A prospective study of calf factors affecting first-lactation and lifetime milk production and age of cows when removed from the herd¹

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ABSTRACT

This prospective study was designed to investigate possible carryover effects of calf management practices and how events occurring during the first 16 wk of life affect first-lactation and lifetime milk production as well as age when animals are removed from production. This is the final of 3 stages in a longitudinal study that encompassed 10 yr of data collection. First, management and nutritional data were collected in the first 16 wk of life. The second part of this study evaluated conditions of animals at the time of first calving as affected by calf management, nutrition, and health. Both of these studies have been previously reported. This third portion covers the same calf effects on lactation performance and age at culling. Observations for the current study were collected from on-farm and Dairy Herd Improvement records. The multiple imputation technique was used in this analysis to avoid bias due to missing data. This study concluded that delivery score, weaning dry matter intake, days of illness before 4 mo, days treated before 4 mo, and body weight at first calving all had significant effects on first-lactation production of Holsteins. Delivery score and grain intake at a young age affected lifetime production. Age at culling was only affected by early grain intake in this study.

Key words: calf and heifer management, health, milk production, longitudinal data analysis

INTRODUCTION

Calf health, management, and nutrition can affect production and age at removal from the herd (Britney et al., 1984; Warnick et al., 1995). Many components of a heifer-raising system affect growth and health of replacements and impact overall farm economics as these relate to animal production and age at removal from the herd (Tozer and Heinrichs, 2001). Dairy heif-

ers represent a large expenditure of resources for dairy operations and must be managed efficiently to control costs (Gabler et al., 2000).

Research has shown an association between management and health of dairy replacements at young ages. Curtis et al. (1988) indicated that calf management appeared to directly affect the risk of respiratory illness within 14 d of birth. Waltner-Toews et al. (1986) found that a variety of management and housing factors were related to calf and heifer morbidity and mortality, including many variables related to farm size and season. Furthermore, Heinrichs et al. (1987) showed associations between calf mortality, herd size, and the person caring for the calf. Relating these factors to the older heifer, Correa et al. (1988) showed that heifers without respiratory illness were 2 times more likely to calve and calved 6 mo earlier than heifers with respiratory illness.

The effect of early calfhod health status on survivorship and age at first calving (**AFC**), after controlling for farm effect, has been evaluated (Waltner-Toews et al., 1986). Heifers that had been treated for pneumonia during the first 3 mo of life were 2.5 times more likely to die after 90 d of age than heifers that had not been treated. Heifers with a calfhod history of being treated for diarrhea were 2.5 times more likely to be sold for dairy purposes than other calves, and heifers that had been treated for diarrhea were 2.9 times more likely to calve after 900 d (30 mo) of age than other heifers (Waltner-Toews et al., 1986). Other observations have found that a calving age <730 d (24 mo) is much more economical, based on extra costs and lost production associated with older calving ages (Hoffman and Funk, 1992; Gabler et al., 2000).

Health status has been shown to have a significant effect on growth rate of calves especially during the first 6 mo of life (Donovan et al., 1998). Season of birth and occurrence of diarrhea, septicemia, and respiratory disease can significantly decrease heifer growth (height and weight). Donovan et al. (1998) reported that these variables plus farm, birth weight, and exact age when 6-mo data were collected explained 20 and 31% of the variation in BW and pelvic height growth, respectively from birth to 6 mo. Although calf health has been

Received February 14, 2010.

Accepted September 19, 2010.

¹This research is a component of NC-1042; Management Systems to Improve the Economic and Environmental Sustainability of Dairy Enterprises.

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shown to influence later AFC (Correa et al., 1988), some researchers using commercial herds did not show an effect on production (Warnick et al., 1995), but did observe an effect on mortality before calving. Britney et al. (1984) also did not see effects on first-lactation milk production.

Previous work by Place et al. (1998) showed that housing and season had significant effects on ADG and that other variables, such as calving location, parity of the dam, and delivery score at calving, had significant effects on ADG to 4 mo of age. A subsequent study (Heinrichs et al., 2005) using the same initial data set followed these animals from 4 mo through first calving. That study found that AFC, BW, BCS, and withers height at calving were all affected by nutrition, housing factors, and management of the calf. Additional studies have shown that AFC can affect first-lactation milk production (Ettema and Santos, 2004), with both early and late calving ages having less production.

The current project, an example of field research that encompasses long-term tracking of individual animal data, was undertaken to study possible carryover effects of calf management practices including calving management, nutrition, and environment conditions of calves to early adulthood (Place et al., 1998) and how calf-related events might affect first-lactation and lifetime production and age when animals are removed from production.

MATERIALS AND METHODS

Effects of calf management practices, nutrition, and environment on ADG of dairy heifers were studied from birth to 4 mo of age on 795 Holstein calves from 21 commercial dairy farms in Pennsylvania (Place et al., 1998). These farms participated in an 18-mo study following procedures of the National Dairy Heifer Evaluation Project (Heinrichs et al., 1994). Farms were chosen at random and represented approximately 5% of the dairy farms and 9% of the dairy cows in 2 northeastern Pennsylvania counties (Susquehanna and Wyoming) in 1991. During the initial 18-mo phase of the study, when individual animals were followed to 16 wk of age, farms were visited biweekly. During each visit animals were identified and health records were updated or collected for the previous 2 wk. At each visit calf growth was measured, nutrition parameters noted, environmental measurements taken, and health records updated as described previously (Place et al., 1998). In addition, an existing management survey from the National Dairy Heifer Evaluation Project (Heinrichs et al., 1994) was conducted at the commencement of the study to record current farm practices.

Following the initial 18-mo phase of the study, farms were visited every 3 mo to follow health events, breeding, and animal movement. When heifers approached calving age, visits occurred every 2 to 4 wk to collect data related to first calving. Data collection concluded on each farm when all identified heifers had calved. Data of interest included growth, calving difficulty, and health events. Identification information was also collected in this period so that future lactation records could be obtained.

Three of the original farms dropped out of the second phase of the study for reasons unrelated to the study. In addition, only animals that survived to the completion of the first phase of the study (112 d) were used in the second phase. The number of calves was therefore reduced to 686 on 18 farms for phase 2. All procedures involving animals in the previous publications (Place et al., 1998; Heinrichs et al., 2005) were done in accordance with approved guidelines of the Pennsylvania State University Institutional Animal Care and Use Committee.

Once all animals had been culled, lactation records were obtained from the USDA ARS and matched with calf records. Data were included even if the animal was not on the original farm whenever data were obtainable. To make record matching possible, DHI index identification numbers (recorded in most cases as the animals freshened) were cross-referenced with identification information from calf records (e.g., dam identification, name, vaccination number) and additional information collected in phase 2. This accounted for 500 out of the 686 animals. Of these, first-lactation records were found for 442. When a heifer begins her first lactation at more than 1,095 d of age, the ARS database considers it her second lactation for purposes of bull evaluation. For our purposes, true lactation number was wanted and records were adjusted accordingly.

With the linkage of 2 phases and their respective data sources, it is especially critical to avoid biases when addressing missing data in longitudinal trials of this nature. Therefore, as in the previous study (Heinrichs et al., 2005), multiple imputation (Rubin, 1987) was used. The imputation model used in this analysis included farm-specific survey information collected at initiation and other auxiliary variables of possible predictive value (Collins et al., 2001), as well as the proposed predictors. The response variables derived from ARS data were actual milk, fat, and protein production by lactation and 305-d mature-equivalent (**305-d ME**) milk, protein, and fat production. Within the ARS data set, different patterns of "missingness" existed. An example was when a lactation was missing that was known to have occurred, such as when lacta-

tion 2 was missing when the animal was known to have had 4 lactations before being removed from the herd. In other cases, herd removal dates were missing and it was not known how many lactations existed. Therefore, the data set was structured so that these could be imputed and later aggregated for lifetime records. Similar procedures were used previously (Rubin, 1987; Heinrichs et al., 2005). If the exit date was known for an animal, additional lactations were not imputed. Twenty complete data sets were imputed using these techniques. First-lactation data required no further manipulation; however, lifetime lactation data required additional calculation. If the exit date was imputed, lactations after that exit date were deleted. At that point, lifetime data was simply the sum of an animal's production. Thus, variability for lactation number could be accounted for in the final analyses.

The 20 complete data sets were analyzed with a linear mixed model in which farm was considered a random component using PROC MIXED in SAS (version 9.1.3, SAS Institute, Cary, NC). Because this was a continuation of a previous paper (Heinrichs et al., 2005) the same predictor variables were used. These were based on the quality of data and significant association with the response variables. The responses reported here are 305-d ME and actual production (milk, fat, and protein) during first lactation and lifetime as well as age when removed from the herd. Fixed effects in the models were

- Delivery score = difficulty of the heifer's birth (1 = unassisted; 2 = easy pull; 3 = hard pull, mechanical extraction, or caesarean section);
- Parity of the heifer's dam (0 = first-calf heifer, 1 = older cow);
- Days ill = number of days heifer had scours or cough during her first 4 mo of life;
- Days treated = number of days during first 4 mo of life that heifer had scours or cough requiring antibiotic treatment;
- DMI at weaning;
- Maximum milk DMI on BW basis in first 16 wk;
- Grain DMI on BW basis at 16 wk of age;
- Week of age that heifer first consumed 0.91 kg/d grain (DM);
- Phosphorus intake from grain at weaning;
- ADF content of forage fed at 4 mo of age;
- Maximum humidity heifer was exposed to during first 4 mo of life;
- Mean temperature heifer was exposed to during first 4 mo of life; and
- Maximum NH_3 heifer was exposed to during first 4 mo of life.

Table 1. Herd variables used in the analysis to study effects of calf and heifer management on milk production and removal from the herd

Item	Mean	SE
Delivery score ¹	2.2	0.90
Weaning age ²	1.5	0.60
Wean DMI ³	2.8	1.14
Grain age ⁴	70.5	19.77
Days ill ⁵	1.0	1.9
Days treated ⁶	0.2	0.74
AFC ⁷	868.7	128.50
BWC ⁸	552.6	73.97

¹Delivery score = difficulty of heifer's birth; 1 = unassisted, 2 = easy pull, 3 = hard pull, mechanical extraction, or caesarean section.

²Weaning age categories: 0 = ≤ 60 d, 1 = 61 to 90 d, 2 = > 90 d.

³DMI at weaning (grain and forage; kg/d).

⁴Age that heifer first consumed 0.91 kg/d of grain (DM basis).

⁵Number of days heifer had scours or cough during first 4 mo of life.

⁶Number of days during first 4 mo of life that heifer had scours or cough requiring antibiotic treatment.

⁷Age at first calving (d).

⁸BW at first calving (kg).

In the analysis presented, we began with the list of potential predictors that were important from previous papers. It was determined that several predictor variables were not significant for any current outcomes and these were therefore dropped from the final analysis. Significance in all analyses was declared at $P \leq 0.05$ and trends at $P \leq 0.10$.

RESULTS AND DISCUSSION

A summary of the herd variables used in the analysis to study effects of calf and heifer management on milk production and removal from the herd are shown in Table 1. Although these values are not what may be considered optimal current farm characteristics, they are the data from farms in 1991 when initial data collection was carried out for this series of studies. The predictor variables used in the final analysis are as follows: delivery score, weaning age, weaning DMI, age when heifers first consumed 0.91 kg of grain, number of days heifers had scours or cough during the first 4 mo of life, number of days during first 4 mo of age that heifers had scours or respiratory illness and required antibiotic treatment, age at first calving, and BW at first calving.

The analysis of the data showed that as delivery score increased by 1 unit, first-lactation 305-d ME milk production was reduced by 195.0 kg and actual production decreased by 284.6 kg (Table 2). Delivery score also affected protein (actual) production in a similar negative manner; component production decreased as delivery score increased. In addition, a trend ($P \leq 0.10$) was observed for increased delivery score to negatively

Table 2. Analysis of effect of calf factors on 305-d mature-equivalent and actual production during first lactation

Factor	305-d mature-equivalent production					Actual production				
	Estimate	SE	df	<i>t</i> Stat	<i>P</i> -value	Estimate	SE	df	<i>t</i> Stat	<i>P</i> -value
Milk, kg										
(Intercept)	9,290.12	308.98	45,225	30.07	<0.01	6,996.02	315.49	13,777	22.18	<0.01
Delivery score ¹	−195.03	99.88	378	−1.95	0.05	−284.65	133.63	236	−2.13	0.03
Weaning age	−463.83	206.29	860	−2.25	0.02	−106.27	282.85	289	−0.38	0.71
Wean DMI ²	286.73	122.29	1,606	2.34	0.02	200.46	158.03	889	1.27	0.21
Grain age ³	9.72	5.77	514	1.68	0.09	10.14	7.41	340	1.37	0.17
Days ill ⁴	−126.00	44.27	9,117	−2.85	<0.01	−109.19	57.61	4,545	−1.90	0.06
Days treated ⁵	200.59	122.12	717	1.64	0.10	310.47	175.28	179	1.77	0.08
AFC ⁶	−2.37	0.84	356	−2.83	<0.01	−1.43	1.12	210	−1.28	0.20
BWC ⁷	2.37	1.46	193	1.63	0.11	2.84	2.08	92	1.37	0.18
Protein, kg										
(Intercept)	278.80	9.79	56,783	28.47	<0.01	227.43	10.41	14,121	21.85	<0.01
Delivery score ¹	−4.78	2.73	799	−1.75	0.08	−8.58	4.29	234	−2.00	0.05
Weaning age	−9.36	5.97	676	−1.57	0.12	−0.59	9.16	261	−0.06	0.95
Wean DMI ²	9.56	3.50	1,802	2.73	0.01	7.30	5.03	1,166	1.45	0.15
Grain age ³	0.081	0.17	359	0.48	0.63	0.16	0.24	360	0.66	0.51
Days ill ⁴	−4.09	1.26	8,576	−3.23	<0.01	−3.61	1.85	4,452	−1.96	0.05
Days treated ⁵	7.20	3.39	1,513	2.13	0.03	10.86	5.47	227	1.99	0.05
AFC ⁶	−0.075	0.024	294	−3.09	<0.01	−0.045	0.035	235	−1.27	0.21
BWC ⁷	0.076	0.044	140	1.76	0.08	0.093	0.067	88	1.38	0.17
Fat, kg										
(Intercept)	345.85	9.36	12,430	36.95	<0.01	262.07	9.84	6,882	26.64	<0.01
Delivery score ¹	−3.22	3.85	781	−0.84	0.40	−8.25	5.13	291	−1.61	0.11
Weaning age	−9.31	8.90	264	−1.05	0.30	2.38	11.00	291	0.22	0.83
Wean DMI ²	14.91	5.00	634	2.98	<0.01	10.81	6.10	710	1.77	0.08
Grain age ³	−0.15	0.23	262	−0.66	0.51	0.034	0.28	352	0.12	0.90
Days ill ⁴	−5.18	1.78	10,347	−2.91	<0.01	−4.47	2.26	4,362	−1.97	0.05
Days treated ⁵	6.17	4.86	924	1.27	0.20	11.37	6.75	211	1.69	0.09
AFC ⁶	−0.071	0.034	227	−2.06	0.04	−0.035	0.042	274	−0.84	0.40
BWC ⁷	0.15	0.059	164	2.60	0.01	0.15	0.077	113	1.99	0.05

¹Delivery score = difficulty of heifer's birth on a scale of 1 to 3 (1 = unassisted, 2 = easy pull, and 3 = hard pull, mechanical extraction, or caesarean section).

²DMI at weaning (grain and forage; kg/d).

³Age that heifer first consumed 0.91 kg/d of grain (DM basis).

⁴Number of days heifer had scours or cough during first 4 mo of life.

⁵Number of days during first 4 mo of life that heifer had scours or cough requiring antibiotic treatment.

⁶Age at first calving (d).

⁷BW at first calving (kg).

affect lifetime mature-equivalent and actual milk production and lifetime actual protein production (Table 3). An increase in calving difficulty has been shown to have a greater effect on production and culling in first lactations than in subsequent lactations and has a high impact on herd amortization costs in relation to easy calving (López de Maturana et al., 2007).

Weaning DMI was associated with improved 305-d ME milk, fat, and protein production. In this case, for every increase of 1 kg of DMI at weaning there was a corresponding increase of 286.7 kg of first-lactation 305-d ME milk production. This may be related to body size at weaning or feeding management, which could result in greater BW at first calving (**BWC**); however, it did not show up in previous analyses as a factor affecting age or size at first calving (Heinrichs et al., 2005).

The age when calves first consumed 0.91 kg/d of grain (DM basis) showed significant positive effects

on lifetime milk, fat, and protein production but not on first-lactation production. In addition, an increased age when grain intake reached 0.91 g/d also increased age when heifers were removed from the herd. It is unknown why this parameter had an effect on lifetime parameters. Possible explanations could be related to greater milk intake that may have postponed grain intake, or perhaps some season, management, genetic, or health effects that did not enter into the current model; however, several of these factors were significant in affecting calf growth in these data (Place et al., 1998). This variable also had previously shown a significant negative effect on BCS at calving (Heinrichs et al., 2005).

The health of the young calf, as determined by the number of days that calves had scours or coughing during the first 4 mo of life, had a significant negative effect on first-lactation 305-d ME and actual milk, protein,

Table 3. Analysis of effect of calf factors on lifetime mature-equivalent and actual production and age at removal from the herd

Factor	Lifetime mature-equivalent production					Lifetime actual production				
	Estimate	SE	df	<i>t</i> Stat	<i>P</i> -value	Estimate	SE	df	<i>t</i> Stat	<i>P</i> -value
Milk, kg										
(Intercept)	34,554	1,745.55	1,572	19.80	<0.01	28,213	1,716.45	1,966	16.44	<0.01
Delivery score ¹	−2,337.02	1,214.28	407	−1.92	0.06	−2,149.06	1,142.58	366	−1.88	0.06
Weaning age	−1,590.60	2,703.49	219	−0.59	0.56	−124.60	2,509.78	240	−0.05	0.96
Wean DMI ²	484.12	1,439.25	456	0.34	0.74	703.48	1,373.63	387	0.51	0.61
Grain age ³	168.87	56.81	2,107	2.97	<0.01	159.21	54.14	1,836	2.94	<0.01
Days ill ⁴	−202.49	561.92	2,131	−0.36	0.72	−285.45	529.85	1,456	−0.54	0.59
Days treated ⁵	137.85	1,557.81	421	0.09	0.93	862.26	1,449.96	430	0.59	0.55
AFC ⁶	−9.23	9.37	492	−0.98	0.33	−4.56	8.66	676	−0.53	0.60
BWC ⁷	−18.97	15.76	375	−1.20	0.23	−15.82	14.52	516	−1.09	0.28
Protein, kg										
(Intercept)	1,028.03	53.478	1,670	19.22	<0.01	894.90	55.91	2,326	16.01	<0.01
Delivery score ¹	−68.16	36.43	395	−1.87	0.06	−67.15	36.17	352	−1.86	0.06
Weaning age	−38.120	81.57	207	−0.47	0.64	3.39	79.33	242	0.04	0.97
Wean DMI ²	12.58	42.86	539	0.29	0.77	19.47	43.22	446	0.45	0.65
Grain age ³	4.40	1.71	2,184	2.57	0.01	4.44	1.72	1,914	2.57	0.01
Days ill ⁴	−6.13	16.90	1,757	−0.36	0.72	−8.58	16.76	1,330	−0.51	0.61
Days treated ⁵	11.35	46.81	394	0.24	0.81	32.49	45.83	415	0.71	0.48
AFC ⁶	−0.27	0.28	516	−0.97	0.33	−0.15	0.27	701	−0.56	0.57
BWC ⁷	−0.52	0.47	411	−1.10	0.27	−0.46	0.46	570	−1.01	0.31
Fat, kg										
(Intercept)	1,300.25	60.68	797	21.43	<0.01	1,063.01	58.26	1,145	18.25	<0.01
Delivery score ¹	−72.48	45.10	387	−1.61	0.11	−67.33	42.27	376	−1.59	0.11
Weaning age	−18.96	102.30	171	−0.19	0.85	30.94	94.98	186	0.33	0.75
Wean DMI ²	−5.52	51.86	521	−0.11	0.92	8.07	49.26	461	0.16	0.87
Grain age ³	4.68	2.04	2,175	2.29	0.02	4.49	1.95	1,777	2.31	0.02
Days ill ⁴	−9.33	20.95	1,782	−0.45	0.66	−14.00	19.72	1,409	−0.71	0.48
Days treated ⁵	5.52	58.26	381	0.09	0.92	38.03	54.35	387	0.70	0.48
AFC ⁶	−0.24	0.34	495	−0.70	0.48	−0.064	0.32	674	−0.20	0.84
BWC ⁷	−0.76	0.57	406	−1.32	0.19	−0.62	0.53	602	−1.17	0.24
Age when removed from herd, d										
(Intercept)						1,803.31	111.96	4.64×10^7	16.11	<0.01
Delivery score ¹						−58.29	36.87	1.42×10^3	−1.58	0.11
Weaning age						8.46	75.19	5.13×10^5	0.11	0.91
Wean DMI ²						23.14	45.39	1.73×10^6	0.51	0.61
Grain age ³						5.93	2.06	1.77×10^4	2.88	<0.01
Days ill ⁴						−6.32	17.08	1.61×10^6	−0.37	0.71
Days treated ⁵						26.32	44.30	1.61×10^5	0.59	0.55
AFC ⁶						0.39	0.31	1.60×10^3	1.27	0.21
BWC ⁷						−0.64	0.50	2.80×10^3	−1.28	0.20

¹Delivery score = difficulty of heifer's birth on a scale of 1 to 3 (1 = unassisted, 2 = easy pull, and 3 = hard pull, mechanical extraction, or caesarean section).

²DMI at weaning (grain and forage; kg/d).

³Age that heifer first consumed 0.91 kg/d of grain (DM basis).

⁴Number of days heifer had scours or cough during first 4 mo of life.

⁵Number of days during first 4 mo of life that heifer had scours or cough requiring antibiotic treatment.

⁶Age at first calving (d).

⁷BW at first calving (kg).

and fat production. In the previous analysis (Heinrichs et al., 2005) days of illness also affected AFC. Thus, this study corroborates the importance of calf health on productivity (Donovan et al., 1998), yet this effect is not consistent in the literature and has been observed to have no effect on first-lactation production (Warnick et al., 1995). In the present data set the number of days ill did not significantly affect culling age or lifetime production. The number of days that calves were treated for scours or cough during the first 4 mo of life had a positive effect or trend for milk, fat, and protein production but no effects on lifetime production. Although no specific reason can be given for this, days treated also showed a positive effect on withers height at calving (Heinrichs et al., 2005). This effect could be related to overall improved health management, resulting in better overall health of these animals.

Age at first calving and BWC showed significant effects on first-lactation milk production. Age at calving showed negative effects on first-lactation milk, fat, and protein 305-d ME production consistent with Ettema and Santos (2004), who showed that mid-range AFC was best in terms of improving economic returns. Lifetime production and age removed from the herd were not affected by AFC. Previously, milk production and culling have been to shown to be affected by AFC; however, this was shown in much larger data sets (Pirlo et al., 2000). Increased BWC showed corresponding increases in first-lactation 305-d ME fat and tended to increase milk protein production. This response has been shown previously (Keown and Everett, 1986) and the ability to detect a significant response in first-lactation milk production may have been limited in this study because of sample size and variation in BWC. Body weight at first calving did not affect lifetime production or age at culling.

CONCLUSIONS

The results of the present study showed that delivery score, days of illness before 4 mo, and increasing AFC had negative effect on first-lactation production of Holsteins. Weaning DMI, days treated before 4 mo, and BWC all had positive effects on first-lactation production of Holsteins. Delivery score had a negative trend on lifetime milk production, and grain intake at a young age was shown in this data set to positively affect lifetime production. These data help corroborate the effect of early calf nutrition, health, and management on later production of dairy cows.

ACKNOWLEDGMENTS

Early components of this study were supported in part by USDA Cooperative Agreement number 12-43-99-0011 and The Pennsylvania Department of Agricul-

ture, Animal Health Commission. Appreciation is given to Nick Place, Chris Lathrop, and Jim Garner (all formerly of Penn State University, Montrose) for calf and heifer data collection; Coleen Jones (Penn State University) for technical editing; H. Duane Norman and USDA AIPL for production data; and the dairy farmers from Susquehanna and Wyoming Counties, Pennsylvania, who supplied the data.

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