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Population Dynamics of Undifferentiated Neonatal Calf Diarrhea among Ranch Beef Calves

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Abstract

We conducted a retrospective longitudinal study of a single population of calves from a grass-managed beef cattle system to determine which factors of time and subject explained the probability for calves to die from undifferentiated neonatal diarrhea. Data were collected from 402 beef calves at risk for undifferentiated neonatal calf diarrhea during a single calving season. Descriptive statistics from birth and mortality records were summarized, and factors of time and subject explaining the probability for calves to die of undifferentiated neonatal diarrhea were identified using a multivariable logistic regression model. Forty-eight of 402 calves (11.9%) died from undifferentiated neonatal diarrhea. Thirty-nine of 47 calves with age-at-death information (83%) died between six and 15 days of age. The mean age at death did not change over the calving season, however, the weekly cumulative incidence of mortality increased as the calving season progressed. The probability of death was increasingly greater for calves born later in the calving season. The period of time a calf was born in the calving season ($P<0.0001$) and the age of the dam ($P=0.006$) explained the probability for a calf to die of neonatal diarrhea. Calves of two-year-old dams were more likely to die than calves of mature cows (OR= 5.79, $P=0.003$). The calves of three-year-old dams were intermediate in risk compared to calves of mature cows (OR= 2.21), but not significantly different from calves from the other dam age-groups ($P>0.10$). The probability for calves to die was not explained by gender ($P=0.68$) or birth weight ($P=0.43$). Factors explaining mortality were age of the calf, age of the dam and point of time in the calving season the calf was born. Because the incidence of scours increased with the passage of time within the calving season, undifferentiated neonatal calf diarrhea might be prevented by designing beef calving systems which can maintain the more ideal conditions existing at the beginning of the calving season, which include low doses of pathogen exposure and fewer opportunities for older, highly-infective calves to transmit pathogens to younger, susceptible animals.

Keywords: bovine, calf, neonatal diarrhea, epidemiology

Résumé

Nous avons fait une étude longitudinale rétrospective d'une population de veaux provenant d'un élevage de bovins de boucherie nourris à l'herbe pour déterminer les caractéristiques individuelles et temporelles permettant de prédire la probabilité que les veaux meurent de diarrhée néonatale non différenciée. Les données provenaient de 402 veaux de boucherie à risque pour la diarrhée néonatale non différenciée durant une seule saison de vêlage. Les statistiques descriptives ont été compilées à partir des dossiers de mortalité et de natalité et les caractéristiques individuelles et temporelles permettant de prédire la probabilité que les veaux meurent de diarrhée néonatale non différenciée ont été analysées avec un modèle de régression logistique multiple. Un total de 48 veaux (11.9%) sont morts des suites de la diarrhée néonatale non différenciée. Parmi les 47 veaux dont l'information sur l'âge à la mort était disponible, 39 (83%) sont morts entre 6 et 15 jours d'âge. L'âge moyen à la mort ne variait pas durant la saison de vêlage. Toutefois, l'incidence cumulative hebdomadaire de mortalité augmentait plus tard dans la saison de vêlage. La probabilité de mort était plus élevée chez les veaux qui naissaient plus tard dans la saison de vêlage. Le moment de la naissance dans la saison de vêlage

(p<0.0001) et l'âge de la mère (p=0.006) expliquait la probabilité qu'un veau meurt de la diarrhée néonatale. Les veaux dont les mères avaient deux ans étaient plus à risque de mourir que les veaux de vaches plus âgées (RC = 5.79, p = 0.003). Les veaux dont les mères avaient trois ans avaient des chances intermédiaires par rapport aux veaux de vaches plus âgées (RC = 2.21); mais ces chances ne différaient pas de celles des veaux de vaches des autres groupes d'âge (p>0.10). La probabilité de mourir n'était pas associé ni au sexe (p=0.68) ni au poids à la naissance (p=0.43). Les facteurs associés à la mortalité des veaux étaient l'âge du veau, l'âge de la mère et le moment de la naissance dans la saison de vêlage. Parce que l'incidence de diarrhée augmente avec le temps durant la saison de vêlage, il serait possible de prévenir la diarrhée néonatale non différenciée dans les systèmes d'élevage de veaux de boucherie qui maintiennent les conditions plus idéales rencontrées en début de saison de vêlage. Ces dernières incluraient une moins grande exposition aux pathogènes et une réduction des chances que les individus plus vieux et plus infectés transmettent les pathogènes aux individus moins âgés et plus susceptibles.

Introduction

Neonatal diarrhea is an important cause of morbidity and mortality for many beef and dairy cattle operations.[44,45] In addition to costs associated with medical treatment or losses due to death from neonatal calf diarrhea, affected calves also experience reduced growth performance.[3,40] The disease is complex and multifactorial.[1,2,37] Factors explaining illness and death from undifferentiated neonatal calf diarrhea include those that influence host susceptibility, pathogen virulence and further transmission within the production system.[6]

The complexity of neonatal calf diarrhea is due to multifactorial host-pathogen interactions occurring within dynamic populations of susceptible, infective or recovered calves. Much is known about the common agents of neonatal calf diarrhea.[2,4,6,10,19,23,24,27,42] Although the important protective effect of maternal antibodies has been recognized for some time,[46] we now better understand many of the important details of neonatal immunology.[7,8,9] Even though we have long understood the importance of hygiene in the control of neonatal calf diarrhea,[17,46] our understanding of how population dynamics influence opportunities for pathogen exposure and transmission is still incomplete.[6]

We studied mortality records from a beef cattle herd with a history of excessive losses due to acute undifferentiated neonatal calf diarrhea. In the year of study, this ranch had undertaken a policy to not treat or otherwise intervene to prevent neonatal calf diarrhea. Further, the cattle were maintained as a single population moving through a series of grass-managed pastures. These circumstances provided a unique opportunity to study the population dynamics of neonatal calf diarrhea without biases inherent to multiple management units or treatment interventions. The objective of this study was to determine which factors of time and subject explained the probability for calves to die from undifferentiated neonatal diarrhea.

Materials and Methods

The cattle ranch was located in the Sandhills region of Nebraska. Cows calved during early summer in a rotational grazing system, and calving occurred as the cows moved through a series of pastures every one to five days in a grass management system. During the previous calving season this herd experienced 6.5% mortality (28 deaths /433 live births), primarily attributed to undifferentiated neonatal calf diarrhea. The ranch owner reported similar rates of morbidity and mortality attributed to neonatal calf diarrhea in previous years. Cattle currently calving at six years of age or older had received at least one annual pre-calving vaccination against viral diarrhea pathogens (with various products); however, this practice had been discontinued four years prior to the current calving season. Cattle currently calving as two- or three-year old cows had received an oral dose of a modified-live vaccine against rotavirus and coronavirus[a] on the day they were born.

Deaths of calves in the current calving season attributed to neonatal diarrhea were based on clinical signs of diarrhea and depression observed by the ranch owner. Health records from the current calving season were analyzed for patterns of calf mortality by factors of time or subject.

Cumulative incidence of mortality was calculated for each week of the calving season. To calculate cumulative incidence for each week the numerator was the number of calves that died from neonatal diarrhea in that week, and the denominator was the population of calves defined as at-risk for death from acute undifferentiated neonatal calf diarrhea. The population at risk was the number of calves born in the previous three weeks and alive at the beginning of that week.

The probability of death for calves born in a given week was calculated as the number of calves born during that week that subsequently died from undifferentiated neonatal calf diarrhea divided by the total number of calves born in the same week.

The relationship between the date of death and the age of the calf at death was tested by simple linear regression using spreadsheet software.[b]

A multivariable logistic regression model was used to determine what factors explained the probability for calves to die of undifferentiated neonatal calf diarrhea.

The model used generalized estimation equations with the logit link, and binomial probability distribution.[c] The model was built by manual forward selection. Variables were included in the model if they contributed significance to the likelihood ratio statistic for Type 3 analysis at an alpha level of ≤0.05.

The dam's age was tested as a variable categorized into three levels: two years of age, three years of age and four years of age or greater (mature). The birth period was tested as a categorical variable with four levels, representing two-week periods from the beginning of the calving season. The fourth birth period represented the last four weeks of calving. Birth weight was tested as a continuous variable and also as a categorical variable with three levels, representing calves less than 75 lb (34 kg); calves 75 to 85 lb (34 to 39 kg); and calves greater than 85 lb (39 kg). Other variables tested in the logistic model included the gender of the calf and whether or not the calf was born on the day of a pasture move.

Least squared means of the parameter estimates from the multivariable logistic regression model were used to estimate adjusted probabilities for each level of the categorical variables in the model, such that:

Adjusted probability (P_{adj}) = exp[estimate]/(1+ exp[estimate])
and: Standard Error (SE) of $P_{adj} = P_{adj} \times (1- P_{adj}) \times$ SE estimate

Specific contrasts of the least squared means of the parameter estimates were tested for significance between each level of the categorical variables in the logistic model.

Results

Calving occurred between May 2 and July 12. Ranch health records included data from 411 calf births, including specific information about the calves and their dams. Nine calves died at birth, or shortly after birth, due to causes unrelated to neonatal diarrhea. These data were excluded from analysis, leaving 402 calves at risk for neonatal diarrhea. The majority of calves at risk for neonatal diarrhea (265 of 402, 66%) were born within the first four weeks of the calving period (Figure 1).

Two hundred-thirteen calves were male (53%). Birth weights of all calves ranged from 51 to 130 lb with a mean of 79 lb (23 kg to 59 kg, mean 35.8 kg). Thirty-eight (9.5%) of the dams were heifers, 54 (13.4%) were three-year-olds, 54 (13.4%) were four-year-olds and the remaining 256 cows (63.7%) were five or more years of age. The mean and also median age of the dam was six years (range two to 14 years).

The pastures were intensively grazed and the herd was moved to different pastures 22 times between May 3 and July 13. On average, cattle were moved to a new pasture every 3.2 (range 1 to 5) days. One hundred twenty-four of 402 calves (30.8%) were born on the same day that the herd was moved to a new pasture.

All of the 48 recorded deaths from the 402 at-risk calves (11.9%) were attributed to neonatal diarrhea; the date of death was recorded for 47 calves. Calf deaths occurred between May 29 and July 23, inclusive. Calves died of undifferentiated neonatal calf diarrhea within a narrow range of age. Thirty-nine of 47 calves with age-at-death information (83 percent) died between six and 15 days of age (Figure 2). No relationship was found between the date of death and the age that calves died (R^2=0.02, P=0.33; Figure 3).

The first death due to undifferentiated neonatal calf diarrhea occurred in the fourth week of the calving season, and deaths continued into July (Figure 4). After the outbreak was established, approximately

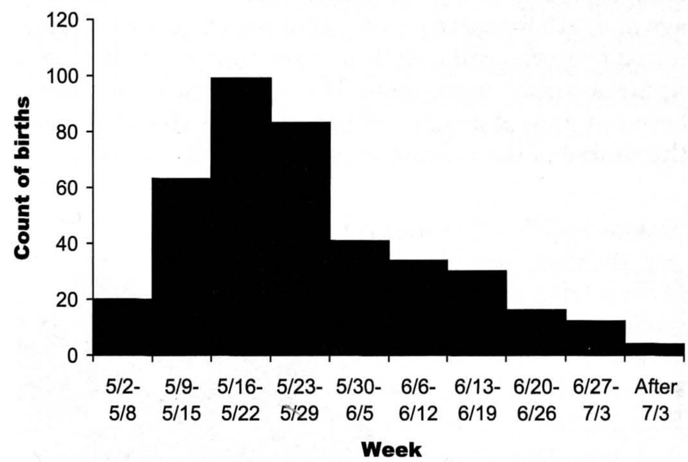

Figure 1. Frequency distribution of live calf births (n=402) by week of the calving season.

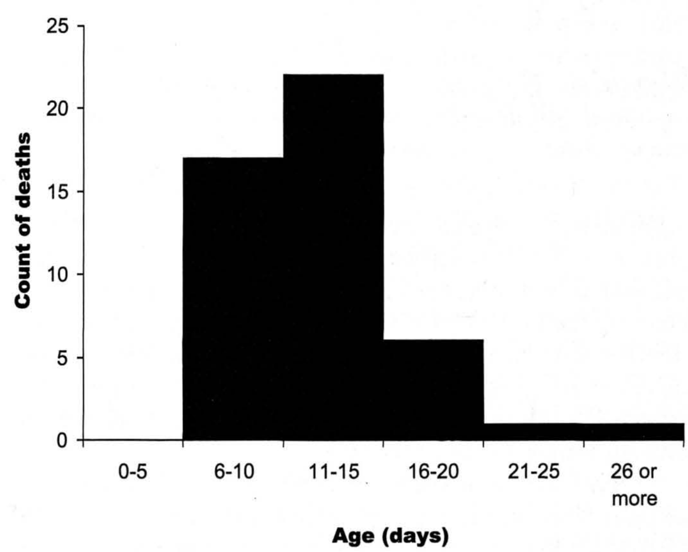

Figure 2. Frequency distribution by age of calves (n=47) that died due to undifferentiated neonatal calf diarrhea.

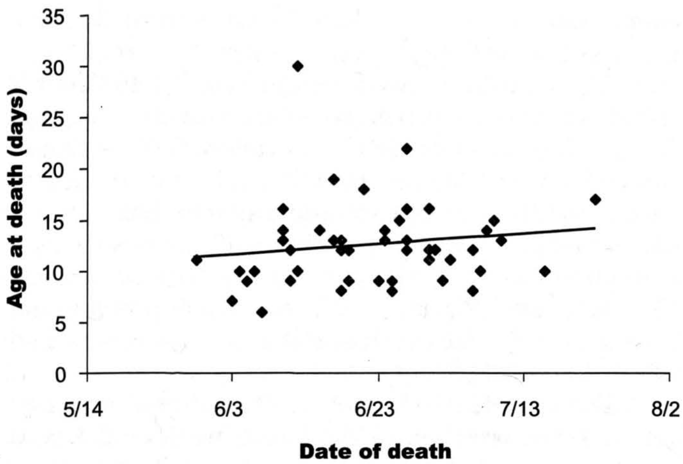

Figure 3. Relationship between the age of calves that died from undifferentiated neonatal calf diarrhea and date of their death. Points represent date of death and age at death for calves (n=47) that died from undifferentiated neonatal calf diarrhea. Line represents the least squares linear regression. There was no relationship between date of death and age of calves that died over the course of the calving season (R^2=0.02, P=0.33).

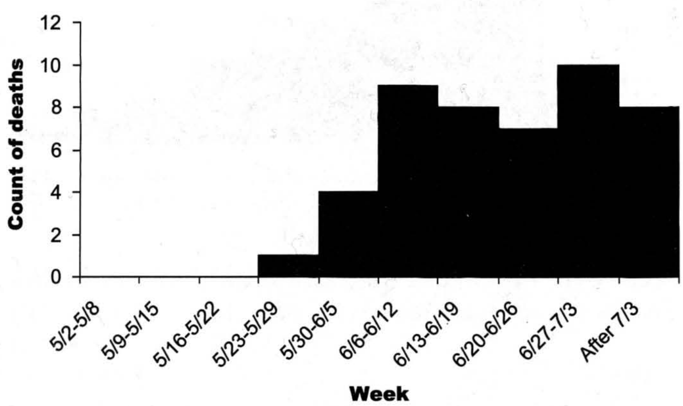

Figure 4. Number of deaths due to undifferentiated neonatal calf diarrhea occurring each week of the calving season.

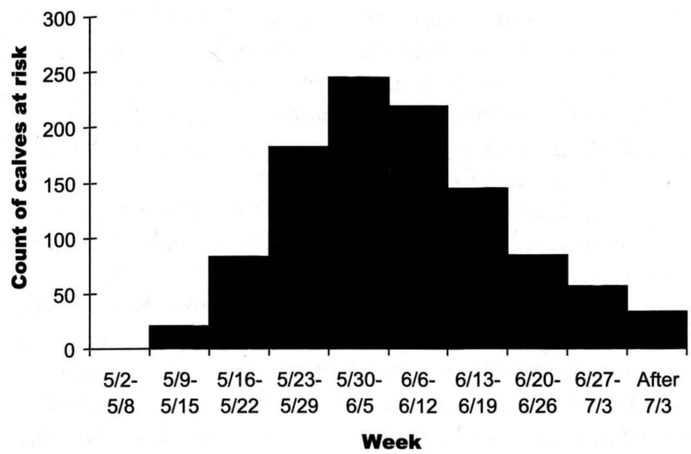

Figure 5. Frequency distribution of the number of calves considered at-risk, or infective, for neonatal calf diarrhea for each week of the calving season. The at-risk population was calculated as the number of calves born in the previous three weeks and alive at the beginning of that week.

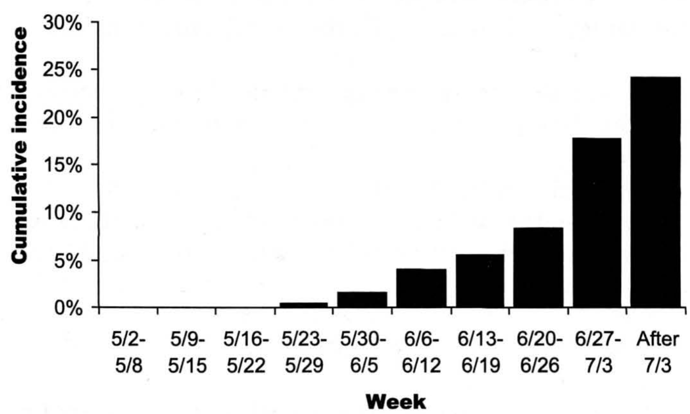

Figure 6. Cumulative incidence of death due to undifferentiated neonatal calf diarrhea calculated for each week of the calving season. Calculated as the number of deaths occurring each week divided by the number of calves at risk for undifferentiated neonatal calf diarrhea.

eight deaths were recorded each week. The number of calves at risk for undifferentiated neonatal calf diarrhea peaked at 244 calves in the fifth week of the calving season (Figure 5). Descriptively, the cumulative incidence of death due to neonatal diarrhea for each week increased as the calving season progressed (Figure 6), as did the probability that calves born within a given week would subsequently die (Figure 7).

The period of time a calf was born in the calving season (P<0.0001; Figure 8) and the age of the dam (P=0.006; Figure 9) explained the probability for a calf to die of neonatal diarrhea in a multivariable logistic regression model (Table 1). Calves of two-year-old dams were more likely to die than calves of mature cows (OR=5.79, P=0.003). The calves of three-year-old dams were intermediate in risk (OR=2.21), but not significantly different from calves from the other dam age-groups (P>0.10). The probability for calves to die was not statistically explained by gender (P=0.68) or birth weight as a continuous (P=0.82) or categorical variable (P=0.43). Although calves born on the day of a pasture move were observed to be more likely to die (OR=1.9), the risk was not statistically significant (P=0.09).

Discussion

We were able to make important observations about the population dynamics of neonatal calf diarrhea

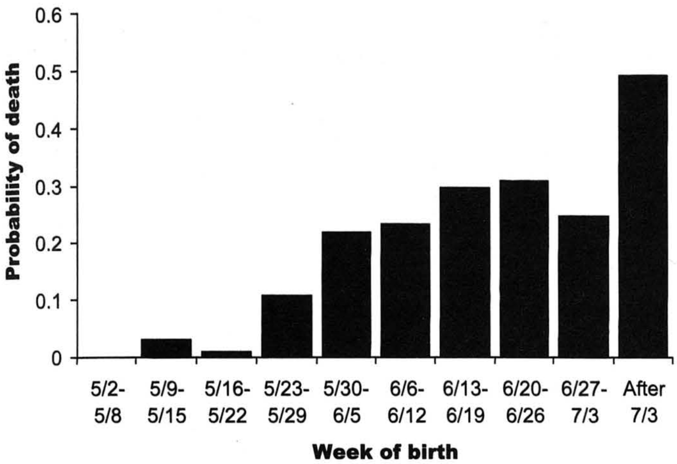

Figure 7. The probability for calves born each week of the calving season to subsequently die due to undifferentiated neonatal calf diarrhea. The probability of death for calves born in a given week was calculated as the number of calves born during that week that subsequently died from undifferentiated neonatal calf diarrhea divided by the total number of calves born in the same week.

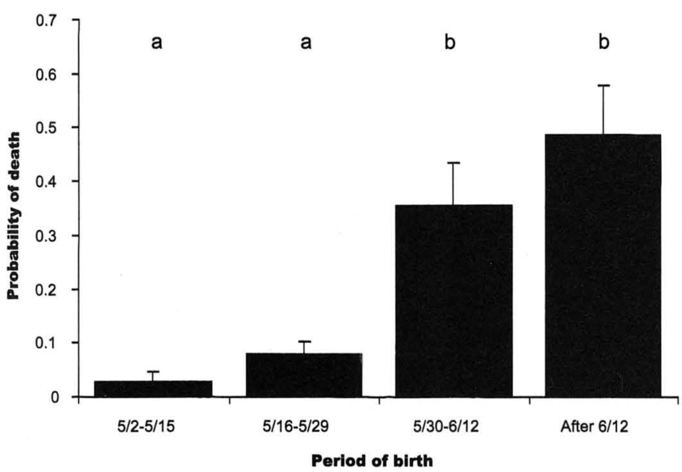

Figure 8. Model-adjusted probability for calves to die due to undifferentiated neonatal calf diarrhea, depending on the period of time the calf was born during the calving season. Calves differed significantly in their risk for death depending on how late in the calving season they were born. Error bars represent the standard error of the mean. The outcomes of variables with different superscripts are statistically different ($P \leq 0.05$).

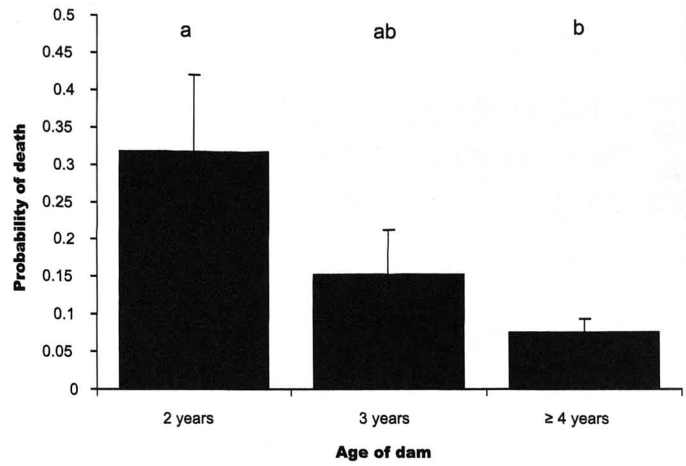

Figure 9. Model-adjusted probability for calves to die due to undifferentiated neonatal calf diarrhea, for calves born to dams of different ages. Calves differed significantly in risk for death depending on the age of their dam. Error bars represent the standard error of the mean. The outcomes of variables with different superscripts are statistically different ($P \leq 0.05$).

in this ranch system because the cattle were managed as a single population, and because the disease process in this population was not impeded by treatment or control interventions–both unique circumstances. The etiologic agents involved during this calving season were not determined; however, diagnostic workups in previous years had revealed the presence of multiple enteric pathogens. Most agents of neonatal calf diarrhea are endemic to cattle herds and it is not uncommon for multiple agents to be recovered from sick, or healthy, calves during outbreaks of neonatal calf diarrhea.[6]

The age distribution of deaths due to calf scours on this ranch was typical of outbreaks of undifferentiated neonatal calf diarrhea observed among both beef and dairy herds.[1,10,12,42] The narrow range of ages that calves are susceptible to undifferentiated neonatal calf diarrhea has long been recognized.[46] The age specificity of neonatal diarrhea is probably because calves are within an age window of increased susceptibility, rather than the timing of exposure, because lactogenic immunity wanes with age and the calf is not yet fully capable of developing an active immune response.[7]

The age specificity of undifferentiated neonatal calf diarrhea defines not only the susceptible sub-population, but also the ages of those calves most likely to be shedding agents of neonatal calf diarrhea in feces.[16,26,29,30,35,43] The fact that undifferentiated neonatal calf diarrhea occurs during a narrow window of age has important implications when considering the transmission of infection, because the size of the population of susceptible and infective calves can change dynamically in some calving systems. In this seasonal calving ranch system, the number of calves at risk (to be susceptible or infective) was extremely dynamic and peaked in the middle of the calving season.

We observed approximately the same number of deaths each week after the outbreak became established.

Table 1. Multivariable logistic regression model of the probability for calves to die of undifferentiated neonatal calf diarrhea. The deviance parameter was 0.61.

Variable	Parameter	Odds ratio	95% CI		*P*-value
Intercept	-0.903				0.0015
Birth cohort					<0.0001
Born May 2 – May 15	-3.524	0.029	0.006	0.148	
Born May 16 – May 29	-2.41	0.090	0.036	0.224	
Born May 30 – June 12	-0.543	0.581	0.265	1.275	
Born after June 12	Ref.	1.0			
Age of the dam					0.006
Two years of age	1.756	5.79	1.95	17.1	
Three years of age	0.798	2.21	0.828	5.95	
Four or more years of age	Ref.	1.0			

This pattern suggests a propagated epidemic (e.g. due to ongoing transmission) rather than a point source of exposure (e.g. from the sudden introduction of a pathogen at a single point in time).[21] Ongoing transmission of infection makes sense in terms of the endemic and contagious nature of the agents of undifferentiated neonatal calf diarrhea. Within a calving season there is a continual introduction of potentially susceptible calves into the population. Because of the age specificity of neonatal calf diarrhea, one might expect to observe a waxing and waning of the number of cases in approximation to the number of susceptible and potentially infective animals in the population. However, in this herd, we did not observe a corresponding reduction in the number of deaths as the number of susceptible calves decreased.

Rather, the incidence of deaths due to neonatal diarrhea increased as the calving season progressed. Cumulative incidence summarizes the "force of disease" in the herd for a given time period.[20] In this population, the force of disease became greater each week as the calving season progressed. Similarly, in the logistic model there was a significant increase in the probability for calves to die from undifferentiated neonatal calf diarrhea as they were born later in the calving season. How late in the calving season these calves were born explained their risk for dying from neonatal calf diarrhea. This is consistent with other observations that beef ranch calves born later in the calving seasons are more likely to become ill with neonatal calf diarrhea.[12]

These findings suggest that although incidence of neonatal calf diarrhea increases with time, the risk for sickness and death at any point in time is not uniform among calves of all ages in the population. The higher incidence of diarrhea that occurred later in the calving season was borne by the younger calves in the herd as they passed through their window of age-susceptibility. This emphasizes the importance of carefully considering time and the population at risk when conducting population-based studies of undifferentiated neonatal calf diarrhea.

Compared to conditions existing earlier, the latter part of the calving season favored calf exposure and transmission of the pathogens of neonatal calf diarrhea to calves of susceptible age. It is possible that for some reason calves became more susceptible to infection over time, or that the agents involved became

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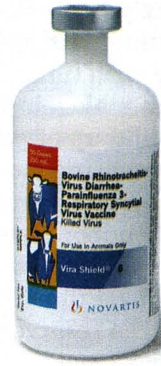

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2. Data on file at APHIS' Center for Veterinary Biologics.

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increasingly virulent. More likely, the dose-load of diarrhea-causing pathogens to which calves were exposed increased with time. The grass management system of this ranch makes indirect transmission from environmental build-up of pathogens an unlikely explanation for the increasing incidence of death because every few days calves were born in, and continued to move through, previously unpopulated pastures. It is more likely that effective contacts from direct calf-to-calf transmission increased over time. Although the adult cow-herd likely serves as the reservoir of neonatal diarrhea pathogens from year to year,[13,14,15,22,35,47] the average dose-load of pathogen exposure is likely to increase over time because of a calf multiplier effect within a calving season.[5] Each susceptible calf serves as culture media for pathogen production, thereby amplifying the dose-load of pathogen it received.[16,36,43] Calves born later in the calving season may receive a larger number of pathogens (amplified by calves born earlier in the season) and, in turn, may become relatively more infective by growing even greater numbers of agents. As the average dose-load of exposure increases, presumably so does the probability for susceptible calves to express clinical signs of disease, or die.

In our study, the age of the dam also explained a calf's risk for death due to undifferentiated neonatal diarrhea. Greater risk for death was observed among calves born to younger dams. This may be explained by unmeasured immune parameters due to exposure to vaccine or wild-type pathogens, or due to greater maternal instincts among older cattle. Calves born to heifers are recognized as being at higher risk for neonatal diarrhea.[39] Calves born to two-year-old heifers may have lower maternal antibody levels than calves born to older cows.[25] Increased susceptibility to disease of calves born to heifers is likely because heifers produce a lower volume of colostrum, although decreased calf vigor due to dystocia may contribute.[31,32]

We tested the probability for a calf to die from diarrhea if it was born on the day cattle were moved to a new pasture because we empirically believed these calves might not have received colostrum as timely as other calves because of the confusion that occurs on the day of a move. On the day of a move, cows often leave their calves to feed on the newly available forage. Our observation was that a greater proportion of calves born on the day of a move did die, although the difference was not statistically significant.

To prevent the occurrence of undifferentiated neonatal calf diarrhea one could, at least theoretically, act to eliminate the presence of pathogens, decrease calf susceptibility, or alter the production system factors to reduce opportunities for pathogen exposure and transmission. The endemic nature of the common pathogens of neonatal calf diarrhea offer little hope for developing cattle populations that are biosecure from these agents. Maternal immunity is clearly important to calf susceptibility to these agents,[28,37] but lactogenic immunity wanes with time,[7] and managers of extensive beef cattle systems have limited practical opportunities to improve rates of passive transfer. In addition, vaccines are not available against all pathogens of calf diarrhea, vaccines may not be sufficiently cross-protective[26] and pathogens evade the protection afforded by vaccination by evolving away from vaccine strains.[18] Genetic selection for disease resistance may hold future promise.[11]

Conclusions

Factors explaining mortality due to undifferentiated neonatal calf diarrhea were age of the calf, age of the dam and when in the calving season the calf was born. Several production systems have been designed to prevent neonatal calf diarrhea by changing the cattle population dynamics to disfavor pathogen exposure and transmission.[33,34,38,41] The observations of this study suggest that undifferentiated neonatal calf diarrhea might be prevented by designing beef calving systems which can maintain the more ideal conditions existing at the beginning of the calving season, which include low doses of pathogen exposure and fewer opportunities for older, highly-infective calves to transmit pathogens to younger, susceptible animals.

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Endnotes

[a]CalfGuard®, Pfizer Animal Health, New York, NY
[b]Excel 2002, Microsoft Corp., Redmond, WA
[c]PROC GENMOD, SAS Institute, Cary, NC

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