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S. M. Azzam

University of Nebraska-Lincoln

J. E. Kinder

University of Nebraska-Lincoln, kinder.15@osu.edu

Merlyn K. Nielsen

University of Nebraska-Lincoln, mnielsen1@unl.edu

L. A. Werth

University of Nebraska-Lincoln

K. E. Gregory

Roman L. Hruska U.S. Meat Animal Research Center, USDA-ARS, Clay Center, NE

See next page for additional authors

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Authors

S. M. Azzam, J. E. Kinder, Merlyn K. Nielsen, L. A. Werth, K. E. Gregory, Larry V. Cundiff, and R. M. Koch

Environmental Effects on Neonatal Mortality of Beef Calves¹

S. M. Azzam*, J. E. Kinder*, M. K. Nielsen*, L. A. Werth*,
K. E. Gregory†, L. V. Cundiff†, and R. M. Koch*

*Department of Animal Science, University of Nebraska, Lincoln 68583-0908 and

†Roman L. Hruska U.S. Meat Animal Research Center,
ARS, USDA, Clay Center, NE 68933

ABSTRACT: Calving records from 1969 to 1989 from the Roman L. Hruska U.S. Meat Animal Research Center were used to investigate how climatic conditions, in addition to dystocia, age of dam, size of calf, and sex affect calf survival from birth to 1 wk of age. Data were analyzed separately for cows calving with ($n = 11,094$) or without ($n = 72,187$) dystocia. Neonatal mortality was described by a logit model and parameters were estimated by maximum-likelihood procedures. Calves born to cows with dystocia were five times as likely to die neonatally than calves born without assistance. Of all calves that died, 43.6% were

born with difficulty. Of these calves, survival was lowest for those that were small relative to their genetic group, sex, and age of dam. Large calves had markedly increased mortality only when born to 2-yr-old dams. Average ambient temperature and precipitation on day of calving affected survival nonlinearly and the magnitude of the effect depended on age of dam, sex and size of calf, and dystocia incidence. Calves born to 2-yr-old cows were more susceptible to severe weather conditions than calves born to older cows. The negative effect of precipitation on survival increased with decreasing temperature.

Key Words: Beef Cows, Neonatal Mortality, Survival, Dystocia, Birth Weight, Climate

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Introduction

Increasing the proportion of calves that survive to weaning is of utmost economic importance. There are approximately 32,958,000 beef cows in the United States (USDA-ERS, 1989), of which approximately 51% or 16,809,000 are in states with moderate to cold winters. Thus, approximately 15,128,100 beef calves are born (assuming a conception rate of 90%) in an environment in which cold stress is a concern. Total neonatal mortality has been estimated to be approximately 9% (Cundiff et al., 1982), with approximately 7% of this mortality attributable to cold stress (Bellows et al., 1987; 6.9%). Therefore, the calf losses during a single year, due to cold stress, could be approximately 95,000.

The purpose of this study was to investigate how climatic conditions, in addition to dystocia, age of dam, size of calf, and sex, affect calf survival from birth to 1 wk of age.

Materials and Methods

Data

Data on calf mortality from birth to weaning came from several experimental projects at the Roman L. Hruska Meat Animal Research Center: 1) the germ plasm evaluation program, excluding Cycle III Phases IV and V (Cundiff et al., 1988); 2) the germ plasm utilization project (Gregory et al., 1988a); 3) the twinning project (Gregory et al., 1988b); 4) the heterosis retention project (Koch et al., 1985); 5) the genetic variation study (Cundiff and Gregory, 1982); and 6) the Hereford selection experiment (Buchanan et al., 1982). Genetic effects on calf survival have been reported from some of these projects (Gregory et al., 1978a,b, 1990, 1991; Notter et al., 1978; Cundiff et al., 1986). In addition, calves born to cows not included in a specific project were included in the present study. The total number of records was 97,161.

The data were edited to include only calves born at the Research Center from spring of 1969 to spring of 1989; the majority of calves were born in the spring. Calves that were stillborn, deformed, aborted, injured, slaughtered for experimental reasons, or had a recorded birth weight of less than 10 kg were deleted from the data set. Calves classified as stillborn (44

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calves) were deleted because the calf was assumed dead before parturition and the death should, therefore, not be attributed to any effects of weather. However, calves classified as dead at birth or dead soon after birth were included in the data set. After editing the data, the number of calves that had complete records was 90,087. Of the calves, 5,763 (6.4%) died within 1 wk of age, 2,545 (2.8%) died between 1 wk and weaning, 889 (1%) were sold before weaning, and 80,890 (90%) were weaned. Before analyzing the data, 2,802 calves with *Bos indicus* inheritance were also eliminated because of the relatively low numbers and because they have higher mortality rates under cold, windy, and wet conditions than *Bos taurus* calves (Josey et al., 1987).

Daily observations of weather conditions at the Research Center were compiled by the National Climatic Data Center, Asheville, NC and included minimum and maximum ambient temperature, amount, and type (rain or snow) of precipitation. Data on wind speed were not available. In the analysis, average daily ambient temperature was calculated as the mean of the minimum and maximum temperature. Amount of daily precipitation measured for snowfall was the amount of water in the snow and not the depth of the fallen snow.

Statistical Analysis

Parameter Estimation. Data on neonatal mortality (birth to 1 wk of age) were described by logit models with parameters estimated by maximum-likelihood procedures (SAS 1985; CATMOD procedure). Maximum-likelihood procedures were used because too many subclasses had 0% mortality rate. The data were divided into categories (subclasses) determined by the class variables in the linear model specified for each analysis. In order to get convergence of the estimates and to get reasonable standard errors of the estimates, levels of factors (variables) in the linear model that occurred less than five times in combinations with levels of other factors were deleted.

The purpose of the study was not to estimate breed effects on neonatal survival, and, therefore, the breed proportions in the calves were not included in the model describing neonatal survival. Instead, a birth weight variable was created to describe whether a calf was light or heavy compared with the average calf of the same sex born to the same type of cow. Birth weight was thus expressed in terms of standard deviations from the mean birth weight for the sex \times age of dam \times genetic selection line or breed composition sub-category. The seven birth weight categories (BWT) were < -1.5 , -1.5 to -1.0 , -1.0 to -0.5 , -0.5 to 0.5 , 0.5 to 1.0 , 1.0 to 1.5 , and > 1.5 standard deviations. The proportion of calves expected to be in these categories, based on a normal distribution of birth weights, are .0668, .0919, .1498, .3830, .1498, .0919, and .0668, respectively.

After the initial editing, the data were divided into two sets by dystocia score. The first set (referred to as no dystocia) included calves born without assistance, with the assistance of pulling by hand, or of pulling with a calf puller but the attendant may actually have been able to pull the calf by the hand. The second set (referred to as dystocia) included all other calving situations.

The Logistic Linear Model. Both sets of data were described by the same logistic linear model but parameters were estimated independently for the two sets of data. The model describing survival from birth to 1 wk of age (P_n) was as follows:

$$P_n = (1 + e^{z_{jklmn}})^{-1},$$

where

$$z_{jklmn} = \mu + y_j + s_k + a_l + b_m + \beta_1 X_1 + \beta_2 X_1^2 + \beta_3 X_2 + \beta_4 X_2^2 + \beta_5 X_1 X_2 + \beta_6 X_1 X_2^2 + e_{jklmn},$$

and

- μ = overall mean,
- y_j = effect of the j^{th} year,
- s_k = effect of the k^{th} sex,
- a_l = effect of the l^{th} age of dam,
- b_m = effect of the m^{th} birth weight category (BWT),
- β_i = partial regression coefficients,
- X_1 = average ambient temperature (°C) on day of birth,
- X_2 = amount of precipitation (millimeters) on day of birth, and
- e_{jklmn} = random error associated with the n^{th} cell,

as well as all possible two-way interactions between sex of calf, age of dam, and birth weight category. Sex of calf was coded as bull, heifer, or steer. The decision to castrate a bull calf depended on the experimental project. Age of dam at calving was classified as 2-yr-old, 3-yr-old, and older cows.

After editing to assure convergence and reasonable precision, a total of 72,187 calves were included in the data set of calves that had not experienced dystocia and 11,094 records were in the data set of calves born with dystocia.

Marginal Means. Marginal means (MM), equivalent to least squares means obtained when parameters are estimated by least squares procedures, were obtained by multiplying the vector of parameter estimates (θ) with vectors (k) describing the estimable functions:

$$MM = k'\theta. \quad [1]$$

Standard errors (SE) of the marginal means were calculated by taking the square root of the product

Table 1. Chi-square tests of the variables in the maximum likelihood analysis of neonatal mortality (birth to 1 wk)

Source	df	No dystocia		Dystocia	
		Chi-square	P ^a	Chi-square	P ^a
Intercept	1	5,440	.0001	827	.0001
Birth year	20	273	.0001	273	.0001
Sex	2	146	.0001	51	.0001
Age of dam (AOD)	2	141	.0001	17	.0002
Birth wt category ^b (BWT)	6	154	.0001	128	.0001
AOD × BWT	12	63	.0001	31	.0020
Temperature (T)	1	111	.0001	4	.0497
T × T ^c	1	17	.0001	5	.0216
Precipitation (PCP)	1	63	.0001	—	—
PCP × PCP	1	13	.0003	—	—
T × PCP	1	22	.0001	—	—
T × PCP × PCP	1	10	.0019	—	—

^aSignificance level.^bDefined in the text.^cDesignates quadratic function.

obtained from pre- and post-multiplying the variance-covariance matrix (**V**) of the estimates with the vector (**k**) describing the estimable functions:

$$SE = \sqrt{k'Vk} \quad [2]$$

The marginal means of the dependent variable in the analysis were then converted to marginal means of mortality rate (**MR**) by the logistic cumulative distribution function:

$$MR = \frac{1}{1 + e^{-MM}} \quad [3]$$

Approximate 95% confidence limits (**CL**) for MR were obtained by inserting MM plus or minus 1.96 (based on a *t*-distribution with large degrees of freedom) times the SE into the same function (Azzam et al., 1989):

$$CL = \frac{1}{1 + e^{-(MM \pm 1.96 SE)}} \quad [4]$$

Results

Effects of Dystocia, Sex of Calf, and Age of Dam. Parameters were estimated after nonsignificant effects had been dropped from the initial model. The chi-square tests of the variables in the model are in Table 1 and the parameter estimates are in Table 2. Marginal means of neonatal mortality were calculated using [1] and [3]; the values for temperature and precipitation were the average values for all calves born. Thus, all marginal means were adjusted to a 9.77°C ambient temperature and a 2.35 mm of

precipitation. For example, the marginal mean of mortality rate (MR) for a bull calf born without dystocia was calculated as follows:

$$\begin{aligned} MM &= 2.843 - .357 + .05251(9.77) - .001(9.77)^2 \\ &\quad - .069116(2.35) + .00105(2.35)^2 \\ &\quad + .002869(9.77)(2.35) \\ &\quad - .000048(9.77)(2.35)^2, \\ &= 2.81 \end{aligned}$$

and

$$\begin{aligned} MR &= \frac{1}{1 + e^{-2.81}} \\ &= .06. \end{aligned}$$

Sex of calf did not interact with age of dam or birth weight category. Bull calves had the highest mortality rates even when dystocia and relative size of the calf (BWT) was accounted for. The estimates were .24 and .06 for bull calves born with and without dystocia, respectively. The same estimates for steers were .16 and .03, respectively. This does not imply a positive effect of castration on survival. Calves selected at birth to be castrated were, for some reason, less likely to die during the 1st wk of life. In this study, this could be a genetic effect in that calves selected to be castrated were crossbred calves. The mortality rate for heifer calves born to cows with or without dystocia was .21 and .04, respectively.

The interaction of BWT and age of dam was the only significant interaction in the model (Table 1). The marginal means for the two sets of data (no dystocia, dystocia) are shown in Figure 1. Optimal survival occurred when calves were of moderate size. Small calves born to cows with dystocia had the highest mortality rates. There was a tendency for

small calves born to 2-yr-old cows with dystocia to have a lower mortality rate than calves of similar size born to older cows with dystocia. This could be explained by possible preferential care of the 2-yr-olds. However, the numbers of calves in these extreme categories were not large enough for the differences to be significant.

When cows did not experience dystocia (Figure 1; lower three lines), calf mortality decreased with age of cow. The lowest mortality rate of calves born to 2-yr-old cows without dystocia (4.1%) occurred when calves were .5 to 1 SD below mean BWT. The lowest mortality rate of calves born to 3-yr-old cows without dystocia (2.0%) occurred when calves were .5 to 1 SD below mean weight. However, the estimated mean mortality rates for calves born to 3-yr-old cows did not differ significantly (based on overlapping confidence intervals) for BWT in the range of -1 to > 1.5 SD. The lowest mortality rate of calves born to older cows

without dystocia (2.0%) occurred when calves were within -.5 to 1.5 SD of the mean weight. However, only when calves were < -1.5 SD of average weight was the mortality rate significantly higher.

Effects of Temperature and Precipitation. Average ambient temperature on the day of birth had a curvilinear effect on the logarithm of the odds of survival (and not on survival itself; for interpretation of regression parameters in logit models see Pindyck and Rubinfeld, 1981). Precipitation affected survival only in calves born without dystocia. A likely explanation for this difference is that cows that required extensive assistance in calving would be brought under roof and the calf would not be exposed to the precipitation. Survival of calves born without dystocia was, in addition to being affected by precipitation and temperature separately, also affected by the interaction of precipitation and temperature. Graphing the functions

Table 2. Estimates of the parameters^a in the logistic linear model describing neonatal mortality

Variable	No dystocia		Dystocia	
	Estimate	SE	Estimate	SE
Intercept	2.843	.039	1.312	.046
Sex				
Bull	-.357	.030	-.232	.035
Heifer	.044	.028	-.039	.036
Steer	.313	.038	.271	.044
AOD × BWT ^b				
2 yr, < -1.5 SD	-.562	.139	-.499	.177
2 yr, -1.5 to -1.0 SD	-.135	.124	.245	.151
2 yr, -1.0 to -.5 SD	-.014	.097	.639	.105
2 yr, -.5 to .5 SD	-.295	.061	.398	.059
2 yr, .5 to 1.0 SD	-.639	.102	.349	.078
2 yr, 1.0 to 1.5 SD	-.280	.171	.329	.010
2 yr, > 1.5 SD	-.798	.229	-.265	.089
3 yr, < -1.5 SD	-.709	.112	-1.348	.242
3 yr, -1.5 to -1.0 SD	-.031	.122	-.032	.233
3 yr, -1.0 to -.5 SD	.552	.119	.436	.186
3 yr, -.5 to .5 SD	.283	.072	.420	.108
3 yr, .5 to 1.0 SD	.267	.119	.196	.140
3 yr, 1.0 to 1.5 SD	.061	.146	-.034	.152
3 yr, > 1.5 SD	-.157	.167	-.043	.137
> 3 yr, < -1.5 SD	-.473	.068	-1.047	.199
> 3 yr, -1.5 to -1.0 SD	.228	.078	-.456	.177
> 3 yr, -1.0 to -.5 SD	.498	.069	.142	.149
> 3 yr, -.5 to .5 SD	.711	.052	.135	.089
> 3 yr, .5 to 1.0 SD	.603	.078	.499	.139
> 3 yr, 1.0 to 1.5 SD	.572	.098	.016	.126
> 3 yr, > 1.5 SD	.318	.101	-.079	.113
Temperature (T)	.052510	.004988	.0111302	.0056713
T × T	-.001000	.000240	-.0006300	.0002800
Precipitation (PCP)	-.069116	.008732	—	—
PCP × PCP	.001050	.000290	—	—
T × PCP	.002869	.000610	—	—
T × PCP × PCP	-.000048	.000016	—	—

^aParameter estimates for year of birth ranged from -.728 to .818 in the analysis of cows with no dystocia and from -.877 to .853 in the analysis of cows with dystocia.

^bAge of dam × birth weight category interaction. Birth weight category is defined in the text.

1

$$\hat{P}_{no\ dystocia} = \frac{1}{1 + e^{2.843 + .053T - .0017T^2 - .069PCP + .001PCP^2 + .003T \times PCP - .00005T \times PCP^2}} \quad [5]$$

and

$$\hat{P}_{dystocia} = \frac{1}{1 + e^{1.312 + .011T - .0006T^2}} \quad [6]$$

aids in interpreting the effects of the two variables on survival (Figure 2). The isograms of precipitation are only extended over the range of temperature that actually occurred (e.g., 50 mm of precipitation only occurred between 10 and 24°C). Extrapolation of the functions outside the data range would result in erroneous predictions. When cows experienced dystocia, there was no effect of precipitation on mortality and the effect of temperature was not as large as when cows did not experience dystocia. This difference might also be caused by preferential treatment of the cow-calf pair that required extensive calving assistance.

When cows did not experience dystocia, precipitation had greater effects on mortality at lower temperatures. This is evident if one compares the estimated mortality rates in Figure 2 at for example -6 and 10°C. This is expected because the amount of precipitation would affect the insulating ability of the hair coat. When precipitation was heavy (75 mm), mortality increased slightly with temperature. It is possible that this is a spurious relationship due to confounding effects with sources of variation not accounted for in the model.

The relative effect of temperature and precipitation on mortality also depends on the fixed effects in the model (i.e., the intercept in the logistic regression equation). This is depicted in Figure 3 in which the effect of temperature and precipitation on mortality are estimated for two types of calves: 1) a heifer that is > 1.5 SD of average calf size and is born to a 2-yr-old cow without dystocia and 2) a heifer that is of average size and born to a mature cow without dystocia. The intercept (2.843) in [5] is thus replaced by 2.089 (2.843 + .044 - .798, Table 2) for the first type of calf and by 3.598 (2.843 + .044 + .711, Table 2) for the second type of calf. Figure 3 shows that precipitation has a greater effect on mortality of calves with higher mean mortality rates (2-yr-old cow, large calf; Figure 1) than on calves with lower mean mortality rates (mature cow, average calf; Figure 1).

Optimal Time of Calving. To study the effects of calving time and age of dam on calf survival, the daily temperatures and precipitations for January to June (Figure 4) were used in [5] (no dystocia). The marginal means of mortality rate (MR) for age of dam were obtained by multiplying the MR for age of dam \times BWT by the expected proportions of calves in each BWT (based on a normal distribution) and summing the products across BWT (Figure 5). The mortality rates for each month were calculated by averaging the daily MR and are also shown in Figure 5. Mortality

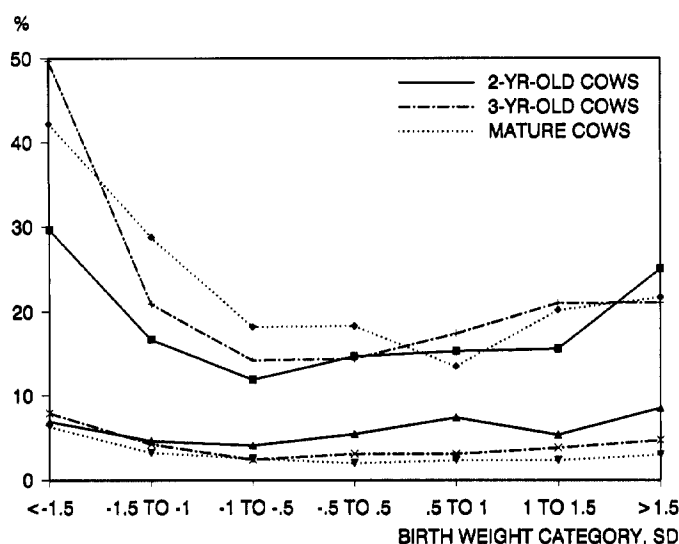


Figure 1. Estimated mortality rates (percentage) for different ages of cows and relative birth weights of calves (SD from the mean birth weight for the sex \times age of dam \times genetic selection line or breed composition sub-category). Upper three lines are for cows experiencing dystocia; lower three lines are for cows with no dystocia.

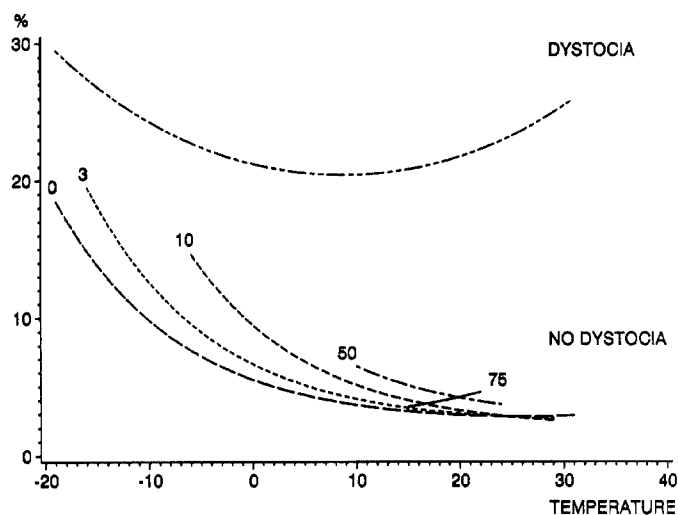


Figure 2. Effects of ambient average temperature (°C) and amount of precipitation (0, 3, 10, 50, and 75 mm) at day of birth on mortality rate (percentage) for calves born with or without dystocia.

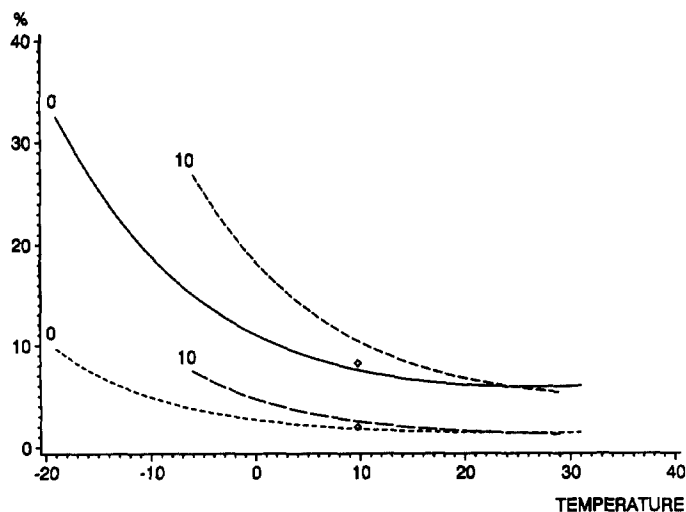


Figure 3. Effects of ambient average temperature ($^{\circ}\text{C}$) and amount of precipitation (0 or 10 mm) at day of birth on mortality rate (percentage) for 1) a heifer that is ≥ 1.5 SD and is born to a 2-yr-old cow without dystocia (two upper lines) and 2) a heifer that is of average size and is born to a mature cow without dystocia (two lower lines). The marginal means for the two types of calves, adjusted to the average temperature (9.77°C) and precipitation (2.35 mm) are also shown (\diamond).

decreased with month of calving (Figure 5). The decrease was largest from January to April with only slightly lower mortality rates in May and June. There was not a large differential effect of calving month on survival between calves born to 3-yr-old and mature cows. However, calves born to 2-yr-old cows were more adversely affected by calving conditions in early spring than were calves born to older cows.

The predictions of mortality only take the weather variables into consideration. Other environmental variables that affect calf survival that might vary with month were not included in the predictions.

Discussion

Calf survival is influenced by both genetic and environmental factors and could be increased either by exploring and using genetic diversity in tolerance of cold stress or by changing current management strategies. Both approaches need to be considered.

First, genetic selection for survival could be explored. Cundiff et al. (1986) found that heritability of survival to weaning was low with breeds (6.7%) but the variation among breeds was great. Cundiff et al. (1982) suggested that selection for survival could be accomplished by including survival related biological components such as cold resistance, immunological factors, skin thickness, and type of birth coat. Selection on any of these traits would be at the expense of selection for other important performance

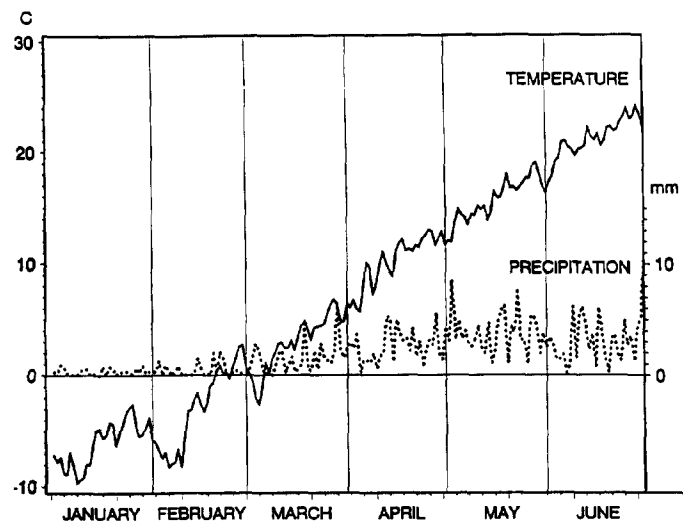


Figure 4. Average ambient temperature and precipitation at Clay Center, NE (1969 to 1989).

traits. Thus, if survival could be optimized by a cost-effective change of management, this would be preferable.

Second, neonatal survival could be increased by changing the management of the cow-calf herd. This requires information on the effects of environmental factors on neonatal survival. Many of these are well documented.

The effect of age of dam on neonatal mortality was discussed by Hohenboken et al. (1987) and reported estimates range from 2.5 to 9.2% in mature cows and from 5.9 to 13.4% in heifers (Marlow et al., 1984; Morris et al., 1986; Patterson et al., 1987; Ray et al., 1989). Our estimates (weighted and summed over BWT and adjusted to the average temperature and precipitation) for 2-yr-old (heifers), 3-yr-old, and mature cows were 5.7, 3.6, and 2.6% for cows without dystocia and 16.3, 18.8, and 20.5% for cows with dystocia, respectively. The incidence of dystocia was 15% (11,094/72,187).

Birth weight has also been linked to mortality (Cundiff et al., 1982; Morris et al., 1986). McElhenney et al. (1986) found that the preweaning mortality of calves sired by large breed bulls was 14.6% compared with calves sired by bulls of a medium-sized breed (4.7%). Koch et al. (1982) also found that calf mortality increased in 2-yr-old cows with selection for growth to weaning or to 1 yr of age. However, Baker and Morris (1984) in a literature review also found selection experiments for growth rate in which no increase in calf mortality occurred. In our study, birth weight per se was not used but rather the relative size of the calf was used. Survival was at an optimum for average-sized or slightly smaller (-1 to -5 SD) calves. This is in agreement with estimates reported by Notter et al. (1978), Morris et al. (1986), and Gregory et al. (1991).

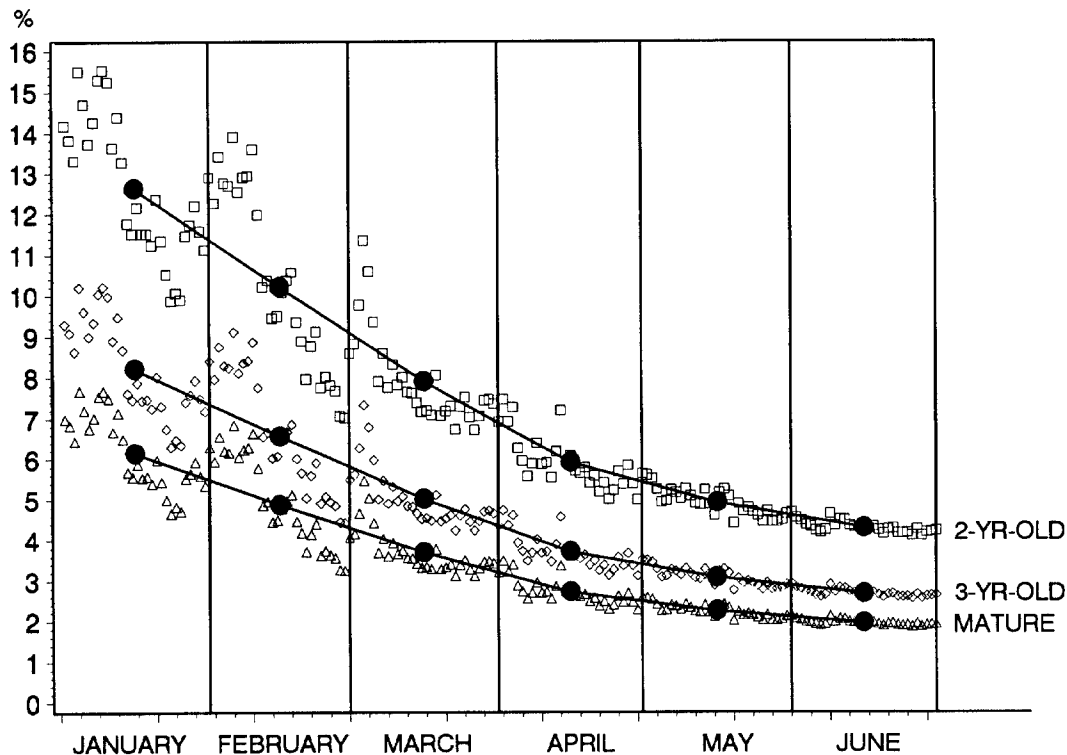


Figure 5. Estimated mortality rates (percentage) for different ages of cows calving during different months (January to June), based on the daily temperatures and precipitations during the given month. Average mortality rate for the month is indicated by ●.

Dystocia and its effect on calf mortality were studied by Laster and Gregory (1973). They found that the calf was four times as likely to die if the cow experienced dystocia as if she did not. In our study, neonatal mortality in cows that did not experience dystocia was .04, whereas it was .20 in cows that did experience dystocia, resulting in a ratio of five. Patterson et al. (1987) found that 45.9% of all preweaning deaths resulted from dystocia. In our study, the actual number of calves that died in the no-dystocia and dystocia groups were 2,869 and 2,218, respectively, resulting in 43.6% of all neonatal deaths occurring in calves born to cows experiencing dystocia.

Climatic effects on calf mortality have been reported by Withers (1952) based on analysis of approximately 9,000 dairy and beef calves in Great Britain. The mortality attributed to severe weather was 3.6%. Sparse information is available on the effects of weather-related stress on neonatal survival under range conditions. Bellows et al. (1987) attributed 6.9% of the mortality in 620 normal calves to exposure (chilling). Manak and Kvasnicka (1982) reported a study on weak calf syndrome in Nebraska where this condition seemed to be associated with weather stress and that an increased frequency of deaths from this syndrome occurred during periods of cold, wet weather. Stanko et al. (1991) found that Brahman calves that were < 24 h old were less able to

cope with cold environmental temperatures than were older calves. Our study shows that the amount of precipitation and the average ambient temperature on the day of birth interact and affect mortality non-linearly. The magnitude of the effect of climate on neonatal survival depends on age of dam, sex and size of calf, and on dystocia incidence.

Of the many factors affecting neonatal survival, dystocia is the most important. Therefore, research focusing on means of reducing the incidence of dystocia should receive the highest priority. Of particular interest are the reasons for the high mortality rates of small calves born to cows with dystocia. The possibility of endocrine factors responsible for prolonged labor (weak labor) when calves are small, should be given attention in addition to the anatomical factors usually associated with dystocia. Anthony et al. (1986) reported different prepartum hormone levels in cows experiencing dystocia and cows not experiencing dystocia.

Higher mortality rates of small calves occurred in all age groups of cows, whereas large calves only seemed to be a problem in 2-yr-old cows (for which size of calf is defined as being relative to its sex \times age of dam \times genetic composition mean BWT). From a management point of view, selecting bulls that sire large calves should, therefore, only be avoided when used to breed heifers.

Protecting calves from wet conditions at birth might be cost effective, especially early in spring when temperatures are lower. If this is not possible or feasible, calving later in the spring would increase the survival rate. This is especially true if the replacement rate in the cow herd is high and a relatively large proportion of cows are 2- and 3-yr old at calving. Higher replacement rates would result from short breeding seasons (Azzam et al., 1990; Werth et al., 1991). Therefore, if a shorter breeding season is preferred, it should be initiated later in the summer in order to increase calf survival.

Implications

Calves born to cows experiencing dystocia were five times as likely to die during the 1st wk of life as calves born without difficulty. Of calves born with difficulty, survival was lowest for those that were small relative to their genetic group, sex, and age of dam. Large calves had increased mortality when born to 2-yr-old dams. Temperature and precipitation affected survival rates nonlinearly and the rates depended on age of dam, sex and size of calf, and dystocia incidence. Calving late in spring, compared with earlier calving, would result in decreased mortality, especially in calves born to 2-yr-old dams.

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