literature search was not able to find any previous work evaluating the association between calfhood BRDC and reproductive performance, so it is not possible to compare this finding with other work.

CONCLUSIONS

In conclusion, this study found that calfhood BRDC is associated with an increase the rate of departure from the herd prior to first calving and between first and second calving. In addition, BRDC occurrence pre-weaning was associated with an increased rate of departure from the herd prior to first calving compared to BRDC post-weaning, but the age at BRDC occurrence was not associated with departure from the herd between first and second calving. Calfhood BRDC was associated with a decreased lactation-one milk production but a decrease in production was not noted in subsequent lactations. Finally, calfhood BRDC was not associated with an increase in first calving interval. Calfhood BRDC occurrence in replacement dairy heifers has significant long-term effects on subsequent cow departure from the dairy herd and milk yield during the first lactation could have a significant impact on dairy profitability.

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Table 2.1. Occurrence and case fatality rate of bovine respiratory disease complex (BRDC) by birth year in a population of Holstein calves on a farm in central Utah

Year	# Calves born (% of total)	Cases of BRDC, n (Incidence risk, %)	Deaths attributed to BRDC, n (case fatality risk, %)
2007	2,042 (14.56)	111 (5.43)	12 (10.81)
2008	2,351 (16.76)	306 (13.02)	58 (18.95)
2009	2,521 (18.00)	162 (6.43)	44 (27.16)
2010	2,864 (20.42)	53 (1.85)	10 (18.87)
2011	2,642 (18.81)	64 (2.42)	15 (23.44)
2012	1,604 (11.42)	172 (10.72)	38 (22.09)
Total	14,024	868 (6.19)	177 (20.39)

Table 2.2. Age of bovine respiratory disease complex (BRDC) occurrence in a population of Holstein calves on a farm in central Utah

Age at BRDC occurrence, wk	Cases of BRDC, n (% of total BRDC)	Incidence rate (per 100 animal days)
1	229 (26.38)	0.24
2	62 (7.14)	0.07
3	48 (5.53)	0.05
4	30 (3.46)	0.03
5	33 (3.80)	0.04
6	19 (2.19)	0.02
7	17 (1.96)	0.02
8	16 (1.84)	0.02
9	3 (0.35)	0.00
10	12 (1.38)	0.01
11	21 (2.42)	0.02
12	37 (4.26)	0.04
13	78 (8.99)	0.08
14	94 (10.83)	0.10
15	73 (8.41)	0.07
16	47 (5.41)	0.05
17	44 (5.07)	0.04
18	5 (0.58)	0.00

Table 2.3. Univariable analysis of the association between birth year, occurrence of bovine respiratory disease complex (BRDC) and birth season with departure prior to first calving from a single dairy herd located in central Utah: number of animal per category, number of animals that departed from the herd prior to first calving and *P*-values

Variable	Category	Animals, n (%)	Animals that departed, n (% of level)	*P*-value[1]
Birth year	2007	2,042 (14.56)	277 (13.56)	< 0.001
	2008	2,351 (16.76)	522 (22.20)	
	2009	2,521 (17.98)	606 (24.04)	
	2010	2,864 (20.42)	592 (20.67)	
	2011	2,642 (18.84)	380 (14.38)	
	2012	1,604 (11.44)	213 (13.28)	
BRDC	Yes	868 (6.19)	302 (34.79)	< 0.001
	No	13,156 (93.81)	2288 (17.39)	
Birth Season	Dec 1 to Feb 28	3,564 (25.41)	631 (17.70)	0.219
	March 1 to May 31	3,608 (25.73)	631 (17.49)	
	June 1 to Sept 30	4,782 (34.10)	925 (19.34)	
	Oct 1 to Nov 30	2,070 (14.76)	403 (19.47)	

[1]Statistically significant ($P < 0.40$) variables

Table 2.4. Univariable analysis of the association between birth year, birth season, season of bovine respiratory disease complex (BRDC) and age at BRDC occurrence with departure prior to first calving from a single dairy herd located in central Utah: number of animals per category that contracted BRDC during the first 120 days of life, number of those animals that departed from the herd prior to first calving and *P*-values

Variable	Category	Animals that contracted BRDC, n (% of total)	Animals that departed, n (% of level)	*P*-value[1]
Birth year	2007	111 (12.79)	17 (15.32)	< 0.001
	2008	306 (35.25)	96 (31.37)	
	2009	162 (18.66)	66 (40.74)	
	2010	53 (6.11)	23 (43.40)	
	2011	64 (7.37)	28 (43.75)	
	2012	172 (19.82)	72 (41.86)	
Birth season	Dec 1 to Feb 28	124 (28.84)	61 (49.19)	0.138
	March 1 to May 31	100 (23.26)	57 (57.00)	
	June 1 to Sept 30	101 (23.49)	59 (58.42)	
	Oct 1 to Nov 30	105 (24.42	51 (48.57)	
Season of BRDC	Dec 1 to Feb 28	176 (20.28)	52 (29.55)	< 0.001
	March 1 to May 31	204 (23.50)	79 (38.73)	
	June 1 to Sept 30	307 (35.37)	123 (40.07)	
	Oct 1 to Nov 30	181 (20.85)	48 (26.52)	
Age	Pre-weaning	454 (52.30)	201 (44.27)	< 0.001
	Post-weaning	414 (47.70)	101 (24.40)	

[1]Statistically significant ($P < 0.40$) variables.

Table 2.5. Univariable analysis of the association between birth year, birth season, occurrence of bovine respiratory disease complex (BRDC), season of first calving, quartile of lactation-one production and age at first calving with departure between first and second calving from a single dairy herd located in central Utah: number of animals per category, number of animals that departed from the herd and *P*-values

Variable	Category	Animals, n (% of total)	Animals that departed, n (% of level)	*P*-value[1]
Birth year	2007	1,719 (23.58)	324 (18.85)	< 0.001
	2008	1,745 (23.94)	361(20.69)	
	2009	1,843 (25.25)	338 (18.34)	
	2010	1,972 (27.05)	198 (10.00)	
	2011	10 (0.01)	0 (0.00)	
Birth season	Dec 1 to Feb 28	1,635 (22.43)	306 (18.71)	0.340
	March 1 to May 31	1,785 (24.48)	317 (17.76)	
	June 1 to Sept 30	2,676 (36.71)	440 (16.44)	
	Oct 1 to Nov 30	1,193 (16.36)	159 (13.33)	
BRDC	Yes	402 (5.51)	98 (24.38)	0.002
	No	6,887 (94.48)	1124 (16.28)	
Season of first calving	Dec 1 to Feb 28	1,853 (25.42)	376 (20.29	0.068
	March 1 to May 31	1,994 (27.35)	320 (16.05)	
	June 1 to Sept 30	2,292 (31.44)	347 (15.14)	
	Oct 1 to Nov 30	1,150 (15.77)	179 (15.56)	
Lactation-one production, kgs	3,383 to 11,885	1,819 (24.95)	700 (38.48)	< 0.001
	11,886 to 13,224	1,826 (25.05)	231 (12.66)	
	13,225 to 14,473	1,823 (25.01)	158 (8.67)	
	14,474 to 19,761	1,821 (24.98)	133 (7.30)	
Age at first calving, 10^{ths} of mo	-	-		< 0.001

[1]Statistically significant (*P* < 0.40) variables.

Table 2.6. Univariable analysis of the association between birth year, age of bovine respiratory disease complex (BRDC) occurrence and lactation-one production with departure between first and second calving from a single dairy herd located in central Utah: number of animals per category that contracted BRDC during the first 120 d of life, number of those animals that departed from the herd between first and second calving and *P*-values

Variable	Category	Animals that contracted BRDC, n (% of total)	Animals that departed, n (% of level)	*P*-value[1]
Birth year	2007	94 (21.86)	28 (29.79)	0.189
	2008	210 (48.84)	73 (34.76)	
	2009	96 (22.33)	18 (18.75)	
	2010	29 (6.74)	5 (17.24)	
Age	Pre-weaning	222 (51.63)	67 (30.18)	0.231
	Post-weaning	208 (48.37)	57 (27.40)	
Lactation-one production, kg	3,383 to 11,885	138 (34.33)	65 (47.10)	< 0.001
	11,886 to 13,224	101 (25.12)	15 (14.48)	
	13,225 to 14,473	90 (22.39)	15 (16.67)	
	14,474 to 19,761	73 (18.16)	3 (4.11)	

[1]Statistically significant ($P < 0.40$) variables.

Table 2.7. Univariable analysis of the association between birth year, occurrence of bovine respiratory disease complex (BRDC), season of second calving and quartile of lactation-two production with departure between second and third calving from a single dairy located in central Utah: number of animals per category, number of animals that departed from that herd between second and third calving and *P*-values

Variable	Category	Animals, n (% of total)	Animals that departed, n (% of level)	*P*-value[1]
Birth year	2007	1,393 (34.73)	346 (24.84)	< 0.001
	2008	1,373 (34.26)	332 (24.16)	
	2009	1,223 (30.49)	197 (16.11)	
BRDC	Yes	262 (6.53)	67 (25.57)	0.247
	No	3,749 (93.47)	809 (21.48)	
Season of second calving	Dec 1 to Feb 28	928 (23.14)	219 (23.60)	0.213
	March 1to May 31	1,113 (27.75)	272 (24.44)	
	June 1 to Sept 30	1,384 (34.51)	283 (20.45)	
	Oct 1 to Nov 30	586 (14.61)	102 (17.41)	
Lactation-two production, kg	4,594 to12,517	949 (24.99)	337 (35.51)	< 0.001
	12,518 to 13,855	951 (25.04)	170 (17.88)	
	13,856 to 15,080	950 (25.01)	122 (12.84)	
	15,081 to 19,631	948 (24.96)	93 (9.81)	

[1]Statistically significant ($P < 0.40$) variables.

Table 2.8. Univariable analysis of the association between birth year, occurrence of bovine respiratory disease complex (BRDC) and calving interval with mean lactation-one production on a single dairy herd located in central Utah: mean production per category (standard errors) and *P*-values

Variable	Category	Mean production (kg)	SE	*P*-value[1]
Birth year	2007	13,637	47.61	< 0.001
	2008	12,840	47.95	
	2009	13,807	50.42	
	2010	13,644	50.42	
BRDC	Yes	13,037	112.80	< 0.001
	No	13,443	29.78	
Calving interval, mo	< 12.0	13,143	49.28	< 0.001
	12.0 to 13.4	13,394	45.82	
	13.5 to 15.0	13,715	73.03	
	> 15.0	13,864	81.77	

[1]Statistically significant ($P < 0.40$).

Table 2.9. Univariable analysis of the association between birth year, occurrence of bovine respiratory disease complex (BRDC) and calving interval with mean lactation-two production on a single dairy herd located in central Utah: mean production per category (standard errors) and *P*-values

Variable	Category	Mean production (kg)	SE	*P*-value[1]
Birth year	2007	13,708	56.94	< 0.001
	2008	13,777	57.68	
	2009	13,543	62.69	
	2010	12,739	62.69	
BRDC	Yes	13,691	35.23	0.332
	No	13,557	133.22	
Calving interval, mo	<12.0	13,626	69.89	< 0.001
	12.0 to 13.4	14,114	67.82	
	13.5 to 15.0	14,398	100.97	
	>15.0	14,502	105.12	

[1]Statistically significant ($P < 0.40$) variables.

Table 2.10. Univariable analysis of the association between lactation-one production, season of first calving, birth year, occurrence of bovine respiratory disease complex (BRDC), season of birth and age at first calving with calving interval on a single dairy herd located in central Utah: number of animals per each category within each calving interval level and *P*-values

Variable	Category	Calving interval, mo < 12.0 n (% of calving interval)	12.0 to 13.4 n (% of calving interval)	13.5 to 15.0 n (% of calving interval)	> 15.0 n (% of calving interval)	*P*-value[1]
Lactation-one production, kg	3,383 to 11,885	413 (41.47)	382 (38.35)	121 (12.15)	80 (8.03)	< 0.001
	11,886 to 13,224	366 (36.67)	389 (38.98)	133 (13.33)	110 (11.02)	
	13,225 to 14,473	303 (30.48)	393 (39.54)	170 (17.1)	128 (12.88)	
	14,474 to 19,761	276 (27.68)	379 (38.01)	178 (17.85)	164 (16.45)	
Season of first calving	Dec 1 to Feb 28	211 (21.75)	457 (47.11)	153 (15.77)	149 (15.36)	< 0.001
	March 1 to May 31	398 (36.58)	385 (35.39)	165 (15.17)	140 (12.87)	
	June 1 to Sept 30	486 (39.32)	454 (36.73)	180 (14.56)	116 (9.39)	
	Oct 1 to Nov 30	264 (38.15)	247 (35.69)	104 (15.03)	77 (11.13)	
Birth Year	2007	406 (29.17)	559 (40.16)	229 (16.45)	198 (14.22)	< 0.001
	2008	450 (32.77)	561 (40.86)	186 (13.55)	176 (12.82)	
	2009	503 (41.2)	423 (34.64)	187 (15.32)	108 (8.85)	
BRDC	Yes	85 (32.44)	106 (40.46)	43 (16.41)	28 (10.69)	0.735
	No	1,274 (34.21)	1,437 (38.59)	559 (15.01)	454 (12.19)	
Season of birth	Dec 1 to Feb 28	263 (29.75)	378 (42.76)	127 (14.37)	116 (13.12)	< 0.001
	March 1 to May 31	261 (27.33)	406 (42.51)	149 (15.6)	139 (14.55)	
	June 1 to Sept 30	573 (38.12)	521 (34.66)	237 (15.77)	172 (11.44)	
	Oct 1 to Nov 30	262 (40.68)	238 (36.96)	89 (13.82)	55 (8.54)	
Age at first calving, mo	20	45 (33.09)	50 (36.76)	21 (15.44)	20 (14.71)	0.119
	21	327 (31.53)	422 (40.69)	150 (14.46)	138 (13.31)	
	22	462 (33.62)	532 (38.72)	226 (16.45)	154 (11.21)	
	≥ 23	525 (36.48)	539 (37.46)	205 (14.25)	170 (11.81)	

[1]Statistically significant variables (*P* < 0.40).

Table 2.11. Multivariable analysis of the associations between the occurrence of bovine respiratory disease complex (BRDC), birth year and the interaction between the occurrence of BRDC and birth year with departure prior to first calving from a single dairy herd located in central Utah

Variable	Category	Coefficient	SE	*P*-value
BRDC	No	Reference	Reference	0.914[1]
	Yes	0.03	0.25	0.916
Birth year	2007	Reference	Reference	< 0.001[1]
	2008	0.48	0.08	< 0.001
	2009	0.63	0.08	< 0.001
	2010	0.49	0.08	< 0.001
	2011	0.45	0.09	< 0.001
	2012	0.60	0.11	< 0.001
BRDC * Birth year		See Table 2.12		< 0.001[1]

[1]*P*-values were derived from an F-test.

Table 2.12. Hazard ratios of departure from the herd prior to first calving comparing animals that contracted bovine respiratory disease complex (BRDC) to animals within the same birth year that did not contract BRDC

Variable	HR[1]	95% CI	*P*-value
2007 BRDC vs. 2007 No BRDC	1.03	0.63, 1.69	0.916
2008 BRDC vs. 2008 No BRDC	1.62	1.30, 2.03	< 0.001
2009 BRDC vs. 2009 No BRDC	2.06	1.59, 2.66	< 0.001
2010 BRDC vs. 2010 No BRDC	2.58	1.70, 3.92	< 0.001
2011 BRDC vs. 2011 No BRDC	3.71	2.52, 5.47	< 0.001
2012 BRDC vs. 2012 No BRDC	4.98	3.74, 6.65	< 0.001

[1]HR = Hazard ratio.

Table 2.13. Multivariable analysis of the associations between age of bovine respiratory disease complex (BRDC) occurrence and birth year with departure prior to first calving from a single dairy herd located in central Utah

Variable	Category	Coefficient	SE	HR[1]	95% CI	*P*-value
Age	Pre-weaning	0.96	0.13	2.62	2.02, 3.41	< 0.001
	Post-weaning	Reference	Reference	Reference	Reference	< 0.001[2]
Birth year	2007	Reference	Reference	Reference	Reference	< 0.001[2]
	2008	0.74	0.28	2.09	1.21, 3.64	0.009
	2009	1.27	0.29	3.56	2.01, 6.31	< 0.001
	2010	1.19	0.34	3.29	1.69, 6.41	< 0.001
	2011	1.70	0.33	5.50	2.89, 10.47	< 0.001
	2012	2.19	0.30	8.91	4.93, 16.12	< 0.001

[1]HR = Hazard ratio.
[2]*P*-value derived from F-test.

Table 2.14. Multivariable analysis of the associations between the occurrence of bovine respiratory disease complex (BRDC), birth year, lactation-one production, and age at first calving with departure from a single dairy herd located in central Utah between first and second calving

Variable	Category	Coefficient	SE	HR[1]	95% CI	*P*-value
BRDC	No	Reference	Reference	Reference	Reference	0.023[2]
	Yes	0.25	0.12	1.28	1.03, 1.59	0.025
Birth Year	2007	Reference	Reference	Reference	Reference	< 0.001[2]
	2008	-0.07	0.09	0.93	0.78, 1.11	0.432
	2009	0.51	0.09	1.67	1.39, 2.01	< 0.001
	2010	0.44	0.11	1.56	1.26, 1.93	< 0.001
Lactation-one production, kg	3,383 to 11,885	Reference	Reference	Reference	Reference	< 0.001[2]
	11,886 to 13,224	-1.48	0.08	0.23	0.20, 0.26	< 0.001
	13,225 to 14,473	-1.96	0.09	0.14	0.12, 0.17	< 0.001
	14,474 to 19,761	-2.33	0.10	0.10	0.08, 0.12	< 0.001
Age at first calving, 10[ths] of mo	Continuous	0.08	0.02	1.08	1.04, 1.13	< 0.001[2]

[1]HR = Hazard ratio.
[2]*P*-value derived from F- test.

Table 2.15. Multivariable analysis of the associations between the age of bovine respiratory disease complex (BRDC) occurrence and lactation-one production with departure from a single dairy herd located in central Utah between first and second calving

Variable	Category	Coefficient	SE	HR[1]	95% CI	*P*-value
Age	Pre-weaning	-0.06	0.21	0.94	0.63, 1.41	0.760
	Post-weaning	Reference	Reference	Reference	Reference	0.760[2]
Lactation-one production, kg	3,383 to 11,885	Reference	Reference	Reference	Reference	< 0.001[2]
	11,886 to 13,224	-1.49	0.29	0.22	0.13, 0.40	< 0.001
	13,225 to 14,473	-1.78	0.32	0.17	0.09, 0.32	< 0.001
	14,474 to 19,761	-2.91	0.59	0.05	0.02, 0.17	< 0.001

[1]HR = Hazard ratio.
[2]*P*-value derived from F-test.

Table 2.16. Multivariable analysis of the associations between the occurrence of bovine respiratory disease complex (BRDC), birth year and lactation-two production with departure from a single dairy herd located in central Utah between second and third calving

Variable	Category	Coefficient	SE	HR[1]	95% CI	*P*-value
BRDC	No	Reference	Reference	Reference	Reference	0.509[2]
	Yes	0.09	0.14	1.10	0.83, 1.45	0.511
Birth Year	2007	Reference	Reference	Reference	Reference	< 0.001[2]
	2008	0.23	0.09	1.26	1.05, 1.49	0.010
	2009	0.74	0.12	2.09	1.66, 2.63	< 0.001
Lactation-two	4,594 to 12,517	Reference	Reference	Reference	Reference	< 0.001[2]
production, kg	12,518 to 13,855	-0.99	0.10	0.37	0.31, 0.45	< 0.001
	13,856 to 15,080	-1.46	0.11	0.23	0.19, 0.29	< 0.001
	15,081 to 19,631	-1.91	0.12	0.15	0.12, 0.19	< 0.001

[1]HR = Hazard ratio.
[2]*P*-value from F- test.

Table 2.17. Multivariable analysis of the associations between birth year, occurrence of bovine respiratory disease complex (BRDC) and calving interval with lactation-one production on a single dairy herd located in central Utah

Variable	Category	Estimated difference, kg	SE	95% CI	*P*-value
BRDC	Yes	Reference	Reference	Reference	0.040[1]
	No	233	113	11, 456	0.040
Birth year	2007	-327	404	-1,118, 465	0.419
	2008	-1085	404	-1,877, -294	0.007
	2009	-84	403	-876, 707	0.834
	2010	Reference	Reference	Reference	< 0.001[1]
Calving interval, mo	< 12.0	-814	94	-998, -631	< 0.001
	12.0 to 13.4	-492	91	-671, -314	< 0.001
	13.5 to 15.0	-228	107	-437, -19	0.032
	> 15.0	Reference	Reference	Reference	< 0.001[1]

[1]*P*-value from F-test.

Table 2.18. Multivariable analysis of the associations between the occurrence of bovine respiratory disease complex BRDC), age at first calving and calving interval with lactation-two production on a single dairy herd located in central Utah

Variable	Category	Estimated difference, kg	SE	95% CI	*P*-value
BRDC	Yes	Reference	Reference	Reference	0.667[1]
	No	-70	163	-391, 250	0.667
Birth year	2007	-831	335	-1489, -172	0.014
	2008	-781	335	-1439, -132	0.020
	2009	Reference	Reference	Reference	0.049[1]
Calving interval, mo	< 12.0	-961	127	-1210, -712	< 0.001
	12.0 to 13.4	-415	124	-658, -172	0.008
	13.5 to 15.0	-124	144	-406, 158	0.388
	> 15.0	Reference	Reference	Reference	< 0.001[1]

[1]*P*-value from F-test.

Table 2.19. Multivariable analysis of the associations between lactation-one production, season of first calving, birth year and occurrence of bovine respiratory disease complex (BRDC) with calving interval

Variable		Calving interval, mo[1]					
		< 12.0		13.5 to 14.9		> 15.0	
		OR[2]	95% CI	OR[2]	95% CI	OR[2]	95% CI
Lactation-one production, kg*	3,383 to 11,885	1.79	1.43, 2.24	0.71	0.54, 0.94	0.44	0.32, 0.61
	11,886 to 13,224	1.43	1.14, 1.78	0.76	0.58, 0.99	0.62	0.47, 0.83
	13,225 to 14,473	1.14	0.91, 1.43	0.95	0.73, 1.22	0.72	0.54, 0.94
	14,474 to 19,761	Reference	Reference	Reference	Reference	Reference	Reference
Season of first calving*	Dec 1 to Feb 28	0.45	0.34, 0.58	0.79	0.59, 1.05	1.08	0.78, 1.49
	March 1 to May 31	0.92	0.71, 1.19	1.02	0.76, 1.36	1.23	0.88, 1.72
	June 1 to Sept 30	1.05	0.82, 1.33	0.94	0.71, 1.26	0.80	0.57, 1.12
	Oct 1 to Nov 30	Reference	Reference	Reference	Reference	Reference	Reference
Birth Year*	2007	0.56	0.44, 0.71	0.93	0.74, 1.17	1.48	1.11, 1.98
	2008	0.55	0.43, 0.70	0.79	0.61, 1.00	1.53	1.13, 2.06
	2009	Reference	Reference	Reference	Reference	Reference	Reference
BRDC†	Yes	0.85	0.63, 1.16	1.10	0.76, 1.59	0.85	0.55, 1.33
	No	Reference	Reference	Reference	Reference	Reference	Reference

[1]Calving interval to 12.0 to 13.4 mo was used as the reference interval.
[2]OR- odds ratio.
**P*-value from F-test < 0.001.
†*P*-value from F-test = 0.533.