Housing and management characteristics of calf automated feeding systems in the Upper Midwest of the United States

M. W. Jorgensen,* K. Janni,† A. Adams-Progar,* H. Chester-Jones,* J. A. Salfer,‡ and M. I. Endres*¹

*Department of Animal Science, and

†Department of Bioproducts and Biosystems Engineering University of Minnesota, St. Paul 55108

‡St. Cloud Regional Office, University of Minnesota Extension, St. Cloud 56301

ABSTRACT

Automated milk feeders are used by dairy producers to manage preweaned calves in group housing, but little is known about how these feeding systems are being used in the United States. To better understand how US dairy producers are operating these systems, this study investigated characteristics of barn design, environment, and management practices on 38 farms in the Upper Midwest of the United States via a questionnaire and on-farm measurements. Farms using automated feeders ranged in size from 7 to 300 calves on site. Natural ventilation was used on 50% of the farms, followed by barns with mechanical ventilation (39.5%), tunnel ventilation (7.9%), or outdoor facilities (sheltered plastic domes; 2.6%). Calves were kept in groups of 17.6 ± 9.8 animals (range: 5.9 to 60.5) with an average space allowance of 4.6 ± 2.0 m²/animal (range: 1.6 to 11.9). Calves on these farms received 3.7 ± 0.75 L (range: 2 to 6) of colostrum, but 22% of the tested calves had serum total protein values lower than 5.0 g/dL. Calves had an initial daily allowance of 5.4 ± 2.1 L (range: 3 to 15 L) of milk or milk replacer, rising to a peak amount of 8.3 ± 2.0 L (range: 5 to 15 L) over 18 ± 11.4 d (range: 0 to 44 d). Milk replacer was fed to calves on 68.4% of the farms compared with whole milk supplemented with nutrient balancer on 23.7% and whole milk alone on 7.9% of the farms. Calves were completely weaned at 56.8 ± 9.0 d of age (range: 40 to 85.5) and 52.1 ± 7.5 d (range: 40 to 79) since introduction into the group pen with the feeder. Notably, bacterial contamination of milk was common; the median coliform count was 10,430 cfu/mL (interquartile range: 233,111; range: 45 to 28,517,000) and standard plate count was 2,566,867 cfu/mL (interquartile range: 15,860,194; range 6,668 to 82,825,000) for samples collected from the feeder tube end (or feeder hose). Some areas of deficiency might be

of concern as they might be influencing the success of using automated calf feeding systems. In particular, a better understanding of the dynamics of pathogen load is needed in both the group pen area and in the automated feeder unit itself, as these reservoirs represent significant risk to calf health and welfare.

Key words: automated calf feeder, calf management

INTRODUCTION

In the United States dairy calves are commonly kept in individual housing systems (Nordlund, 2008; USDA, 2016). These systems aim to decrease calf-to-calf contact to minimize the transmission of pathogens between animals during the vulnerable preweaning period (Callan and Garry, 2002). Housing calves individually has been linked with reduced levels of both morbidity and mortality (Waltner-Toews et al., 1986a,b). However, these systems have been criticized for restricting calf movement and social interaction (Dellmeier et al., 1985). Individually housed calves may also have a higher labor requirement for feeding and management (Nordlund, 2008). As a result of consumers' animal welfare concerns, legislation and public pressure have largely eliminated individual housing in Europe (Rushen et al., 2008). Many US dairy producers have followed this trend toward group housing preweaned calves in part because of animal welfare concerns and the difficulty of sourcing sufficient farm labor to provide adequate calf care. Concurrent to this trend, computer-controlled automated calf feeding systems are increasing in popularity for the benefits that they offer to producers, including the significant reduction in manual calf-care labor (de Passillé et al., 2004), flexibility in diet administration and weaning, and the increased access to data, which support the management of individual animals in a group-housed system.

The amount of information related to the management of group housing systems in the United States is surprisingly sparse. Because group housing and automated feeding management continue to grow in

Received February 23, 2017.

Accepted August 21, 2017.

¹Corresponding author: miendres@umn.edu

popularity in the United States, and particularly in the Upper Midwest, it is important that the practices being used within these systems be documented. The objectives of this study were to describe housing and management practices employed by producers using automated calf feeding systems in the Upper Midwest of the United States and to investigate the association between milk bacterial counts and automated feeder cleaning practices used on the farms.

MATERIALS AND METHODS

Data Collection

At the start of the study, 64 dairy farms were identified as using automated calf feeding systems in the study area (Minnesota, Wisconsin, and northwest Iowa) for some or all of the preweaning period. From this population, 38 farms were randomly selected as a representative sample. Those farms used Förster-Technik (Engen, Germany) automated calf feeders, with the exception of 2 farms: 1 with a Holm & Laue (Westerröfeld, Germany), the other with an Urban feeder (Wüsting, Germany). Each farm was visited up to 8 times each, approximately once every 2 mo (repeated cross-sectional measurements) between November 2012 and May 2014. Seasons were defined from the onset of study to December 20, 2012 (fall 1), December 21, 2012, to March 20, 2013 (winter 1), March 21, 2013, to June 20, 2013 (spring 1), June 21, 2013, to September 20, 2013 (summer 1), September 21, 2013, to December 20, 2013 (fall 2), December 21, 2013, to March 20, 2014 (winter 2), and March 21 to May 20, 2014 (spring 2). The study was carried out in accordance with the recommendations of the Institutional Animal Care and Use Committee and the protocol was approved by the committee. Consent was granted by the farm operators.

Data were collected through a combination of on-farm measurement, farmer records, and questionnaire. Management practices were gathered via the questionnaire, which was administered by study personnel during farm visits or was left on farm and returned by mail. The questionnaire had 63 questions covering practices from birth through weaning. Feeding management (liquid diet allowance, timing, and weaning pattern) and automated feeder cleaning data were supplemented by information gathered from the automated feeder software.

On farm measurements, including housing and environmental factors, were taken in the pens during each visit. Static housing characteristics were measured during the first farm visit and changes were noted thereafter. These included barn layout and dimensions, ventilation, and pen characteristics. Bedding type, depth,

and area were measured at each visit. Bedding wetness was scored at 4 locations within each pen on a 0 to 4 scale (0 = dry; 4 = very wet; Canadian Dairy Research Project, 2011). Environmental measurements, such as barn temperature, humidity, aerial ammonia concentrations, air velocity, and light intensity were taken in 2 calf pens on smaller farms (4 or fewer total pens; 33 farms) or in 3 pens (5 or more total pens; 5 farms). Thermal environment of the calves was assessed using temperature-humidity loggers (HOBO A23 Pro Series, Onset Corp., Bourne, MA), which were installed in a central location within each calf barn during the first visit. These loggers recorded temperature and humidity hourly throughout the study period. Aerial ammonia concentration was measured using portable NH₃ meters (Dräger Pac 7000, Dräger Safety Inc., Pittsburgh, PA) placed at a height of 1.2 m and set to record a reading once a min during each visit. Air velocity was measured using an anemometer (TSI Velocicheck air velocity meter, model 8330, TSI Inc., Shoreview, MN). Readings were taken across 3 planes, 1 vertical (perpendicular to the ground), and 2 horizontal (one parallel to the ground and one at a 90° angle from the first) at the feeder station and the resting area. Light intensity was measured at 1 m height at 2 locations in each calf pen (at the automated feeder station and the resting area at which the most calves were lying down) using a digital portable meter (model TES1337, TES Electrical Electronic Corp., Taiwan, ROC).

Colostrum management quality (success or failure of passive transfer) was evaluated by measuring serum total protein (STP) in a convenience sample of young calves. Blood samples were collected from the jugular vein into vacutainer tubes from all available healthy calves 24 h to 7 d of age (up to 12 calves per farm) at each visit. Samples were centrifuged at $1,800 \times g$ for 10 min and tested for STP using a handheld light refractometer (model HR-200 ATC, AFAB Enterprises, Eustis, FL). The refractometer was calibrated using distilled water before testing the samples collected that day.

Milk samples for bacterial analysis were collected quarterly at each farm from the mixing tank (mixer) and from the feeder tube (or feeder hose) immediately anterior to the nipple from which the calves nurse (tube-end). Once collected, samples were immediately placed on ice and frozen as quickly as possible (within 6 h). Milk samples were analyzed for SPC and for coliform bacteria count at the University of Minnesota Veterinary Diagnostic Laboratory (St. Paul, MN). Milk samples were also collected twice (in summer and winter) following a protocol identical to that for the mixing tank sample and analyzed for milk components (fat, protein, and solids) using wet chemistry methods

Table 1. Medians and interquartile range values summarizing farm factors with nonnormal distributions on dairy farms with automated calf feeders in the Upper Midwest of the United States

Factor	Median	Interquartile range
Farm size		
No. of lactating cows	367	452
No. of calves on feeders	45	69.3
Maternity pen		
Bedding depth (cm)	22.9	21.0
Bacterial counts in feeder tube		
Coliform bacteria count (cfu/mL)	10,430	233,111
SPC (cfu/mL)	2,566,867	15,860,194
Bacterial counts in mixing tank		
Coliform bacteria count (cfu/mL)	336	28,689
SPC (cfu/mL)	166,916	2,066,782

(AOAC method #985.09; AOAC method #930.29; SMEDP #15.114, respectively). All component analysis was conducted by AgSource Laboratories (Marshfield, WI).

Data Analysis

The means procedure (PROC MEANS, SAS 9.3, SAS Institute Inc., Cary, NC) was used to calculate means and standard deviations or medians and interquartile range (**IQR**). Variable skew was visually assessed. For continuous variables that appeared normally distributed, means and standard deviations or ranges are reported. For continuous variables which appeared to be skewed in one direction, median and IQR are reported. The frequency procedure (PROC FREQ, SAS 9.3) was used to report the distribution of categorical variables. Pearson correlation (PROC CORR) was used to evaluate relationships between bacterial counts and automated feeder cleaning practices (significance at $P < 0.05$).

RESULTS AND DISCUSSION

Data Summary

Important farm management, housing, and environmental factors are reported in Table 1 (nonnormally distributed factors), Table 2 (normally distributed factors), and Table 3 (questionnaire percent responding).

Farm Demographics

Farm size varied widely with those milking cows (i.e., not a calf-only facility) reporting a median milking herd size of 367 (IQR: 452; range 60 to 3,000) cows. Median number of calves on automated calf feeders on the farm at any one time was 45 (IQR: 69.3; range 7 to 300). The 3 facilities custom raising calves had a median of 60 calves (range 24 to 62). According to USDA (2010)

standards, most farms on this study fell into the large (11 study farms; ≥ 500 cows) and medium (19 study farms; 100 to 499 animals) categories. A lesser proportion of farms would be categorized as small (3 farms; < 100 cows) and custom calf raisers (3 farms). The majority of the farms (61.1%) had only Holsteins, with the remainder having Holsteins and crossbred animals (33.3%) or Holsteins and Jerseys (5.5%).

Table 2. Means and SD values summarizing farm factors with normal distribution on dairy farms with automated calf feeders in the Upper Midwest of the United States

Factor	Mean	SD
Maternity pen		
Times checked/d	13.2	10.7
Colostrum management		
Colostrum delivered (L)	3.67	0.75
Calf serum total protein (g/dL)	5.44	0.72
Group pen bedding		
Bedding depth (cm)	16.3	7.1
Straw	16.8	6.9
Cornstalks	16.3	8.1
Wood shavings	8.0	4.0
Soybean straw	15.1	4.4
Sand	16.1	3.9
Bedding changes (times/mo)	1.2	1.0
Calf grouping		
Calf age at grouping (d)	5.1	3.9
Group size (no.)	17.6	9.8
Reported ideal group size (no.)	19.9	9.4
Reported maximum group size (no.)	26.2	11.6
Pen size (m ²)	71.0	36.0
Stocking density (m ² /calf)	4.6	2.0
Age range in pen (wk)	3.1	2.0
Calf feeding plans		
Milk allowance at start (L)	5.4	2.1
Milk allowance at peak (L)	8.3	2.0
Time to reach peak allowance (d)	18.0	11.4
Weaning time (d)	12.9	7.7
Age of calves at weaning start (d)	44.5	6.9
Age of calves at weaning end (d)	56.8	9.0
Feeder cleaning practices		
Automated cleaning frequency (times/d)	2.5	0.8
Circuit cleaning frequency (times/wk)	3.4	3.6
Nipple cleaning frequency (times/wk)	6.1	4.0
Manual tube cleaning frequency (times/wk)	1.9	3.1
Tube replacement (times/yr)	19.3	23.0

Table 3. Frequency of management practices for farms with automated calf feeders in the Upper Midwest of the United States

Response	%
Breed	
Holstein only	61.1
Holstein and crossbred	33.3
Holstein and Jersey	5.5
Maternity pen management	
Using group pen	81.8
Using individual pen	18.2
Pen exposed to elements	29.4
Pen fully enclosed	70.6
Pen disinfected at cleaning	18.2
Newborn calf care	
Licked clean by mother	76.5
Dried in warming chamber	14.5
Towel dried	5.9
Dried with bedding	2.9
Umbilicus disinfected	77.8
Iodine	92.9
Isopropyl alcohol	3.6
Chlorhexidine	3.6
Umbilicus not disinfected	22.2
Colostrum delivery method	
Bottle	47.1
Esophageal tubing	41.2
Nurse from dam	8.8
Nurse and bottle	2.9
Colostrum source	
Dam only	67.7
Pasteurized dam only	11.7
Pooled fresh	8.8
Other cows	5.9
Colostrum evaluated	
Colostrometer/refractometer	35.3
Visual assessment	52.9
Not assessed	11.7
Serum total protein (STP) testing	
STP tested always	8.8
STP tested occasionally	52.9
STP not tested	38.2
Barn construction type	
Retrofitted	60.5
New construction	39.5
Ventilation type	
Natural ventilation	50.0
Mechanical ventilation	39.5
Tunnel ventilation	7.9
Plastic domes	2.6
Positive pressure ventilation	
Yes	86.8
No	13.2
Calf pen bedding type (% of pens)	
Straw	78.0
Cornstalks	12.2
Wood shavings	5.2
Soybean straw	1.4
No bedding	2.7
Sand	0.5
Bedding wetness score (% of tests)	
0	87.5
1–3	12.5
4	2.7
Pens disinfected at cleaning	
Yes	55.6
No	44.4
Stocking approach	
All-in, all-out	17.6
Dynamic	82.4
Liquid diet type	
Milk replacer	68.4
Whole milk with balancer	23.7
Whole milk	7.9

Calving Practices

Close-up cows were group-housed in 81.8% of the farms. A minority of the farms (11.8%) housed sick adult animals in the calving pen as well. Producers reported that maternity pens were fully protected from the elements in 70.6% of facilities, whereas at least 1 side of the maternity pen was exposed in the remaining 29.4%. All but 1 farm reported using bedding in the maternity pen at a median depth of 22.9 cm (IQR: 21.0 cm, range = 0 to 61 cm), and this bedding was removed and replaced a median 20.8 times/yr (IQR: 40, range = 2 to 156). A single farm reported not bedding the maternity pen, while scraping the area twice daily (730 times/yr). Only 18.2% of the farms reported using a chemical disinfectant at the time of cleaning the maternity pen.

On a national basis, group calving pens are the most common across all farm sizes (USDA, 2016). It was reported that $58.7 \pm 1.8\%$ of all producers use pens of this type, although this proportion rises for medium ($69.1 \pm 2.7\%$) and large ($77.1 \pm 2.0\%$) farms to frequencies that are largely comparable to those observed in the current study.

Monitoring of the birthing process varied widely between farms in the current study, with staff visually checking the maternity pen for newly born calves and calving difficulty 13.2 ± 10.7 times/d (or once every 1.8 h). Further, observation cameras were used on 14.7% of the farms, with the remainder not using any special tools to monitor the calving area.

After birth, 61.8% of the farms in the current study reported using special techniques to stimulate weak calves, although only 40.6% of the farms had a standard operating procedure for assessing calf vigor. Most farms (76.5%) left the calf to be licked clean and dried by the dam, whereas 14.5% used a warming chamber, 5.9% used a towel, and 2.9% used the bedding straw from the maternity pen.

Disinfection of the calf umbilicus was standard procedure on 77.8% of the farms. A 7% tincture of iodine was the most popular disinfectant and was used on 92.9% of the farms that performed umbilical disinfection. Of the remaining farms, 1 used a chlorhexidine product and the other used isopropyl alcohol.

Separating the cow and calf immediately, rather than after a period of days or weeks, has been shown to reduce the intensity of behaviors associated with stress in both the cow and calf (Flower and Weary, 2001) and is thought to minimize the effect of postnatal bonding. In the current study, the maximum length of time a calf was allowed to stay with the mother was 24 h, although this occurred on only 10.5% of the farms. In the remainder of facilities, calves were removed after an

average of 1.7 h (range: 0 to 6 h), which was shorter than the length of time to separation observed nationally where 24.2% of the farms reported separating the animals within 1 h of parturition rising to 56.2% removal up to 6 h (USDA, 2016).

Colostrum Management

Automated feeder farms in the current study reported delivering 3.67 ± 0.75 L (range: 2 to 6 L) of colostrum in the first feeding (at an average of 1.7 h after birth), with the primary delivery method being bottle feeding (47.1% of the farms responding), followed by esophageal tubing (41.2%), and a minority (8.8%) allowing calves to nurse from the dam or allowing nursing and using a bottle (2.9%). Colostrum management on farms using automated feeders appeared to differ from the general dairy population in some key areas. A high percent of the farms in our study (68.6%) reported feeding the recommended 4 L of colostrum delivered in the first feeding. This is higher than 21.8% reported nationally for the United States (representing 42% of heifer calves; USDA, 2016). The method of delivering the colostrum also differed between study farms and the typical US dairy, with both esophageal tubing of colostrum and allowing the calf to nurse from the dam being used by a higher proportion of operations than has been reported nationally (tubing: 8.1%, nursing: 6.3%; USDA 2016). Method of feeding colostrum was not related to farm size in the current study.

The great majority of the farms (97.1%) in the current study only used colostrum from the first milking after birth, although the provenance of this colostrum varied. Fresh colostrum from the calf's own dam was the primary colostrum source on the farms (67.7%), although pasteurized individual-cow colostrum (11.7%), pooled fresh colostrum (8.8%), and fresh colostrum from other cows (5.9%) were also used. No primary colostrum source (a mix of sourcing methods) was reported on 5.9% of the farms. Fresh individual colostrum was also the most popular source nationally (used on 88.6% of operations), whereas pooled colostrum was less common on automated feeder farms in the current study than observed in a US survey (16.4% of operations; USDA, 2016).

Tools to measure colostrum quality (i.e., colostrometer, refractometer) were used on only 35.3% of the farms in the current study, whereas 52.9% of the farms reported using only a visual assessment and 11.7% reported not assessing colostrum quality at all. Colostrum replacer was present as a failsafe, or to boost inadequate colostrum, on 44.1% of the farms.

Only 8.8% of the farms in the current study reported testing STP on every calf as a method of monitoring

the success of immune transfer, although this percentage was higher than reported nationally (2.1%; USDA, 2010). The STP testing was used as a tool occasionally or in case of an issue on 52.9% of the farms, and was not used at all on the remaining 38.2%.

Calf STP concentration was 5.44 ± 0.72 g/dL ($n = 925$ calves); 22% were <5.0 and 33.6% were <5.2 g/dL. Farm average STP was 5.44 ± 0.39 g/dL, but 14.3% of the farms averaged <5.0 and 25.7% of the farms averaged <5.2 g/dL. The rate of failure of passive transfer observed in this study is generally consistent with the national average, in which 19.2% of calves had IgG levels indicative of inadequate passive transfer (USDA, 2010).

Overall, farms using automated feeding systems appeared to be following some recommended practices when managing colostrum. Although the feeding rates were typically at or above recommended levels, the general lack of colostrum assessment may be undermining the efficacy of management programs. The number of calves exhibiting failure of passive transfer is indicative of the need for further improvement in this area.

Calf Housing and Pen Characteristics

We found that 60.5% of the farms in the current study retrofitted existing structures to house their calves and the automated feeding system with the remaining 39.5% building new facilities. Natural ventilation (barns featuring adjustable curtain walls on at least one side) was used on 50% of the farms, followed by mechanical ventilation (solid-wall structures featuring one or more exhaust fans) on 39.5% of the farms. A smaller proportion of the farms had tunnel-ventilated barns (solid-wall structures featuring air inlets at one end and exhaust fans at the other end of the building; 7.9%) or outdoor facilities (sheltered plastic domes; 2.6%) for their calves. In the latter case, the feeder itself was housed in an indoor, insulated facility.

Proper ventilation is an important factor in controlling the airborne pathogen load, which can contribute to the incidence of respiratory disease in calf facilities. The requirement to distribute fresh outdoor air uniformly without creating drafts is difficult in a calf facility. It is often recommended that calf facilities feature at least some positive pressure ventilation to provide clean, fresh air to calves year-round (Nordlund, 2008). This recommendation was being implemented across automated feeder farms in our study regardless of barn type, with positive pressure tube ventilation in use on 86.8% of the farms compared with 13.2% without tubes. It should be noted that while 97% of the facilities using ventilation tubes were delivering fresh air from outside of the barn, 3% of the farms were recir-

Table 4. Seasonal summary of daily average (°C; ± SD), minimum, and maximum temperature recordings on dairy barns with automated calf feeders in the Upper Midwest of the United States

Season	Average	SD	Minimum	SD	Maximum	SD
Fall 1	1.70	1.63	−1.30	2.33	4.67	1.46
Winter 1	−0.85	4.07	−4.76	5.85	3.37	3.49
Spring 1	11.94	2.09	7.32	4.37	16.82	3.41
Summer 1	21.73	0.74	16.68	2.13	26.89	1.55
Fall 2	6.08	2.83	1.96	4.76	10.63	3.56
Winter 2	−3.28	4.96	−7.68	6.69	1.62	4.58
Spring 2	11.69	2.30	9.55	4.89	13.76	1.82

culating air from inside the calf area. A higher proportion of retrofitted calf housing featured solid walls and mechanical ventilation systems (56.5% of the farms) than naturally ventilated systems (30.4% of the farms). All of the tunnel ventilated barns were retrofits, and 2 of the 3 also housed older animals in the same facility with preweaned calves. We took a total of 3,282 air velocity readings (6/pen) and found that the maximum recorded air speed was 0.32 ± 0.39 m/s (range: 0 to 2.84) at the feeding station and 0.32 ± 0.39 m/s (range: 0 to 3.12) at the resting area. Maximum recorded air speed followed a clear seasonal pattern at both areas, peaking during summer at 0.63 ± 0.66 m/s (range 0 to 3.95) at the feeder and 0.68 ± 0.57 m/s (range: 0.006 to 4.17) at the resting area and being slowest during winter at 0.14 ± 0.16 m/s (range: 0 to 0.81) at the feeder and 0.13 ± 0.16 m/s (range: 0 to 1.03) at the resting area.

High concentration of aerial ammonia has been linked to irritation of the respiratory tract (Kiorpes et al., 1988); recommended maximum is 25 ppm. Only 1 operation (2.6% of total) exceeded the recommended level at any time of reading. Of 35,466 readings taken, only 120 (0.3%) exceeded 25 ppm, 222 readings (0.6%) were between 10 and 25 ppm, 1,755 (5.0%) were between 1 and 10 ppm, and 33,374 readings (94.1%) detected no ammonia (<1 ppm).

Light intensity was $805 \pm 1,877$ lx (range: 9 to 20,000) at the feeder and $1,227 \pm 2,471$ lx (range: 12 to 20,000) at the calf resting area. Although lighting approached relatively low levels at times on farms in this study, it

was never sufficiently dark to severely inhibit visual acuity.

The majority of facilities kept the automated feeder in a heated space, but did not heat the calf area. A single farm (2.6%) kept the calf area heated above a minimum set temperature during colder periods. The thermoneutral zone of the dairy calf ranges between 10 and 26°C for newborn calves, expanding to a range of 0 to 23°C once the animals reach 1 mo of age (Wathes et al., 1983). Table 4 shows the daily average, minimum, and maximum recorded temperatures on all farms categorized by calendar season. Mean temperature across all farms (the mean of all temperature readings in a 24-h period averaged within a season) was below 0°C during both winter 1 ($-0.85 \pm 4.07^\circ\text{C}$) and winter 2 ($-3.28 \pm 4.96^\circ\text{C}$), whereas mean minimum temperature was below 0°C during fall 1 ($-1.30 \pm 2.33^\circ\text{C}$), winter 1 ($-4.76 \pm 5.85^\circ\text{C}$), and winter 2 ($-7.68 \pm 6.69^\circ\text{C}$). Maximum temperature was over 23°C during summer 1 ($26.89 \pm 1.55^\circ\text{C}$). When comparing temperature by ventilation type (Table 5), only tunnel-ventilated barns never had seasonal mean temperature below 0°C, whereas no ventilation type had seasonal mean temperature above 23°C during this study.

Barn daily mean temperature regularly fell outside of calf thermoneutral zone (0 to 23°C). Across farms, the daily mean temperature was below 0°C for 127 ± 56.7 d and above 23°C for 35.4 ± 10.0 d. Daily mean temperature was recorded outside the thermoneutral zone on $34 \pm 10.4\%$ of days measured during the study. The maximum daily temperature was above the thermoneutral

Table 5. Seasonal daily average temperature (°C; ± SD) recordings on dairy barns with automated calf feeders in the Upper Midwest of the United States by ventilation type

Season	Naturally ventilated (n = 19)	SD	Mechanically ventilated (n = 15)	SD	Tunnel ventilated (n = 3)	SD	Igloo (n = 1)	SD
Fall 1	0.90	1.35	2.42	1.58	—	—	—	—
Winter 1	−2.90	1.80	0.71	0.71	4.76	0.09	−4.21	—
Spring 1	11.78	2.31	12.13	1.91	13.01	1.91	9.71	—
Summer 1	21.72	0.80	21.78	0.59	22.22	0.87	20.12	—
Fall 2	4.66	1.14	7.22	3.02	10.75	5.00	3.90	—
Winter 2	−5.57	2.64	−0.72	5.61	4.47	—	−8.37	—
Spring 2	10.91	2.57	12.64	1.75	12.07	—	10.18	—

zone ($>23^{\circ}\text{C}$) on $36.7 \pm 6.7\%$ of days, and the minimum daily temperature was outside this zone ($<0^{\circ}\text{C}$) on $38.5 \pm 13.6\%$ of days. The daily mean temperature was outside the thermoneutral zone in mechanically ventilated barns on $30.2 \pm 10.4\%$ of days, compared with $39.7 \pm 5.1\%$ in naturally ventilated barns, $15.1 \pm 7.1\%$ in tunnel-ventilated barns, and 39.0% in outdoor plastic domes (single farm). Farms using tube ventilation had a daily mean temperature outside the thermoneutral zone on $34.5 \pm 10.0\%$ of days, compared with $31.9 \pm 14.6\%$ in farms without ventilation tubes.

Bedding and Pen Cleaning

Calf pens typically featured a bedding substrate. Straw was the most common bedding material, used in 435 of the 558 pens (78.0% of pens) in which bedding characteristics were measured. Other bedding materials included cornstalks (12.2%), wood shavings (5.2%), soybean straw (1.4%), and sand (0.5%). One automated feeding system was installed in a retrofitted swine barn, which housed calves on a slatted metal floor and in which bedding was not used. Bedding depth measured at the time of visit was 16.3 ± 7.1 cm (range: 2.5 to 40.6 cm). When categorized by bedding type, straw was bedded at the greatest depth (16.8 ± 6.9 cm), followed by cornstalks (16.3 ± 8.1 cm), sand (16.1 ± 3.9 cm), soybean straw (15.1 ± 4.4 cm), and wood shavings (8.0 ± 4.0 cm). It should be noted that sand was used as the primary bedding substrate only during summer and was replaced with straw or cornstalks in colder months. Although temperatures can regularly fall outside of the calf's thermoneutral zone, bedding can provide a mechanism to support thermoregulation (Nordlund, 2008).

Bedding wetness can affect its effectiveness as a tool for thermoregulation, but excessively wet bedding did not appear to be a major issue on automated feeder farms in the current study. Bedding wetness was tested in 547 pens (2,188 individual tests at 4/pen). Most bedding wetness tests scored 0, or completely dry (1915 tests, 87.5%), with 273 tests detecting at least some level of wetness (score of 1 or greater; 12.5%). Only 59 samples (2.7%) received the highest score for wetness, representing a small proportion of the total samples taken, but 1 or more samples with a wetness score of 4 were detected in 50 pens (9.1%). The farm average sum of bedding wetness scores was 1.1 ± 0.9 (range: 0 to 4.2) of a possible maximum of 16 per pen (4 measurements with a maximum value of 4 each).

Producers reported changing the bedding in automated feeder pens 1.2 ± 1.0 times/mo. In addition to affecting the thermal environment of the calf, the regu-

lar addition of clean, dry bedding has been reported as an effective method for separating calves from enteric pathogens on the pen floor (McGuirk, 2008). The cleaning and disinfecting of pens between calf groups is also recommended as a management practice to maintain biosecurity and disrupt disease cycles (Castro-Hermida et al., 2006). Despite the availability and efficacy of multiple sanitizing agents (Patterson et al., 2005; Quilez et al., 2005), only 55.6% of the farms reported the regular washing and disinfecting of the pens between groups.

Insects

Insect pests were reported as an issue in the group housing area on 58.3% of the farms, compared with 41.7% not reporting major pest issues. Insecticide spray was used to control fly populations on 67.6% of the farms, whereas 27.3% of producers used a feed product with larvicide as an ingredient. Nonchemical pest control measures were reported on 41.9% of the farms. Flies may compromise sanitation efforts and can act as a vector for pathogenic organisms such as *Cryptosporidium parvum* (Graczyk et al., 1999).

Calf Grouping

Most study farms reported that calves were kept individually for a short period following birth in order for calves to develop the physical capacity to cope with group housing. Only 25.7% of the farms in the current study reported grouping calves at d 1 of age. Calf age at grouping was 5.1 ± 3.9 d (range: 0 to 14 d). Disease incidence in calves peaks during the second week of life, so it has been recommended that grouping be delayed until after this period (Svensson et al., 2003). If calves have adequate passive immune transfer and are strong enough to gain regular access to critical resources in a group setting, waiting for 14 d may not be necessary. More research is needed on the effect of age at introduction to group housing on calf health and welfare.

The group size measured on farms in the present study was 17.6 ± 9.8 animals (range: 5.9 to 60.5). On the management questionnaire, producers reported an ideal group size of 19.9 ± 9.4 calves/pen and a maximum tolerable group size of 26.2 ± 11.6 animals. Previous studies found that group size had a significant effect on calf health and performance (Svensson et al., 2003), although the exact relationship is not necessarily clear. We found that most automated feeding system operators in our study did not exceed upper limits for group size suggested by manufacturers (25 to 30 calves).

Calf pen size within these facilities ranged from 15.5 to 237 m², although these sizes represent the extremes.

The farm with the largest pen size also had the largest average group size (60.5 calves), which was not typical. The mean per-farm pen size for group-housed calves was $71 \pm 36 \text{ m}^2$. Pen size was commonly related to the number of calves being housed, although this was not always the case. Average pen space allowed per calf was $4.6 \pm 2.0 \text{ m}^2$ (range: 1.6 to 11.9 m^2). Because overstocking is detrimental to calf health, it is recommended that calves be allowed a minimum amount of resting space of 2.3 to 2.8 m^2 (FASS, 2010) and this minimum limit was met in 93.1% of pens in the current study.

The age difference between the oldest and youngest animals in a pen was $3.1 \pm 2.0 \text{ wk}$ (range: 0.3 to 10 wk). Weaned and preweaned animals were kept together in the same pen on 61.1% of the farms, whereas 38.9% of producers removed animals on the day of weaning. Although the measurements taken represent a static example of calf group size, in reality group sizes tended to be significantly more dynamic with calves being added and removed from the group upon reaching certain age limits. Only 17.6% of the farms used an all-in/all-out stocking system in which calf groups were relatively static once the pen had been filled. Much more common (82.4% of the farms) was a dynamic grouping system in which calves were added and removed from the automated feeder as individuals or in small groups. These continuous flow systems effectively increased the group size that a calf was exposed to during the preweaning period likely increasing the risk of infection from other pen mates. However, because of farm size and economic considerations most farms did not implement all-in/all-out systems.

Feeding Plans

The capability of automated feeding systems to deliver more milk, and more feedings per day, to calves was reflected in the relatively high milk allowances observed on the majority of the farms in the current study. When introduced to the automated feeder, calves were started at a daily allowance of $5.4 \pm 2.1 \text{ L}$ (range: 3 to 15 L) of milk or milk replacer. This increased to a peak amount of $8.3 \pm 2.0 \text{ L}$ (range: 5 to 15 L). It took $18 \pm 11.4 \text{ d}$ (range: 0 to 44 d) for calves to reach the peak milk allowance. Milk replacer was fed on 68.4% of the farms compared with whole milk supplemented with nutrient balancer on 23.7% and whole milk alone on 7.9% of the farms.

Although the amount of milk being fed in automated feeding systems was higher than in most conventional systems, there is potential that the liquid diet being delivered to calves is not mixed precisely to specifications. Automated feeders, particularly those feeding a

powdered milk replacer, require regular maintenance to prevent the powder from bridging, caking, or otherwise clogging the dispensing system. The overall fat content of the liquid diet ($n = 73$) was $2.8 \pm 0.7\%$ (range: 1.2 to 4.0), protein content was $3.3 \pm 0.7\%$ (range: 1.9 to 5.1), and TS were $12.2 \pm 1.9\%$ (range: 11.1 to 18.0). For those farms using milk replacer, fat content was $2.4 \pm 0.5\%$ (range: 1.2 to 3.7), protein was $3.1 \pm 0.7\%$ (range: 1.9 to 5.1), and TS were $12.0 \pm 2.2\%$ (range: 7.0 to 18.0). Farms feeding supplemented whole milk had fat content of $3.4 \pm 0.6\%$ (range: 1.7 to 4.0), protein of $3.8 \pm 0.4\%$ (range: 3.2 to 4.6), and TS of $12.8 \pm 1.1\%$ (range: 10.3 to 14.3). Farms using whole milk alone had fat content of $3.5 \pm 0.3\%$ (range: 3.0 to 3.9), protein of $3.4 \pm 0.3\%$ (range: 3.0 to 3.9), and TS of $12.0 \pm 0.5\%$ (range: 11.0 to 12.6). The apparent difference between farms using milk replacer and those using whole-milk-based diets indicates a need to further investigate calibration and dispensing issues in automated feeders and to encourage regular maintenance to ensure proper feeder function.

In total, 76.3% of the farms fed a medicated liquid diet (milk or milk replacer that included antibiotics or coccidiostats in the product delivered to calves) with just 23.7% feeding a nonmedicated diet. Feeding of a medicated liquid diet was more prevalent on farms feeding milk replacer, being used by 89.7% of these farms, when compared with 33.3% of the farms feeding a supplemented or nonsupplemented whole milk.

A generally gradual weaning period lasted $12.9 \pm 7.7 \text{ d}$ (range: 3 to 42 d) from first reduction to complete removal from a liquid diet. While traditional systems make managing a gradual weaning program difficult, the process is relatively simple to administer in automated feeders. The average age at weaning in the United States was reported to be 58.8 d (USDA, 2010). The automated feeding operations on this study were very similar to this national average, and began weaning calves from the liquid diet at $44.5 \pm 6.9 \text{ d}$ of age (range: 32 to 60) and time on the feeder of $39.3 \pm 6.3 \text{ d}$ (range: 20 to 59). Calves were completely weaned at $56.8 \pm 9.0 \text{ d}$ of age (range: 40 to 85.5) and $52.1 \pm 7.5 \text{ d}$ (range: 40 to 79) since introduction into the group pen with the feeder.

Calf Monitoring

Most individuals supervising the calf area also had other farm labor responsibilities, but 28.9% of the farms reported having an employee (or family member) whose primary responsibility was to care for the calves. Automated feeders are designed to provide calf managers information on individual animals' amount of milk con-

sumed per day and per meal, drinking speed, number of visits to the feeder unit for which the calf received milk (rewarded visits) and did not receive milk (unrewarded visits), and the number of times a calf stops drinking in the middle of a meal (break-offs). Although more work needs to be done to determine the strength of relationship between these behavioral factors and actual health outcomes, most producers relied on one or more of them to identify potentially sick animals.

Of the data reported by the automated feeding system, producers reported using the percent of allotment consumed (milk intake) to monitor calf health most frequently (77.4% of the producers) to identify potentially sick calves, followed by measurement of drinking speed (55.9%). The next most popular measure was the frequency of break-offs (when the calf stops drinking before a meal has been fully consumed), used by 29.4% of the producers. Neither the number of times the calf visited the machine (used by 5.9% of the producers) nor the number of unrewarded visits to the machine (used by 2.9% of the producers) were widely used. Almost half of the producers (44.7%) did not use a specific behavioral measure to monitor calf health, relying instead on the automated feeder's default algorithms to detect sick animals. Of those farms that focused on one or more specific measures of calf health (55.3% of the farms), 52.4% focused on a single factor, 42.9% used 2 factors, and 4.8% used 3 factors.

Painful Procedures

Thirty-five farms reported dehorning and 18 farms reported castrating males on site. Of those, thermal (hot iron) dehorning was the most common practice (57.1% of the farms), followed by use of a caustic paste (28.6% of the farms) and physical removal of the horn bud (14.3% of the farms). These percentages are similar to US practices for raising dairy heifers, in which hot iron dehorning is the most popular, followed by caustic paste, and then physical removal (USDA, 2010).

Anesthesia was rarely reported as being used at the time of dehorning, being used by 14.7% of the farms (20% of the farms using chemical paste, 15% of the farms using thermal dehorning), and analgesic pain relief was used on only 5.9% of the farms (10% of the farms using chemical paste, 5% of the farms using thermal dehorning). Of the farms that kept bull calves for a portion or all of the preweaning period, rubber band castration was used on 72.2% of the farms, whereas surgical castration was used on 27.8%. No farms used anesthesia at the time of castration, and only 5.6% (1 farm using surgical castration) of the farms provided analgesic pain relief after the procedure.

Feeder Cleaning, Management, and Bacterial Contamination

The median coliform count on milk samples was 10,430 cfu/mL (IQR 233,111; range 45 to 28,517,000) in the feeder tube end and 336 cfu/mL (IQR 28,689; range 0 to 25,621,330) in the mixing jar. The median SPC was 2,566,867 cfu/mL (IQR 15,860,194; range 6,668 to 82,825,000) in the feeder tube end and 166,916 (IQR 2,066,782; range 125 to 59,396,100) in the mixing jar. When comparing the best- and worst-performing farms (Table 6), the differences in bacterial count between median and IQR of the top 10th and bottom 10th percentile performing farms was very large. Although bacterial counts in the worst-performing farms represent a very real risk to calf health, the performance of the best farms indicates that it is possible to mix and deliver a liquid diet that meets recommended bacterial counts. It has been recommended that bacterial contamination of milk fed to calves be below 100,000 cfu/mL for SPC and 10,000 cfu/mL for coliform bacteria (McGuirk and Collins, 2004).

Automated feeders are designed with certain cleaning tools and procedures integrated into the system, but research determining the effectiveness of these procedures is very limited. In addition to this, some cleaning procedures require the operator to manually initiate the process on the feeder controller, a fact that was often not known by operators at the time of installation. It is possible that farm operators were not aware about the liquid diet contamination. Only 28.1% of the farms reported ever using a bacterial analysis to monitor feeder sanitation, 37.5% did not monitor sanitation, and 31.3% reported using only a visual assessment to monitor sanitation. Visual observation is unlikely to give a good measure of bacterial contamination.

Cleaning of the automated feeders varied widely among farms, particularly for those tasks that must be initiated or fully performed by human staff. Automated feeders were set up to execute an automated cleaning function (of the feed mixing jar) 2.5 ± 0.8 times/d (range: 1 to 4). Producers reported performing the circuit cleaning function (an automated cleaning of machine tubing that must be manually initiated) 3.4 ± 3.6 times/wk (range: 0 to 4) with 11.4% of the farms never running this function. Farmers reported changing and sanitizing the nipples from which the calves nurse 6.1 ± 4.0 times/wk (range: 0.2 to 14). The tubes (or hoses) leading from the mixing unit to the nipple were manually cleaned 1.9 ± 3.1 times/wk (range: 0 to 14), with 36.4% of the farms never cleaning them. These tubes were replaced 19.3 ± 23.0 times/yr (range: 1 to 104).

Table 6. Comparison of median (+interquartile range, IQR; range), lowest (top 10th) and highest (bottom 10th) coliform and SPC bacterial counts (cfu/mL) in milk samples from the feeder mixing jar (mixer) and tube-end (tube) on automated calf feeder farms in the Upper Midwest of the United States

Item	Tube coliform (cfu/mL)	Mixer coliform (cfu/mL)	Tube SPC (cfu/mL)	Mixer SPC (cfu/mL)
Median top 10th (IQR; range)	887 (1,005; 45–2,249)	12 (12; 0–38)	87,590 (102,337; 6,668–520,500)	9,006 (7,084; 125–15,193)
Median bottom 10th (IQR; range)	5,659,567 (13,146,004; 260,068–28,517,000)	522,263 (19,936,649; 35,009–25,621,330)	21,140,625 (52,998,072; 15,383,208–82,825,000)	10,209,920 (40,468,793; 2,195,063–59,396,100)

Unsurprisingly, we detected associations among milk bacterial counts, with contamination in one location (the feeder tube end or mixing jar) increasing the likelihood of measuring contamination in another. We also detected associations between SPC and coliform counts. The coliform count of the feeder tube end samples was related to that from the mixing jar ($r = 0.30$, $P < 0.001$) and the same relationship was detected for SPC ($r = 0.48$, $P < 0.001$). Bacterial counts in the feeder tube end were typically higher than those in the mixing jar, which is reflective of the fact that the cleaning functions of the mixing jar were totally automated whereas those for the tube were not automated at the time of the study. Despite this, it appears that both sites can serve as a reservoir for potentially pathogenic organisms.

We also found associations between milk bacterial counts and the frequency of performing cleaning procedures reported by producers. The coliform count from the mixing jar was negatively associated with the frequency of automated mixer cleaning ($r = -0.26$, $P < 0.001$) as was the SPC of the mixing jar ($r = -0.32$, $P < 0.001$). The SPC from the feeder tube end was correlated with the frequency of automated mixer cleaning ($r = -0.15$, $P = 0.048$) and the frequency of circuit cleaning ($r = -0.28$, $P < 0.001$). The coliform count from the tube was not associated with any of the cleaning factors. It is encouraging to see that more frequent cleaning of the automated feeder unit, including both automated and manual procedures, was associated with a reduced level of bacterial contamination. The relationship between automated feeder cleaning frequency and milk bacterial counts is not well understood, and while more frequent automated and manual cleaning of the machines has been shown to be associated with reduced bacterial contamination in milk, certain cleaning functions may actually loosen built-up biofilms in the machine and increase bacterial content in the short term (Dietrich et al., 2015). More research should be conducted to determine what factors affect bacterial contamination of the milk fed to calves in automated systems, including on-farm cleaning procedures and the environment in which the feeder is housed.

CONCLUSIONS

This study provided novel information about various management practices and housing characteristics for farms using automated feeders for preweaned calves in the Upper Midwest of the United States. Some areas of deficiency might be of concern as they might be influencing the success of using these systems. In particular, a better understanding of the dynamics of pathogen load is needed in both the group pen area and in the

automated feeder unit itself, as these reservoirs represent significant risk to calf health and welfare.

ACKNOWLEDGMENTS

We thank all the dairy producers who participated in the study. In addition, we thank Luis Espejo (St. Augustine, FL) for help with statistical analysis. We thank the following students at the University of Minnesota for help with data entry: Nathan Bos, Kelly Froehlich, Andrew Hetke, Andrew Plumski, and Michael Schmitt. This project was supported by Agriculture and Food Research Initiative competitive grant no. 2012-67021-19280 from the USDA National Institute of Food and Agriculture (Washington, DC).

REFERENCES

- Callan, R. J., and F. B. Garry. 2002. Biosecurity and bovine respiratory disease. *Vet. Clin. North Am. Food Anim. Pract.* 18:57–77. [https://doi.org/10.1016/S0749-0720\(02\)00004-X](https://doi.org/10.1016/S0749-0720(02)00004-X).
- Canadian Dairy Research Project. 2011. Stall Wetness Cluster Project. Accessed Oct. 1, 2012. https://www.dairyresearch.ca/pdf/2D-stall%20bedding%20wetness%20sop_221210.pdf.
- Castro-Hermida, J. A., C. Carro-Corral, M. Gonzalez-Warleta, and M. Mezo. 2006. Prevalence and intensity of infection of *Cryptosporidium* spp. and *Giardia duodenalis* in dairy cattle in Galicia (NW Spain). *J. Vet. Med. B Infect. Dis. Vet. Public Health* 53:244–246. <https://doi.org/10.1111/j.1439-0450.2006.00946.x>.
- de Passillé, A. M., J. Rushen, and D. Weary. 2004. Designing good environments and management for calves. *Adv. Dairy Technol.* 16:75–89.
- Dellmeier, G. R., T. H. Friend, and E. E. Gbur. 1985. Comparison of four methods of calf confinement II: behavior. *J. Anim. Sci.* 60:1102–1109. <https://doi.org/10.2527/jas1985.6051102x>.
- Dietrich, A. M., W. A. Knauer, S. A. Godden, C. S. Petersson-Wolfe, and R. E. James. 2015. Factors associated with aerobic plate count, coliform count, and log reduction of bacteria in automated calf feeders. *J. Dairy Sci.* 98(E-Suppl.2):214. (Abstr.)
- FASS. 2010. Guide for the care and use of agricultural animals in research and teaching. 3rd ed. FASS, Champaign, IL.
- Flower, F. C., and D. M. Weary. 2001. Effects of early separation on the dairy cow and calf: 2. Separation at 1 day and 2 weeks after birth. *Appl. Anim. Behav. Sci.* 70:275–284. [https://doi.org/10.1016/S0168-1591\(00\)00164-7](https://doi.org/10.1016/S0168-1591(00)00164-7).
- Graczyk, T. K., M. R. Cranfield, R. Fayer, and H. Bixler. 1999. House flies (*Musca domestica*) as transport hosts of *Cryptosporidium parvum*. *Am. J. Trop. Med. Hyg.* 61:500–504.
- Kiorpes, A., D. Butler, R. Dubielzieg, and K. Beck. 1988. Enzootic pneumonia in calves: Clinical and morphologic features. *Compend. Contin. Educ. Pract. Vet.* 10:248–258.
- McGuirk, S. M. 2008. Disease management of dairy calves and heifers. *Vet. Clin. North Am. Food Anim. Pract.* 24:139–153. <https://doi.org/10.1016/j.cvfa.2007.10.003>.
- McGuirk, S. M., and M. Collins. 2004. Managing the production, storage and delivery of colostrum. *Vet. Clin. North Am. Food Anim. Pract.* 20:593–603. <https://doi.org/10.1016/j.cvfa.2004.06.005>.
- Nordlund, K. V. 2008. Practical considerations for ventilating calf barns in winter. *Vet. Clin. Food. Anim.* 24:41–54. <https://doi.org/10.1016/j.cvfa.2007.10.006>.
- Patterson, G., P. S. Morley, K. D. Blehm, D. E. Lee, and M. Dunowska. 2005. Efficacy of directed misting application of a peroxygen disinfectant for environmental decontamination of a veterinary hospital. *J. Am. Vet. Med. Assoc.* 227:597–602. <https://doi.org/10.2460/javma.2005.227.597>.
- Quilez, J., C. Sanchez-Acedo, C. Avendano, E. del Cacho, and F. Lopez-Bernard. 2005. Efficacy of two peroxygen based disinfectants for inactivation of *Cryptosporidium parvum* oocysts. *Appl. Environ. Microbiol.* 71:2479–2483. <https://doi.org/10.1128/AEM.71.5.2479-2483.2005>.
- Rushen, J., A. M. de Passillé, M. A. G. von Keyserlingk, and D. M. Weary. 2008. Housing for growing animals. Pages 181–210 in *The Welfare of Cattle*. C. Phillips, ed. Springer, Dordrecht, the Netherlands.
- Svensson, C., K. Lundborg, U. Emanuelson, and S. O. Olsson. 2003. Morbidity in Swedish dairy calves from birth to 90 days of age and individual calf-level risk factors for infectious diseases. *Prev. Vet. Med.* 58:179–197. [https://doi.org/10.1016/S0167-5877\(03\)00046-1](https://doi.org/10.1016/S0167-5877(03)00046-1).
- USDA. 2010. Dairy 2007, heifer calf health and management practices on U.S. dairy operations. USDA-APHIS-VS, CEAH, Fort Collins, CO. Accessed Jul. 1, 2016. https://www.aphis.usda.gov/animal_health/nahms/dairy/downloads/dairy07/Dairy07_ir_CalfHealth.pdf.
- USDA. 2016. Dairy 2014. Dairy cattle management practices in the United States, 2014. USDA-APHIS-VS-CEAH-NAHMS. Fort Collins, CO. Accessed Jul. 1, 2016. https://www.aphis.usda.gov/animal_health/nahms/dairy/downloads/dairy14/Dairy14_dr_PartI.pdf.
- Waltner-Toews, D., S. Martin, and A. Meek. 1986a. Dairy calf management, morbidity and mortality in Ontario Holstein herds. III. Association of management with morbidity. *Prev. Vet. Med.* 4:137–158. [https://doi.org/10.1016/0167-5877\(86\)90019-X](https://doi.org/10.1016/0167-5877(86)90019-X).
- Waltner-Toews, D., S. Martin, and A. Meek. 1986b. Dairy calf management, morbidity and mortality in Ontario Holstein herds. IV. Association of management with mortality. *Prev. Vet. Med.* 4:159–171. [https://doi.org/10.1016/0167-5877\(86\)90020-6](https://doi.org/10.1016/0167-5877(86)90020-6).
- Wathes, C. M., C. Jones, and A. Webster. 1983. Ventilation, air hygiene and animal health. *Vet. Rec.* 113:554–559. <https://doi.org/10.1136/vr.113.24.554>.