Investigation of Factors Affecting Voluntary and Involuntary Culling in Expanding Dairy Herds in Wisconsin using Survival Analysis

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ABSTRACT

Trends in the relative risk of voluntary culling of low-producing cows and involuntary culling of high-producing cows were examined in 186 Wisconsin dairy herds that expanded significantly between 1994 and 1998. A Weibull model for survival analysis was applied to data of 72,456 Holstein cows with first calving from 1981 to 2000; this model included a time-independent effect of age at first calving and time-dependent effects of year-season, age-parity, and within herd-year quintile for combined fat + protein yield (by time period). The relative risk of (involuntary) culling of high-producing cows (versus average cows) increased from 0.5 in 1981 to 1989 to 0.68 in 1996 to 2000. Meanwhile, the relative risk of (voluntary) culling of low-producing cows decreased from 4.20 to 2.55 over the same time period. Variables related to facilities, labor, and management were obtained via survey, and the relative risk of culling for high- and low-producing cows after expansion (1996 to 2000) was calculated for different levels of each variable. Herds with fewer cows per employee and a greater percentage of labor supplied by family members tended to have lower risk of involuntary culling of profitable cows. Likewise, high-producing cows in herds with fans, sprinklers, self-locking manger stalls, palpation rails, and maternity pens had a significantly lower risk of culling than cows in herds without such facilities. Herds that used 100% artificial insemination (AI) had lower risk of involuntary culling than non-AI herds or herds with a cleanup bull, but 3× milking and use of a custom heifer grower led to unfavorable trends in involuntary culling. In summary, this study documented the unfavorable trends in voluntary and involuntary culling in expanding herds and quantified the gains producers can expect in cow survival by investing in improvements in facilities, labor, and management.

(**Key words:** herd expansion, culling, survival analysis, Holsteins)

Abbreviation key: FTE = full-time equivalent.

INTRODUCTION

High culling rates are a concern on many modern dairy farms, particularly those that wish to expand their dairy herds but face a shortage of replacement heifers. Culling of low-producing, unprofitable cows is sometimes desirable, however, so one must differentiate between voluntary and involuntary culling. Voluntary culling occurs when the farmer chooses to remove a healthy, fertile, cow due to poor milk production. Involuntary culling, on the other hand, occurs when the farmer is forced to remove a productive, profitable cow due to illness, injury, infertility, or death. The aim of selection for functional traits, such as udder conformation, SCC, mobility, and fertility is to reduce the level of involuntary culling of high-producing cows and increase a farmer's opportunity to voluntarily cull low-producing cows. Because there is often a tradeoff between these two types of culling, the overall culling or turnover rate generally cannot provide a complete picture of the culling situation in a given herd.

Dairy cow survival is influenced by both management and genetic factors. Heritability estimates range from 5 to 10% in linear model analyses (VanRaden and Klaaskate, 1993), while estimates from survival analysis (proportional hazards) models typically lead to estimates of 15 to 20% (e.g., Ducrocq, 1999). The latter class of models generally provides better fit to survival data due to their ability to properly account for animals that are still alive at the time of analysis, their ability to account for the skewed distribution of survival times, and their ability to model key environmental factors as time-dependent variables. Modeling variables such as herd-year-season class (contemporary group) in a time-dependent manner can better account for the exact conditions present at the time of culling, and this can be important if changes occur in herd size, facilities, or management practices. Likewise, modeling milk yield as a time-dependent variable can account for a particular cow's produc-

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tion level at the specific time when a herd manager considers culling her from the herd.

The objective of the present study was to characterize voluntary and involuntary culling rates in herds that had recently undergone a major expansion. More specifically, we wanted to: 1) describe the general trends in risk of culling of low- and high-producing cows in such herds; 2) assess differences in voluntary and involuntary culling rates between herds with different housing, milking, and animal handling facilities, as well as different management practices or labor situations. Because of the advantages of proportional hazards models for analysis of dairy cow survival data, we chose to employ survival analysis methodology to investigate these questions.

MATERIALS AND METHODS

Cow survival data were obtained from the USDA Animal Improvement Programs Laboratory, and these represented the input data for national dairy sire evaluations for length of productive life (VanRaden and Klaaskate, 1993). Because this was our initial data source, our analysis was restricted to cows with identified sires in herds that participated in qualifying milk recording plans (for national genetic evaluations). From this data set, we extracted culling and production records corresponding to 72,456 Holstein cows in 186 Wisconsin dairy herds that participated in a dairy herd modernization study conducted by Bewley and Palmer (2001a; 2001b); details of this survey are described below. Cows with first calving January 1, 1981, through December 31, 2000, were included in the study; survival records for cows that were still alive after five complete lactations and cows that were still alive as of December 31, 2000, were considered as censored (incomplete).

In our statistical analysis, the hazard function, $h(t)$, for a particular cow at time t was modeled as follows:

$$h(t) = h_0(t) \exp[A_i + YS_j(t) + PD_k(t) + PM_l(t)]$$

where:

$h(t)$ = hazard function (instantaneous probability of culling) of a certain cow at time t ;

$h_0(t)$ = Weibull baseline hazard function (i.e., the general aging process for all cows) at time t ;

A_i = effect of age at first calving (time-independent, with 1-mo classes);

YS_j = effect of year-season (time-dependent, with 4-mo seasons);

PD_k = interaction of parity and DIM (time-dependent, with parity classes from 1 to 5 and DIM classes of < 45, 45 to 270, or > 270; and

PM_l = interaction of time period by production (time-dependent, with periods of 1981 to 1989, 1990 to 1995, and 1996 to 2000, and with production measured as within herd-year quintile for the sum of mature equivalent fat and protein production).

The latter term was included so that we could evaluate the risk of culling for high- and low-producing cows, relative to average-producing cows, within a given time period. We calculated the relative risk of culling for low-producing cows in each time period using the ratio: (culling risk for cows in quintile 1)/(culling risk for cows in quintile 3). Likewise, we calculated the relative risk of culling for high-producing cows in each time period as: (culling risk for cows in quintile 5)/(culling risk for cows in quintile 3). Data were analyzed using the Survival Kit version 3.12 (Solkner and Ducrocq, 1999).

To assess the effect of specific farm facilities, herd management practices, and labor situations, the data were divided into subsets (according to levels of the particular variable), and the aforementioned survival model was applied separately to data from each subset. Within each level of a given variable, the relative risk of culling was calculated for high- and low-producing cows, as compared with average-producing cows, during the time period from 1996 to 2000. Herds that participated in the expansion survey of Bewley and Palmer (2001a, 2001b) were located within Wisconsin, and all increased herd size significantly (by at least 40% if greater than 100 cows or 50% if 60 to 100 cows) between 1994 and 1998. Average herd size after the most recent expansion was 252 cows. However, it is important to note that many of these herds were already expanding (albeit perhaps at a slower rate) prior to 1994, and many continued to expand after 1998. Although 302 herds returned usable surveys in the original expansion study of Bewley and Palmer (2001a, 2001b), many of these herds did not participate in a qualifying milk recording program or lacked sufficient sire identification for inclusion in our study.

Although the original survey of Bewley and Palmer (2001a, 2001b) considered a wide variety of topics related to facilities, labor, and producer satisfaction, the present study focused only on variables that were hypothesized to influence voluntary or involuntary culling rates. Selected variables related to facilities included: type of housing system, type of milking system, primary calving facility, type of freestall bedding, and presence or absence of fans, sprinklers, self-locking manger stalls, and palpation rails. Variables related to management practices included: herd size after expansion, rolling herd average for milk, average calving interval, overall culling (turnover) rate, heifer rearing program, milking frequency, use of bovine somatotropin (bST), and use of

Figure 1. Change in risk of culling for low-producing cows over time, relative to risk of culling for average-producing cows.

Figure 2. Change in risk of culling for high-producing cows over time, relative to risk of culling for average-producing cows.

AI. Variables related to labor included cows per full-time equivalent (FTE) employee, and percentage of total labor supplied by family members. For each of these variables, herds were classified into two or three categories, and different categories for a given variable were mutually exclusive.

RESULTS AND DISCUSSION

The risk of culling for low-producing cows (cows in the bottom 20% for within herd-year mature equivalent fat + protein yield) relative to average-producing cows (cows in the middle 20%) is shown in Figure 1. During the period from 1981 to 1989, low-producing cows in these herds were 4.2 times more likely to be culled than average cows. From 1990 to 1995, the risk of culling for low-producing cows was slightly lower, at 4.08 times that of average cows. However, from 1996 to 2000, the risk of culling for low-producing cows was only 2.55 times the risk of culling for average-producing cows. Therefore, it appears that these expanding herds are currently practicing much less voluntary culling of low-producing cows than they did in the past.

The risk of culling for high-producing cows (cows in the top 20% for within herd-year fat + protein yield) relative to average-producing cows is shown in Figure 2. From 1981 to 1989, high producing cows were only 0.5 times as likely to be culled as average-producing cows. In 1990 to 1995, the risk for high-producing cows increased to 0.62 times that of average cows, and in 1996 to 2000, the risk for high-producing cows increased to 0.68 times the risk of average cows. Therefore, it appears that these expanding herds are now practicing much more involuntary culling of high-producing cows than they did in previous years.

The specific categories corresponding to each survey question, as well as the number of herds and cows in each category, are given in Tables 1 and 2. In Table 1, the effect of management and labor practices on the relative risk of culling for low- and high-producing cows, as compared with average-producing cows, is shown for the time period from 1996 to 2000. As shown in Table 1, usage of bST had no significant impact on the risk of culling for high- and low-producing cows after expansion. However, herds with >150 cows after expansion had a slightly higher risk of culling for high-producing cows (as compared with average-producing cows) than herds with <150 cows. Likewise, herds with a rolling average for milk >25,000 lbs. had a slightly greater risk of involuntary culling of high-producing cows than herds with a rolling average <25,000 lbs. These results seem to indicate that cows under the stress of high production are at greater risk, particularly in large herds, where less individual attention is possible. The relative risk of culling of low-producing cows (compared with average cows) tended to increase as calving interval increased, but the risk of high-producing cows did not differ significantly. Overall culling (turnover) rate was not a consistent predictor of the amount of voluntary and involuntary culling in each herd, as high-producing cows were in greatest risk in herds with reported turnover rates of 25 to 40%.

Herds with <30 cows per FTE employee had a significantly lower risk of culling among high-producing cows than herds with 30 to 50 or >50 cows per employee. Likewise, the relative risk of culling for low-producing cows decreased as the number of cows per employee increased, though not significantly. Herds in which family members provided >80% of the total labor had a significantly lower relative risk of (involuntary) culling of high-producing cows, and herds in which family mem-

Table 1. Effect of management practices and labor situations on relative risk of culling for low- and high-producing cows, as compared with average-producing cows, during the period from 1996 to 2000.

Variable	Category	Number		Risk vs. average cows	
		Herds	Cows	Low cows	High cows
Herd size after expansion (cows)	< 150	71	17,849	2.63	0.62 ^a
	150 to 350	72	25,774	2.55	0.71 ^b
	> 350	43	28,833	2.50	0.70 ^b
Rolling herd average (lb.)	< 20,000	49	14,854	2.48	0.65 ^a
	20,000 to 25,000	108	42,110	2.64	0.67 ^a
	> 25,000	29	15,492	2.37	0.75 ^b
Calving interval (mo.)	< 13	60	19,854	2.45 ^a	0.65
	13 to 15	112	48,035	2.57 ^a	0.70
	> 15	14	4567	2.84 ^b	0.67
Culling rate (%)	< 25	54	19,188	2.57	0.65 ^a
	25 to 40	95	33,717	2.59	0.72 ^b
	> 40	37	19,551	2.49	0.64 ^a
Cows per full-time employee	< 30	65	22,105	2.59	0.62 ^a
	30 to 50	91	36,752	2.56	0.70 ^b
	> 50	30	13,599	2.47	0.76 ^b
Family labor (% of total)	< 50	26	11,446	2.24 ^a	0.74 ^a
	50 to 80	86	30,832	2.64 ^b	0.72 ^a
	>80	74	30,178	2.56 ^b	0.63 ^b
Milking frequency	2X	115	38,596	2.63	0.64 ^a
	3X	65	29,048	2.46	0.75 ^b
bST	No	55	16,493	2.61	0.72
	Yes	130	55,474	2.55	0.68
Heifer raising	Raised on farm	131	53,884	2.52	0.66 ^a
	Custom raised	46	16,347	2.64	0.75 ^b
Artificial insemination	Natural service	9	2364	2.18 ^a	0.71
	AI + clean-up bull	60	28,134	2.46	0.73 ^a
	All AI	115	41,608	2.63 ^b	0.66 ^b
Total		186	72,456	2.55	0.68

^{a,b}Differences between rows with differing superscripts were statistically significant ($P < 0.05$).**Table 2.** Effect of animal handling, housing, and milking facilities on relative risk of culling for low- and high-producing cows, as compared with average-producing cows, during the period from 1996 to 2000.

Variable	Category	Number		Risk vs. average cows	
		Herds	Cows	Low cows	High cows
Primary calving location	Maternity pen	64	25,300	2.50 ^a	0.61 ^a
	Bedding pack	82	35,348	2.56 ^a	0.74 ^b
	Pasture/dry lot	10	2504	3.16 ^b	0.83 ^b
Type of housing	Tie stall/stanchion	9	1549	2.72 ^a	0.63
	Loose housing	5	904	3.79 ^b	0.77
	Free-stall	172	70,003	2.53 ^a	0.68
Free-stall bedding	Mattress	51	24,107	2.32 ^a	0.69
	Sand	106	37,850	2.60 ^b	0.68
Fans	No	17	7265	2.52	0.76 ^a
	Yes	71	31,782	2.60	0.67 ^b
Sprinklers	No	58	24,158	2.52	0.72 ^a
	Yes	30	14,889	2.67	0.63 ^b
Self-locking manger stalls	No	72	36,301	2.48	0.71 ^a
	Yes	110	34,566	2.63	0.65 ^b
Palpitation rails	No	23	10,555	2.52	0.78 ^a
	Yes	159	60,312	2.56	0.67 ^b
Milking system	Stall barn/pipeline	37	8168	2.52	0.55 ^a
	Flat parlor	29	9341	2.52	0.61
	Pit Parlor	119	54,458	2.57	0.72 ^b
Total		186	72,456	2.55	0.68

^{a,b}Differences between rows with differing superscripts were statistically significant ($P < 0.05$).

bers provided <50% of the labor had a significantly lower risk of (voluntary) culling of low-producing cows.

Herds that milked three times daily had a significantly higher relative risk of culling of high-producing cows and a significantly lower relative risk for low-producing cows, compared with herds that milked twice daily, indicating that increased milk yield in these herds might be partially offset by greater replacement costs. Herds that raised their own replacement heifers had a significantly lower risk of culling of high-producing cows than herds that used a custom heifer grower, although no difference was detected in the risk of low-producing cows in these herds. Lastly, herds that used 100% AI had a lower risk of culling among high-producing cows than herds that used primarily natural service and herds that used AI with a cleanup bull. Likewise, the risk of culling of low-producing cows was significantly higher in 100% AI herds than in herds that used natural service bulls. Both results indicated a favorable balance of voluntary and involuntary culling in herds that made heavy use of AI.

Herds that had maternity pens had a significantly lower risk of culling among high-producing cows than herds that used a bedding pack and herds that let cows calve on pasture. The number of herds that reported using tiestalls, stanchions, or loose housing was too limited to detect a consistent effect of housing system on risk of culling. Among freestall herds, low-producing cows on sand bedding were at significantly greater risk of culling than comparable cows on mattresses, indicate that herds using sand bedding had more opportunities for voluntary culling of poor cows than herds with mattresses. Fans and sprinklers were consistently beneficial, in that herds with these climate control facilities had a significantly lower risk of culling among high-producing cows than herds without fans or sprinklers. A similar pattern was observed in herds with self-locking manger stalls or palpation rails, where high-producing cows in herds with these animal handling facilities were at significantly lower risk than cows in herds that did not invest in such facilities. Lastly, high-producing cows that were milked in a pit parlor had higher risk of culling than comparable cows milked in a stall barn, although the number of herds in the latter category was rather small. It is likely that cows receive more individual attention in stall barns, but it is also important to note that the type of milking system is strongly related to herd size.

CONCLUSIONS

Two important conclusions can be drawn from the present study. First, trends in voluntary culling of low-

producing cows and involuntary culling of high-producing cows are unfavorable in expanding herds in Wisconsin. Although this result is not surprising, it is nonetheless important to document the reduction in culling of poor cows on modern dairies and the increase in risk of illness, injury, and infertility among highly productive cows on these farms. These factors undoubtedly contribute to the shortage and corresponding high prices of replacement heifers today. Furthermore, these unfavorable trends in voluntary and involuntary culling can reduce progress in milk yield. For example, consider a hypothetical herd with mean lactation yield of 10,000 kg per cow (SD = 1200 kg) and a total culling rate (voluntary + involuntary) of 35% per year. Based on the risk ratios presented herein, the phenotypic selection differential (difference between retained and culled cows) would have been 456 kg in 1981 to 1989, 428 kg in 1990 to 1995, and only 297 kg in 1995 to 2000. Second, this study quantifies the gains that producers can expect to achieve in voluntary and involuntary culling by investing in facilities for animal handling, climate control, calving, and cow comfort, as well as the benefits of additional labor and use of AI. Although the current data set (sire-identified cows in milk-recorded herds) did not allow an investigation of the role of biosecurity practices and the sources of replacement animals (because many purchased animals did not have valid sire identification), other studies (Faust et al., 2001) have documented the importance of these issues. As herds continue to expand in the future, identification of factors that can lead to enhanced health and survival of high-producing cows will become increasingly important.

REFERENCES

- Bewley, J., R. W. Palmer, and D. B. Jackson-Smith. 2001a. A comparison of free-stall barns used by modernized Wisconsin dairies. *J. Dairy Sci.* 84:528–541.
- Bewley, J., R. W. Palmer, and D. B. Jackson-Smith. 2001b. An overview of Wisconsin dairy farmers who modernized their operations. *J. Dairy Sci.* 84:717–729.
- Ducrocq, V. 1999. Two years of experience with the French genetic evaluation of dairy bulls on production-adjusted longevity of their daughters. Pages 60–67 in *Proc. Intl. Wkshp. Genet. Improvement Funct. Traits in Cattle*, Jouy-en-Josas, France.
- Ducrocq, V., R. L. Quaas, E. J. Pollak, and G. Casella. 1988. Length of productive life of dairy cows: 1. Justification of a Weibull model. *J. Dairy Sci.* 71:3061–3070.
- Faust, M. A., M. L. Kinsel, and M. A. Kirkpatrick. 2001. Characterizing biosecurity, health, and culling during dairy herd expansions. *J. Dairy Sci.* 84:955–965.
- Solkner, J., and V. Ducrocq. 1999. The Survival Kit: a tool for analysis of survival data. Pages 11–15 in *Proc. Intl. Wkshp. Genet. Improvement Funct. Traits in Cattle*, Jouy-en-Josas, France.
- Van Raden, P. M., and E. J. H. Klaaskate. 1993. Genetic evaluation of length of productive life including predicted longevity of live cows. *J. Dairy Sci.* 76:2758–2764.