Dairy calf health and welfare in automated feeding systems in the upper Midwest USA

A thesis
SUBMITTED TO THE FACULTY OF THE UNIVERSITY OF MINNESOTA
BY

Matthew Whitney Jorgensen

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY

Advisor: Dr. Marcia Endres

August 2016

Acknowledgments

This work represents the culmination of four years of work towards improving American dairy farming and improving the lives of young stock in our dairy systems. My profound thanks are due to a number of people who provided assistance along the way.

To Dr. Marcia Endres, my advisor. This work truly could not have been done without your support – both personal and academic.

To my committee members, Drs. Kevin Janni, Hugh Chester-Jones, and Bradley Heins, for their significant efforts towards my training as an animal scientist.

To Drs. Jeff Rushen, Anne-Marie de Passilé, and Sandra Godden, for their collaboration and advice on study protocols.

To Dr. Amber Adams, for her assistance in study design and data collection over a grueling research period and to Dr. Luis Espejo, for his advice and patience in matters statistical.

To the United States Department of Agriculture National Institute of Food and Agriculture for recognizing the importance of this research and providing financial support.

To the undergraduate student workers who assisted with data entry.

And to my family, particularly my father, who provided the moral and emotional support that got me through this process. You are the foundation on which I continue to grow.

Dedication

This work is dedicated to my mother, the late Dr. Sue Jorgensen, for instilling in me a thirst for knowledge. I wish you were here to share in this success, but know you would be proud.

Abstract

Automated feeding systems are growing in popularity for dairy farms in America, but little is known about how these systems are managed. This study investigated the usage of automated feeders, and the implications of management practices for calf morbidity and mortality. Barn design, environmental and management factors were determined on 38 farms in the upper Midwest USA through a combination of questionnaire and on-farm measurements. These measurements were used to describe the current management practices of farms, identify risk factors for adverse calf health outcomes and calf mortality, and to determine best practices for the use of automated feeders.

Farms using automated feeders range in size from 7-300 calves on site. Natural ventilation was used on 19 (50%) of the farms, followed by barns with mechanical ventilation on 15 farms (39.5%), tunnel ventilated barns (3 farms; 7.9%) or outdoor facilities (sheltered plastic domes; 1 farm, 2.6%). Calves are kept in groups numbering an average of 17.6± 9.8 animals (range: 2-63) with an average space allowance of 4.6±2.0 m^2/animal. Calves in these systems receive an average of 3.67±0.75L (range: 2-6) of colostrum, but (22%) returned serum total protein values less than 5.0. Calves receive a daily allowance of 5.4L±2.1L; range: 3-15L of milk or milk replacer, rising to a peak amount of 8.3L±2.0L (range: 5-15L) over an average of 18 days±11.4d (range: 0-44d). Milk replacer was the most popular liquid diet for calves on automated feeders, and was fed on 26 farms (68.4%) compared to a whole milk supplemented with nutrient balancer on 9 farms (23.7%) and whole milk alone on 3 farms (7.9%). Calves are weaned at an average age of 44.5±6.9 days (range: 32-60) and an average time on the feeder of 39.3±6.3 days (range: 20-59). Calves were completely cut off from the feeder at a mean

56.8±9.0 days of age (range: 40-85.5) and a mean 52.1±7.5 days (range: 40-79) on the feeder. Notably, bacterial contamination of milk is common – the median coliform count was 10,430 cfu/mL (IQR: 233,111; range: 45-28,517,000) and average standard plate count was 2,566,867 cfu/mL (IQR: 15,860,194; range 6,668-82,825,000) in the feeder tube – indicating that cleaning practices need more evaluation.

Calves (n=10,179) were scored for attitude (score of 0-4, where 0=normal), ear (0-4), eye (0-3), and nasal health (0-3), as well as evidence of scouring (cleanliness score of hindquarters; 0-2). Rectal temperatures were taken in calves scoring a 2 or higher in any category and those with a temperature above 39.4°C were categorized as sick (n=550). Associations were determined between farm level variables and health scores to identify risk factors for higher (worse) scores. All scores were significantly associated with season of measurement, with fall and winter seasons increasing the risk of a high health score or sick categorization. High bacterial count measured in the milk or milk replacer was associated with a risk for higher attitude and ear score, and a higher risk of calves being categorized as sick. A higher peak milk allowance was associated with a reduced risk of high cleanliness score, while a longer period of time to reach peak milk allowance was associated with increased risk of a higher attitude, ear, eye and cleanliness scores, as well as categorization as sick. Higher fat content in the liquid diet was associated with an increased risk of high eye score. Less space per calf was associated with higher ear and eye scores, whereas larger group sizes were associated with a small increased risk of higher nasal score and small decreased risk of higher cleanliness score. Rectangular pen shape was associated with a decreased risk of higher eye score. Absence of a positive pressure ventilation tube was associated with an increased risk of a calf being categorized

as sick. These factors could be easily managed to improve health outcomes for dairy calves on automated feeding systems.

Associations were determined between farm level variables and health scores to identify risk factors for higher (worse) scores. All scores were significantly associated with season of measurement, with fall and winter seasons increasing the risk of a high health score or sick categorization. High bacterial levels measured in the milk or milk replacer was associated with a risk for higher attitude and ear score, and a higher risk of calves being categorized as sick. A higher peak milk allowance was associated with a reduced risk of high cleanliness score, while a longer period of time to reach peak milk allowance was associated with increased risk of a higher attitude, ear, eye and cleanliness scores, as well as categorization as sick. Higher fat content in the liquid diet was associated with an increased risk of high eye score. Increased stocking density was associated with higher ear and eye scores, while larger group sizes were associated with a small increased risk of higher nasal score and small decreased risk of higher cleanliness score. Rectangular pen shape was associated with a decreased risk of higher eye score. Absence of a positive pressure ventilation tube was associated with an increased risk of a calf being categorized as sick. These factors could be easily managed to improve health outcomes for dairy calves on automated feeding systems.

Farm records were surveyed for health treatment (26 farms) and mortality (23) on farms using automated feeding systems to raise calves in the upper Midwest USA. Mortality and treatment rates were calculated and relationships determined between these outcomes and farm-level factors collected during farm visits and through management questionnaires. Relationships (least square means estimates) between categorical factors

of interest and mortality rate were calculated using the mixed procedure of SAS. Pearson's correlation was used for continuous variables. Average mortality of calves on farms using automated feeders was 3.85%/year (±3.70%) and 57% of farms (13/23) reported mortality rates below 3%/year. The maximum recorded mortality rate was 13.41%/year and the minimum was 0.24%/year. Farm average serum total protein level of calves was negatively associated with farm annual mortality rate (R= -0.50, *P*=0.02; mean STP=5.4g/dL ±0.74). Farms that disinfect the navels of newborn calves had a lower mean mortality rate (LSM=2.97%, SE=0.80; 78% of farms) than farms that do not disinfect (LSM=7.32%, SE=1.59; *P*=0.03; 22% of farms). Trends were detected in the correlations between mortality rate and bacteria content (standard plate count) of milk gathered from the feeder tube (R=0.37, *P*=0.08; median=435,000 cfu/mL, IQR=4,156,500 cfu/mL) size of the dairy (number of calves on site; R= -0.41, *P*=0.08; mean=82.18 calves ±84.26) and age difference in calf groups (R=0.41, p=0.06; mean=3.07 weeks ±2.03). Farm treatment rate was significantly associated with coliform bacterial content in the feeder tube (R=0.45, *P*=0.02; mean=6.61 ln[cfu/mL] ±4.35) and the age of calves at grouping (R=0.50, *P*=0.01; mean=5.1 days ±3.6), with trends detected for coliform bacterial content of the feeder mixing tank (R=0.37, *P*=0.07; mean=3.54 ln[cfu/mL] ±6.18) and age of weaning (R=0.37, *P*=0.07; mean=57.4 days ±9.6). Seasonal patterns indicated that winter was the season of highest treatment rate. Taken together these outcomes indicate that, while automated feeding systems can achieve mortality rates well below the national average, improvements are needed in fundamental calf care practices like colostrum management and preventing bacterial contamination of the liquid diet.

Overall, these outcomes indicate that automated calf feeding systems can be effectively managed to provide high quality care for preweaned animals. More research is needed to investigate the causal relationships between factors identified in this work with calf health outcomes, particularly focused on encouraging good postnatal practices (colostrum management, navel disinfection), calf grouping strategies (critical ages for grouping, age differences in the group, group size, space allowance), bacterial contamination of the feeder unit and of milk delivered to calves, and strategies for the mitigation of calf health issues resulting from seasonal environmental changes.

Table of Contents

List of Tables

All tables are found in Appendix I

List of Figures

Chapter 1

Literature Review

INTRODUCTION

The calf is a major investment in future production for the dairy farm. Each calf represents significant investment of resources and a major loss in the event of serious morbidity or mortality as costs of raising replacement heifers range from $1200 to $1600 per animal (Karzes, 2005) or approximately $1.40-1.88 per day (Tozer and Heinrichs, 2001; Wolf, 2003),. The majority of calves in North America are housed in traditional, hutch-based systems (Nordlund, 2008; USDA, 2016) which are designed to minimize risk of loss through prevention of calf to calf contact (Callan and Gary, 2002). As a system, individual pens or hutches have been associated with reductions in morbidity and mortality (Waltner-Toews et al. 1986b,c).

Recently farmers have begun to shift away from hutch housing for a variety of reasons. Hutches and individual pens represent an area of high labor input on the farm – proper management of calf hutches requires significant time be spent mixing and delivering milk, as well as cleaning tools and calf areas. When these tasks must be performed in hazardous weather conditions, the burden on farm labor is multiplied (Nordlund, 2008). In addition, increasing public and legal interest in animal welfare is providing pressure for farmers to reassess the benefits of hutches and consider adopting other housing options. Public concern over hutch use stems from several issues inherent to this system, notably that hutches restrict calf movement and inhibit expression of social behavior between animals (Dellmeier et al., 1985). Legislation has followed public pressure, largely eliminating individual housing in Europe (Rushen et al., 2008) with an increasing number of American farmers following suit. Each of these issues provides farmers with reason to shift from outdoor hutches to indoor, group housing and feeding of young animals.

Managing group-housed animals in an efficient manner presents difficulties of its own and interest is increasing in the potential use of certain tools to aid in this task. The automated (computer controlled) calf feeding system is one such tool, increasing in popularity across the United States. Despite growing interest from producers, there is very little research currently available to address the use of automated feeders in American farming systems. Because calves in automated feeding systems have unrestricted access to one another, there is potential for increased morbidity (disease incidence) and mortality (death loss). Further work is needed to examine calf outcomes and current management practices for farms using automated feeding systems, particularly regarding factors like barn and pen design, ventilation, and nutritional programs. Results from this research will guide producers to streamline management and improve the use of automated feeding systems which will contribute to reduced calf morbidity and mortality, enhance dairy productivity and profitability, and improve image of American dairy farms.

This project identified welfare issues presently affecting automated feeding systems on American farms and factors that optimize the use of automated feeders in this American farming context, and described management practices that can help improve the economic viability of automated feeding systems by completing the following four objectives:

Objective 1: Describe housing and management of farms using automated feeder systems;

Objective 2: Document calf welfare (i.e. morbidity, mortality, environmental conditions) in these facilities;

Objective 3: Identify risk factors for morbidity and mortality; and

Objective 4: Identify best management practices for using automated calf feeders to improve animal welfare and dairy farm profitability.

Automated Feeder Function

Automated calf feeding systems are designed to provide milk, reconstituted milk-replacer, or a whole milk and milk-replacer mixture to calves on demand and at a predefined individual level and frequency depending on calf age and farm management preferences. In these systems, group-housed calves are fitted with radio-frequency identification (RFID) tags placed either in the ear or on a collar around the neck. When a calf enters the feeder stall, the machine processor reads the RFID tag, identifies the individual calf, and determines the amount and concentration of liquid to provide before heating, mixing and dispensing the meal to the waiting animal. This function redirects labor away from laborious tasks typically associated with hand mixing milk, delivering individual bottles and washing equipment. Indeed, use of an automated feeding system for feeding group-housed calves has been shown to require less manual labor than in individually-housed calves (Kung et al., 1997; de Passillé et al., 2004; Kack and

Ziemerink 2010) and shifts much of the remaining labor indoors, away from inclement, potentially hazardous conditions.

A major benefit of the hutch system is the ease of observing individual calf health status, feed intake, and water consumption. This trait is lost in the transition to group housing, in which multiple calves are interacting and defecating in the same area and individual issues are more difficult to detect. In addition to mixing and distributing milk, many automated feeding systems monitor calf intake, drinking speed and meal frequency, alerting farmers to any changes in feeding behavior which might indicate that an individual animal is becoming ill (Borderas et al., 2009). The monitoring feature of automated feeders provides farmers with knowledge of individual health status within the calf group, improving the ability to identify and treat each animal on its own. Alongside potential reductions and alterations to labor input, precision features like this are of increasingly interest to dairy farmers in the United States of America.

Group Housing

The traditional recommendation for housing of calves in North America is to keep each animal separate from conspecifics until after weaning on the basis of certain perceived benefits. Individual housing potentially reduces disease transmission between calves by limiting opportunities for physical contact. Observation of individual animals is simplified, as is the identification and treatment of any sick calves. Calf access to food and water is not limited by competition from other animals, ensuring that each animal can fully exploit the resources which it has been allotted. Despite these benefits, individual housing systems present several welfare issues by limiting calf movement and eliminating opportunities for social interaction between calves. The relative benefits and shortcomings of each system have been assessed, but important issues such as disease transmission and relative calf health have not been definitively shown as superior in either individual or group-housed settings with many studies arriving at conflicting results (Rushen et al., 2008).

Calf Health and Mortality

The dairy calf faces many challenges early in life: birth and its associated difficulties, potentially inadequate colostrum delivery, exposure to infectious pathogens from the environment and other animals, and husbandry procedures such as dehorning and tail-docking which add significant stress to an already difficult period. Facing these issues means that dairy calves experience higher morbidity and mortality than any other age group on the farm. Overall, mortality in preweaned dairy heifers is reported to fall somewhere above 6% in the United States (6.3% -Wells et al., 1996; 7.1%-Meyer et al., 2000; 7.8%-USDA, 2007; 8.1%-USDA, 2010). Veal calves raised in similar systems experience 4.2% mortality on average, though this ranges widely from 0-30% in individual farm reports (Stull and McDonough, 1994). Morbidity and mortality are the two most definitive welfare indicators in young calves (Le Neindre, 1993), and their rates are undoubtedly an issue for the industry, both in terms of economic loss and damaged public perception. The theoretical minimization of exposure to many hazardous factors – particularly infectious pathogens – is the primary driver behind currently-popular individual housing systems for raising young dairy animals.

Despite a theoretical decrease in pathogen exposure, it is not definitively clear that individual housing provides a superior environment for growing calves when compared to group-housed systems. Webster et al. (1985a,b) demonstrated a higher mortality rate for calves housed in groups (3.8%) than in individual pens (1.7%) up to 16 weeks of age. A study of veal calves showed that animals housed in groups after 8-10 weeks of age died (3.80%) and were removed due to health issues (6.13%) at a higher rate than those kept individually (3.01% mortality; 4.42% morbidity; Le Neindre, 1993).

Alternatively, more recent studies have shown that calves housed in groups display similar growth patterns (Chua et al., 2002) to, and lower diarrhea levels (Hänninen et al., 2003) than, their individually raised counterparts when the calves are fed and managed in the same way. Epidemiological work has not shown a clear advantage of one housing type over the other (Losinger and Heinrichs, 1997), with no association shown between housing type and chance of infection from important disease-causing organisms such as *Cryptosporidium parvum* (Mohammed et al., 1999), *Salmonella* (Losinger et al., 1995), or *Escherichia coli* (Rugbjerg et al., 2003).

In a large-scale epidemiological study of 1,685 American farms, it was found that housing calves in groups of seven or larger was associated with high levels (>6%) of calf mortality, but that farms with calves kept in groups of six or fewer were no different from those which housed their calves in individual pens (Losinger and Heinrichs, 1997). The problems associated with keeping calves in large groups were also shown in Sweden, where calves kept in larger groups (6-30 animals) displayed more severe diarrhea and double the incidence of respiratory disease when compared to those in smaller groups (3-8 animals) or in individual pens (Svensson et al., 2003). Another Swedish study came to similar conclusions regarding calves in automated feeding systems, with calves in large groups (12-18 animals) showing higher incidence of respiratory disease and lower growth rates than those in small groups (6-9 animals; Svensson and Liberg, 2006). In contrast to these studies, Kung et al. (1997) found lower rates of health problems in calves kept in relatively large groups (12-15 animals) than in those kept individually. The differences in health outcomes observed between group and individual housing systems appear to be more closely linked to important management decisions rather than the actual grouping of animals (Rushen et al., 2008). Because the grouping of preweaned animals is the most significant shift undertaken by farms changing to an automated feeding system, the interaction between group management, environment, and calf health outcomes bears further investigation.

Calving and the Perinatal Period

Because calves are born immunologically naïve, the time immediately following birth represents a period of significant risk for infection. Developing protocols to support calf health should start in the prepartum period, by appropriately separating close-up cows into maternity pens that are not overcrowded (Mee, 2004) and providing adequate monitoring for signs of birth like restlessness, prominent udder distension, and changes in pelvic ligament tone, among others (Mee, 2004). Management of the cow at the time of parturition is also critical, and appropriate monitoring (Duffy, 1981) and birthing assistance (Mee, 2008) can greatly impact birthing success.

Management of the calving area varies between farms, and both the timing and extent of calf exposure to infectious agents range widely. Time in the calving pen impacts both the length of exposure to environmental pathogens and to potential for infection from either the mother or other adult animals housed in the calving pen - the longer the interaction between the calf and mother, the greater the risk of infection (Villarroel et al., 2007; Maunsell & Donovan, 2008), but only a small majority (56.2%) of producers report removing the calf from the dam within six hours of birth (USDA, 2016).

Immediately post birth, it is typically recommended that the umbilical tissue be disinfected, although the efficacy of this practice is somewhat under researched (Mee, 2008). Both iodine and chlorhexidine are common products used in this process, with limited work indicating the superiority of the latter when compared with iodine or no treatment (Waltner-Toews, et al., 1986c).

Colostrum Management

Calves are borne immunologically naïve, with the transfer of maternal antibodies through colostrum providing the majority of protection to calves in the post-natal period. The liquid volume, quality, and timing of colostrum feeding all impact the success of immune transfer between the mother and neonatal calf (Davis & Drackley, 1998). Failure of passive transfer is a major risk factor for both respiratory disease (Van Donkersgoed, 1993; Blom 1982) and diarrhea (Barrington et al., 2002), is associated with increased calf mortality (Wells et al. 1996), and has been linked to production losses once calves mature and enter the milking herd (Faber, 2005). In order to ensure that passive immunity is provided to calves, it is commonly recommended that producers regularly test colostrum quality and calf serum protein to evaluate practices. Despite the critical role that good colostrum management plays in animal health, less than 10 percent of operations (representing 35.3 percent of the heifer calf population) routinely monitor serum protein concentration (USDA, 2016) and almost one fifth of heifer calves do not achieve full immune transfer (USDA, 2010). As in traditional housing scenarios, the appropriate management of colostrum is critical in preventing health issues in group housed calves.

Even when adequate amounts of colostrum are fed, the administration of this first feeding bears risks for newborn animals. Contamination of colostrum, milk, and reconstituted milk replacer diets by pathogenic bacteria is a major risk of infection for young calves, particularly in the stages before immune function is fully established (Lorenz et al., 2011). It is recommended that liquid fed to calves contain a total bacterial load of less than 100,000 colony forming units (cfu)/mL and a fecal coliform load of less than 10,000 cfu/mL (McGuirk and Collins, 2004) to reduce this risk. Conventional pasteurization of colostrum causes several problems, including the denaturing of large proportions of immunoglobulins (Godden et al., 2003), but adapting methods to heat the liquid to a lower temperature for longer periods has shown good outcomes in reducing pathogen load while maintaining adequate IgG activity (McMartin, et al., 2006).

Health Summary

While prevailing calf-raising methods assume that individual housing is superior in terms of calf health and mortality, studies have come to markedly different conclusions depending on many separate factors. The differences in health outcomes observed between group and individual housing systems appear to be more closely linked to important management decisions rather than the actual grouping of animals (Rushen et al., 2008). Cleanliness of housing, feeding method, ventilation, and transfer of passive immunity from cow to calf are all vitally important management factors which affect the success of young animals in *any* system and it is critical to determine how these and other management decisions affect the health of young animals in automated feeding systems.

Feeding

Traditional hutch management systems provide dairy calves a liquid diet equaling about 10% of the animal's bodyweight per day (Thickett et al., 1986), an amount equivalent to approximately half of what would be consumed by calves fed ad libitum (Appleby et al., 2001). This meal is typically delivered twice per day in a bucket or bottle (USDA, 2016), which is a stark contrast to natural bovine feeding patterns. When housed with a cow, calves acquire milk over the course of several, smaller nursing bouts dispersed throughout the day. Young calves housed with cows typically nurse an average of 6.3 times per day, with each bout lasting an average of 8.7 minutes for a total average of 52 minutes of nursing per day, varying slightly depending on calf age and milk production level in the dam (Day et al. 1987). In contrast, calves fed with buckets and even those allowed to nurse from bottles with artificial teats may display reduced meal duration (Jensen, 2003) unless allowed larger volumes per meal (Jung and Lidfors, 2001).

Feeding preweaned dairy calves on a higher plane of nutrition does not appear to negatively impact mammary growth (Daniels et al., 2009), and has been linked to increased expression of mammary DNA (Brown et al., 2005) and increased mammary cell proliferation (Meyer et al., 2006). In the long term, feeding higher amounts of milk has been linked to positive effects on future productivity (Moallem et al., 2010; Soberon et al., 2012). Despite this, the majority of farms continue to provide calves with the restricted diet described above. The disparity between natural feeding and traditional husbandry patterns in frequency and amount of milk delivered to the calf is driven primarily by economic concerns: the amount of milk provided is undoubtedly related to the price of milk, availability of waste milk, or the cost of milk replacer. The frequency of meal delivery in traditional feeding plans is also related to the availability and cost of labor, as well as logistical concerns regarding the mixing, delivering and cleaning of individual buckets/bottles. Producers have also expressed concern that feeding a larger amount of milk has detrimental effects on starter intake – and thus on rumen development and post-weaning performance – as well as contributing to gastrointestinal health issues like diarrhea.

Calves start consuming solid feed at approximately 2 weeks of age (Khan et al., 2008) and the nutrients gained through the consumption of this starter diet is crucial to rumen development (Williams and Frost, 1992). An inverse relationship has been demonstrated between the intake of solid feed and the liquid milk allowance, with calves allowed only limited milk consuming starter at a much higher rate (Raeth-Knight et al., 2009). This relationship means that calves fed higher amounts of milk before weaning may have delayed physical and metabolic development of the rumen, which in turn reduces the intake and digestion of solid feed after weaning (Hill et al., 2010; Sweeny et al., 2010) and has caused some researchers to recommend that calves not be fed high amounts of milk preweaning (Quigley et al. 2006; Hill et al. 2010). Despite this, it is likely that preweaning milk allowance is not the sole factor to impact starter consumption. Solid feed intake at the time of weaning is significantly related to the weaning program itself. Weaning calves on a step-down (gradual) reduction program has been shown to cause significant increases in starter intake, with calves weaned on this method displaying a heavier and more metabolically active forestomach than those calves fed a restricted milk diet throughout (Khan et al., 2007). The volatile fatty acid butyrate plays a crucial role in ruminal development, but other factors likely impact this development as well (Baldwin et al., 2004). Increased energy (Shen et al., 2004), as well as higher amounts of certain growth factors (Blum and Baumrucker, 2002; Blum, 2006) and endocrine factors (Shen et al., 2004) may directly impact rumen epithelial and gastrointestinal development.

The impact of dietary milk allowance on calf health is less clear. Feeding calves a more concentrated milk replacer has been linked to greater morbidity in calves (Quigley et al., 2006), but the authors acknowledged that other factors (calf history, speed of dietary changes) may have played a part in this outcome. A more controlled study has shown that ad libitum feeding decreased the number of days on which calves showed diarrhea (Appleby et al., 2001). A review of milk ration studies concluded that it is safe for calves to consume milk up to 20% of body weight, with higher amounts contributing to increased milk consumption, higher gain of body weight, improved feed efficiency, and reduced disease load, while also providing more opportunity for calves to display natural behaviors (Khan et al., 2010).

Feeding Behavior

Calves are highly motivated to nurse and nursing (sucking) behavior is easily stimulated by the presentation of even small amounts of milk (de Passillé et al., 1992, 1997; de Passillé, 2001). The act of nursing can take up significant time for young animals and the benefits of expressing this behavior are many. Nursing has a calming effect in many young animals, including humans and rats (Blass, 1994) and allowing calves to nurse has been associated with reduced non-nutritive oral activity and a decreased lag between consuming milk and resting (Veissier et al., 2002). The act of sucking is also associated with release of gastrin, cholecystokinin (CCK) and insulin following the meal, which may play a role in satiation and the further reduction of non-nutritive sucking (de Passillé et al., 1993). Furthermore, this behavior is not maintained or reinforced by the continued delivery of milk, but by its own performance (Rushen and de Passillé, 1995), which means that the provision for adequate sucking has significant implications for the establishment and continued presence of negative behaviors like cross-sucking in the calf.

Cross-sucking, a form of non-nutritive sucking directed at conspecific animals, is regarded as an abnormal behavior in dairy calves (Wiepkema et al, 1983) and can cause undesirable and detrimental effects to the health of animals through irritation and infection (Unshelm et al., 1982). This behavior is typically associated with restricted diets or milk delivery processes that provide inadequate opportunity for sucking, such as bucket feeding (Lidfors, 1993). Cross-sucking behavior established in sub-adult stages is also perceived as a long-term concern, as the behavior seems to carry on from the calf barn well into adulthood (Kiel et al., 2001). This issue, alongside its many concomitant negative effects, is a source of concern for many farmers and may discourage the grouping of young animals altogether (Veissier et al., 2002).

Despite fears, it has been shown that group housed animals can be managed in ways which minimize the incidence of cross-sucking behavior. Allowing calves to fully express sucking behaviors on appropriate outlets (e.g. artificial teats) appears to be the ideal means for cross-sucking reduction – teat based feeding systems, such as automated feeders, have been shown to reduce cross-sucking in group-housed calves (Loberg and Lidfors, 2001; Lidfors and Isberg, 2003), while the presence of a dummy teat in the pen reduces the incidence of cross-sucking even when it does not provide milk (de Passillé and Rushen, 2006). Additions to the teat-feeding system, such as a closed feeding station, appear to further reduce displacements and cross-sucking (Weber and Wechsler, 2001) and weaning calves more gradually has been shown to positively impact cross-sucking as well (Nielsen et al., 2008). Calculating and managing a gradual weaning process is laborious, though this effort can be greatly eased through the use of automated feeding systems, which calculate and deliver daily reductions in milk over a set schedule.

Another behavioral concern for some farms is displacement between calves for certain resources, particularly monopolization of the feeder station(s) available in the group pen. The most common set-up for automated feeding systems is to have a single feeder unit servicing two adjacent pens, each with a single station. Manufacturer recommendations for stocking each pen with 25-30 animals means that competition for resources may be high – reduced teat access in these groups increases frequency of competitive behaviors (von Keyserlingk et al., 2004) and may also increase the amount of time each calf spends in the feeding station, to the exclusion of all other calves in the group. Displacements have reportedly been reduced through the feeding of large quantities of milk (Jensen and Holm, 2003; de Paula Vieira et al., 2008); however, these studies were performed with relatively small numbers of calves and the effects of milk allowance on displacements and feeder occupancy are not known for the large groups found on some American farms.

Weaning

Weaning calves off of the liquid diet is an extremely stressful process – during weaning, young animals display marked reductions to weight gain as well as acute behaviors which indicate a stress response (Weary et al., 2008). The weaning process is gradual under natural conditions, but is typically abrupt for dairy calves in productive farms. In addition to reducing cross-sucking, gradual weaning through reduction in volume or concentration of milk has been shown to reduce indicators of stress in these young animals (Budzynska and Weary, 2008; Jasper et al., 2007). As noted above, gradual weaning has also been shown to stimulate intake of starter during the weaning period, contributing significantly to the gastrointestinal development of the calf (Khan et al., 2007). The automated feeding system simplifies the process of gradual weaning and provides farmers with increased flexibility around weaning time – this ability is likely to allow more calves to experience a gradual weaning program.

Feeding Summary

Automated feeding systems provide an opportunity to more closely replicate natural feeding patterns in dairy calves because they replace significant amounts of time-consuming manual labor with a mechanized process for milk mixing, delivery, and cleaning. Calves are able to feed when hungry, which distributes a number of smaller meals throughout the day and more closely mimics natural sucking patterns in which calves receive smaller, more numerous meals.

The need to suck is obviously important for nursing calves, and the versatility of the automated feeder provides many useful tools for managing dietary intake throughout the nursing period. Provision of a liquid diet through a nipple allows calves to suck during and following meals, while versatility in settings for meal size, frequency and concentration allow producers to fine tune the amount of time calves spend in the feeder stalls. Gradual weaning systems reduce the stress of weaning, while also positively impacting abnormal behaviors like cross-sucking that may arise during the weaning process.

While the benefits of automated feeding systems seem evident, more research is needed to address how meal frequency and volume affect calf behavior and health in these systems. Feeder occupancy, waiting and displacement, and cross-sucking are all recognized issues in these systems and should be investigated more thoroughly. The intensive behavioral observations needed to fully investigate these behaviors are logistically impossible in a project of this nature. However, collection of feeder management practices, recorded feeding behavior, and calf health outcomes, in addition to cursory investigation of feeder occupancy while on farm, will provide a clearer picture of how calves are being fed and how this may impact management strategies.

Calf Behavior

The impact of housing type on young calf behavior is a topic that receives considerably less attention in the discussion over effectiveness of different housing systems. It is clear that grouping and regrouping of *adult* animals can be stressful and that the mixing of unfamiliar cows can lead to increased levels of aggressive behavior (Collins et al., 1979) and social stress (Hasegawa et al., 1997), while negatively impacting production traits such as weight (Nakanishi et al., 1991) and feed intake (Nakanishi et al., 1993).

Extension of these studies from the adult experience to that of the calf might seem logical – expectation would be that mixing of calves is likely to negatively impact welfare through increased aggressive interaction and displacements. Elimination of agonistic interaction and competition for resources are perceived benefits of individual housing, and the limitation of contact between calves does prevent these interactions from occurring while calves are still in hutches. This social isolation prevents a certain amount of stress to calves in the short term, but a lack of experience in mixing and socializing with novel pen-mates sets the animals up for future issues when they join heifer groups or the main milking herd.

Aggressive interaction between group-housed calves does occur, but the levels of these behaviors are lower than those observed in adult cows (Veissier et al., 2000) while the frequency of non-agonistic social interaction is higher (Bøe and Færevik, 2003). These characteristics of calf behavior may actually allow young animals housed in groups to develop social behaviors and become accustomed to the processes of grouping and regrouping while the stresses involved are relatively low. Group housed calves sniff, mount and play with other calves more than those raised in individual pens and later mixed (Jensen et al., 1999) and experience fewer agonistic encounters than their individually raised counterparts when animals are grouped at 14 weeks of age (Veissier et al., 1994). Calves raised in individual pens have also been shown to display more fear of novel social situations than those raised in groups (Jensen et al., 1997).

Typically, stress behaviors and agonistic interactions increase during the grouping of unfamiliar calves, but this increase is attenuated in animals with repeated previous experience in the grouping process (Veissier et al., 2000). The influence of this experience is also present in adult cows – those with no previous experience of unfamiliar animals display more negative effects during the grouping process (Sowerby and Polan, 1978) and take longer to form a stable social hierarchy than those that have been more heavily socialized (Kondo and Hurnik, 1990).

Behavior Summary

While the concerns over immediate aggressive interaction between calves may have some foundation, it appears that this behavior is relatively rare in young animals. Furthermore, these incidences may be far outweighed by the long lasting benefits of early socialization. Automated feeding systems, particularly those used on smaller farms, feature a dynamic and relatively constant stream of calves into and out of the feeder pens. This repeated regrouping of animals should provide a very good analog of the upcoming adult experience for calves. Understanding the grouping strategies on different farms – including factors like group size, grouping strategy (dynamic groups vs. all-in all-out stocking) and age of introduction to the group – will give a better understanding of how behavior may affect success within automated feeding systems.

Environment

Although certain management factors are not exclusive to group housed calves, several fundamental aspects of calf management are critical in maintaining the health of calves in grouped situations. Among the most critical factors impacting calf health are those involved in maintaining the calf's environment, including factors such as local pathogen load, thermal conditions, and availability of clean, fresh air. Regardless of calf rearing procedures, infectious disease is a major cause of economic loss on dairy farms.

Preventing the spread of infectious disease between calves is a primary reason for the widespread adoption of individual housing, but continued high national mortality rates indicate that this has not been entirely successful. The majority of calf death losses are caused by two diseases, diarrhea and respiratory infection (Wells et al., 1996; USDA, 2010), which are caused by and influenced by a variety of host, pathogenic, and environmental factors. The majority of pathogens associated with these diseases in neonatal calves are transmitted through direct or indirect contact with infected fecal material (diarrhea) or respiratory secretions (respiratory disease) and are can survive for extended periods even outside of a host animal (Barrington et al., 2002; Callan and Garry, 2002). Potential reservoirs of pathogenic organisms range widely – contact with other animals, housing environment, and management practices all represent potential risk factors for infection.

In both individual and group housing systems, it is vital that the enclosure provides each calf with a clean and dry environment to prevent disease and nurture maximal growth. A poorly designed or managed calf area can increase the chances of infection for calves. Important diseases have been associated with environmental factors, such as the relationship between pneumonia and poor climatic conditions (Kiorpes et al., 1988). In addition to impacting calf health, these outbreaks represent a significant economic toll for producers, through mortality and reduced calf growth performance. The risk of infection and transmission between animals is higher in group pens, yet relatively little work has been conducted with a focus on calves housed indoors.

The pathogen load and air quality of a housing system are impacted by many different factors, including environmental temperature and humidity, bedding traits, and pen and tool cleaning practices. Pathogens are highly transmissible by farm workers, on contaminated clothing (Barrington et al., 2002; Callan and Garry, 2002), and failure to properly clean and disinfect feeding equipment increases the risk of infection for calves (Ames, 1997; Mohammed et al., 1999). As mentioned previously, the diet provided to calves can be a source of infection. Milk or milk replacer that is appropriately processed and stored bears little risk for calves (McGuirk, 2008), but significant issues have been documented in the contamination of milk and colostrum (Butler et al., 2000; Maunsell and Donovan, 2008).

Calf exposure to air within the calf pen is typically constant and chronic, which tends to exaggerate the effects of the airborne contaminants and pathogens that cause diseases in young animals (Webster, 1984). The provision of adequate fresh, clean air to calves is vital and ventilating the barn impacts respiratory health in many ways. Significant proportions of bacteria are removed from the air through ventilation and desiccation (Nordlund, 2008). Although much of the bacteria that remain airborne are non-pathogenic (Wathes et al., 1983), even the presence of these and other microscopic materials in poorly circulated air can present a burden to the calf's respiratory tract. Proper ventilation also helps control humidity within calf areas, allowing the desiccation of pathogens to occur. Humidity above 80% drastically extends the survival time of individual pathogens and overall bacterial density (Webster, 1984). The negative-pressure ventilation systems used successfully in cow barns are not usually effective for calf raising facilities, so alternative ventilation systems are often required. Positive-pressure systems, or a combination of positive and natural ventilation systems (depending on seasonal conditions) have been shown to be effective (Nordlund, 2008). In enclosed barns, cleaning practices such as pressure washing aerosolize bacteria which can compound the risk of infection when ventilation is inadequate (Barrington et al., 2002).

Environmental factors not directly related to pathogen load can also impact calf health, particularly the presence of drafts in the calf housing area (Lundborg et al., 2005). High levels of ammonia have been linked to irritation of the respiratory tract (Kiorpes et al., 1988), with levels for calves recommended to be less than 25 ppm (Martig et al., 1976) although these levels have been limited even further through legislation in some countries (e.g. Sweden; Lundborg et al., 2005).

Maintaining thermal homeostasis is important for calves, and experiencing very low or high temperatures can have a range of effects categorized as thermic stress (Roland et al., 2016). This state of stress, when uncontrolled, can lead to severe health and welfare issues for dairy calves including hyperthermia and heat-stroke, hypothermia and frostbite, and death (Martin et al, 1975b; Olson et al., 1980; Cruz and Naylor et al., 1993). The thermoneutral zone of the dairy calf ranges between 10° and 26°C for newborn calves, expanding to a range of 0°-23°C once the animals reach one month of age (Wathes et al., 1983). Calves are, however, typically housed in facilities without significant thermal controls (e.g. cold barns). The midday air temperature in these facilities can drop to -6.7°C and even lower at night in Northern latitudes (Lago et al., 2006), necessitating additional measures to keep calves healthy. Bedding of various types have been shown effective for housing calves (Panivivat et al., 2004), but deep straw bedding, which allows the calves to nest in cold weather, is among the most effective (Nordlund, 2008).

Environment Summary

Facility design and environmental management are vital elements in the raising of young calves in groups. Automated calf feeders are a new technology for the great majority of American farms, and transitioning from individual stalls or hutches leads to significant experimentation with a wide variety of barn designs and management styles throughout the region. Thus far, there has been relatively little research documenting group housing facilities in the United States and almost none on housing and environmental management for calves on automated feeders.

Rationale and Significance

The health and welfare of animals in agricultural production represent areas of increasing public concern. Consumers and producers alike increasingly realize the impacts of these factors on the efficiency and sustainability of production systems, the quality of food produced, and the social and ethical contracts through which the systems are allowed to exist. As referenced earlier, preweaned calf mortality rates in American farming are currently above 7%, and the processes leading up to these deaths have a very real and substantial impact on animal welfare (Mellor and Stafford 2004). Loss of young animals is economically damaging for farmers directly, through real cost of animal replacement, but may have a greater indirect impact as it reduces overall consumer confidence, satisfaction, and spending on dairy products. Consumer pressure is already affecting change across animal production systems and dairy must keep abreast of shifts in market interests and legislation that may impact the ability to continue operating.

The automated feeding system addresses many of the concerns surrounding the manner in which young calves are raised. Housing in group systems allows for social interaction and locomotory play, while the feeder itself adds flexibility to management and nutritional schemes, while significantly altering farm labor practices. Despite these benefits, neither producers nor consumers will tolerate an increase in already high levels of morbidity and mortality for dairy calves. While automated feeders have been in widespread, successful use in Europe for many years, the great majority of research conducted with these systems has been focused on farming in a European context, with housing and management practices that are not typical of the United States. Despite the lack of research, American farms are increasingly adopting automated feeding systems.

Success with these feeders varies widely and farmers have reported both high levels of success (mortality rates below 5%) and failure (mortality > 20%) which make continued use of the machines both ethically and economically unsustainable. Implementation of automated feeding systems is as varied as the outcomes observed and there is currently no set recommendation for many of the factors which we believe have significant impact on calf health and survivorship. Calf group size and stocking density (Svensson and Liberg, 2003; Rushen et al., 2008) and ventilation of calf facilities (Nordlund, 2007) are reported to impact health and mortality, but even the implementation of these simple, important factors are not clearly known. **Gaining a better understanding of how calves are kept in automated feeding systems, identifying vital factors impacting farms with high morbidity and mortality, and developing best practice management tools for the future will improve implementation of automated feeding systems, reduce**

health and welfare problems for young dairy animals, and help the industry towards meeting consumer expectations for product, and production, quality.

Chapter 2

Housing and management characteristics of dairy calf automated feeding systems in the upper Midwest USA

SUMMARY

The automated feeder is a tool for producers to manage calves in group housing, but little is known about how these feeding systems are being used in the USA. In order to better understand how American producers are operating these systems, barn design, environmental and management factors were determined on 38 farms in the upper Midwest USA through a combination of questionnaire and on-farm measurements. Farms using automated feeders ranged in size from 7-300 calves on site. Natural ventilation was used on 19 (50%) of the farms, followed by barns with mechanical ventilation on 15 farms (39.5%), tunnel ventilated barns (3 farms; 7.9%) or outdoor facilities (sheltered plastic domes; 1 farm, 2.6%). Calves were kept in groups of 17.6± 9.8 animals (range: 5.9-60.5) with an average space allowance of 4.6±2.0 m^2/animal.

Calves in these systems received an average of 3.67±0.75L (range: 2-6) of colostrum, but (22%) had serum total protein values less than 5.0. Calves received a daily allowance of 5.4L±2.1L (range: 3-15L) of milk or milk replacer, rising to a peak amount of 8.3L±2.0L (range: 5-15L) over an average of 18 days±11.4d (range: 0-44d). Milk replacer was the most popular liquid diet for calves on automated feeders, and was fed on 26 farms (68.4%) compared to a whole milk supplemented with nutrient balancer on 9 farms (23.7%) and whole milk alone on 3 farms (7.9%). Calves were weaned at an average age of 44.5±6.9 days (range: 32-60) and an average time on the feeder of 39.3±6.3 days

(range: 20-59). Calves were completely cut off from the feeder at a mean 56.8±9.0 days of age (range: 40-85.5) and a mean 52.1±7.5 days (range: 40-79) on the feeder. Notably, bacterial contamination of milk is common – the median coliform count was 10,430 cfu/mL (IQR: 233,111; range: 45-28,517,000) and average standard plate count was 2,566,867 cfu/mL (IQR: 15,860,194; range 6,668-82,825,000) in the feeder tube.

INTRODUCTION

In the United States dairy calves are most commonly kept in individual housing systems (Nordlund, 2008; USDA 2016). These systems aim to decrease calf-to-calf contact in order to minimize the transmission of pathogens between animals during the vulnerable pre-weaning period (Callan and Gary, 2002) and keeping calves individually has been linked with reduced levels of both morbidity and mortality (Waltner-Toews et al., 1986b,c). However, these systems have been criticized for restricting calf movement and social interaction (Dellmeier et al., 1985) and for increasing the burden placed on farm workers to manage calves in individual crates or hutches (Nordlund, 2008). As a result of concerns for the welfare of animals, legislation and public pressure has largely eliminated individual housing in Europe (Rushen et al., 2008b). In combination with these welfare concerns, the difficulty in sourcing sufficient farm labor to provide adequate calf care has seen many American producers follow this trend toward group housing animals. Concurrent to this trend, the use of computer-controlled calf feeding systems are also increasing in popularity for the benefits that they offer to producers, including the significant reduction in manual calf-care labor (Kung et al., 1997; de Passillé et al., 2004; Kack and Ziemerink, 2010), flexibility in diet administration and weaning, and the increased access to data which support the management of individual animals in a group housed setting.

Many factors affecting calf health have been assessed to determine the functional differences between individual and group-housed facilities, yet these studies have failed to demonstrate a definitive difference between the two housing types (Rushen et al., 2008b). Studies have shown that calves housed individually have lower mortality (Webster et al., 1985a) and morbidity (Le Neindre, 1993) than those housed in groups, whereas other work has shown health advantages to group housing (Hänninen et al., 2003) or no difference between the two (Losinger and Heinrichs, 1997; Chua et al., 2002; Hänninen et al, 2003)There has been some indication that calves housed in larger groups may be at increased risk for adverse health and mortality outcomes (Svensson et al., 2003; Svensson and Liberg, 2006). The disparate results of these studies likely indicate that the relative success of a housing system is more closely related to management decisions than the grouping of animals themselves (Rushen et al., 2008b). Unfortunately, as has been noted in other work (Lundborg et al., 2005), the amount of information related to the management of group housed systems is surprisingly sparse.

Because group-housing and automated feeding management continue to grow in popularity in the United States, and particularly in the upper Midwest, it is critical that the practices being used with these systems be documented. The aim of this study was to describe housing and management practices employed by producers using automated feeding systems in the upper Midwest US region.

MATERIALS AND METHODS

Facilities and Study Area

At the start of the study, 64 dairy facilities were identified as using automated feeding systems in the study area (Minnesota, Wisconsin and NW Iowa) for some or all of the preweaning period. From this pool, 38 farms were randomly selected as a representative sample. Each farm was visited up to a total of 8 times each, with visits occurring once every two months (repeated cross-sectional measurements) between November 2012 and May 2014. Reported farm size varied widely, with producers reporting a calf population range of 7-300 (median 45 calves) animals on site at any given time. When on the automated feeding system, calves were kept in group pens which were generally indoors.

Data Collection

Data were collected through a combination of on farm measurement, farmer records, and questionnaire. Upon enrollment in the study, farmers were requested to maintain records of health treatments and mortality events alongside demographic data for calf birth date. The majority of management practices were gathered via questionnaire (appendix i), which was administered by study personnel during farm visits or were left on farm and returned by mail. The questionnaire comprised 63 questions covering practices from calving through weaning. Feeding management (liquid diet allowance, timing, and weaning pattern) and automated feeder cleaning data was supplemented by information gathered from the machine itself.

On farm measurements, including housing and environmental factors, were taken in the calf pens at the time of each visit. Static housing characteristics were measured at the first farm visit and any changes were noted thereafter. These included factors of barn layout, ventilation and pen characteristics. Environmental measurements were taken within 2 calf pens on smaller farms (4 or fewer total pens; 33 farms) or in 3 pens (farms with 5 or more total pens; 5 farms). Thermal environment of the calves was assessed using temperature-humidity loggers (Hobo A23 Pro Series, Hobo, Bourne, MA) which were installed in a central location within each calf barn at the first visit. These loggers recorded temperature and humidity hourly throughout the study period. Air ammonia concentration was measured using a portable NH_3 meter (Dräger Pac®7000, Dräger Safety Inc., Pittsburgh, PA) for the entirety of each visit.

Bedding characteristics were also assessed at each visit. Assessments included bedding type, depth, and area. Bedding wetness was scored at four locations within each pen on a 0-4 scale (0=dry; 4=very wet; Canadian Dairy Research Portal, 2011).

Up to 12 samples of blood from clinically normal calves between 1-5 days of age were collected at each visit. These samples were centrifuged and the serum from each sample was analyzed using a hand-held light refractometer (model HR-200 ATC, AFAB Enterprises, Eustis, FL). Milk samples for bacterial analysis were gathered quarterly at each farm from the mixing tank (mixer) and from the tubing immediately anterior to the nipple from which the calves nurse (tube-end). Milk samples were also gathered twice (in summer and winter) for component (fat, protein, solids) analysis. Samples were immediate placed on ice and frozen. All bacterial samples were analyzed using a standard plate count for total bacterial content and for coliform bacteria at the University of

Minnesota Veterinary Diagnostic Laboratory (Saint Paul, MN). Component analysis was conducted by AgSource Laboratories (Marshfield, WI).

Data Analysis

Questionnaires were examined for irregular answers, and any sections that were clearly misunderstood were excluded from 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), and Pearson's correlation (PROC CORR) was used to evaluate relationships between bacterial counts and cleaning practices (significance at $P<0.05$).

RESULTS AND DISCUSSION

Response Rates

Of 38 focal farms, 36 submitted answers to at least some questions on the questionnaire. The majority of questions (89.5%) were answered, but this proportion rises (92.4%) when management factors that are not conducted on all farms (e.g bull calf castration and pain management) are removed. Because some management practices were measured in person, these factors are fully representative of the farms on this study.

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 (range 60-3,000) cows and all farms had a median of 45 (range 7-300) calves. The 3 facilities custom raising calves for another dairy had a median of 60 calves (range 24-62). According to standards developed by the USDA (2010), most farms on this study fell into the large (11 study farms; >500 cows) and medium (19 study farms; 100-499 animals) categories. A lesser proportion of farms would be categorized as small (3 farms; <100 cows) and custom calf raisers (3 farms), while 2 farms did not respond to the questionnaire and could not be categorized. The majority of farms (61.1%) kept only Holstein cattle, with the remainder keeping a mix of Holsteins and cross-bred animals (33.3%) or Holsteins and Jerseys (5.5%).

Calving Practices

Cows were group housed in 81.8% of maternity pens, meaning that calves were only restricted from contact with adult animals in 18.2% of farms. A small minority of farms (11.8%) housed sick adult animals in the calving pen. Producers reported that maternity pens were fully protected from the elements in 70.6% of facilities, whereas at least one side of the maternity pen was exposed in the remaining 29.4%. All but one farm reported using bedding in the maternity pen at a median 22.9 cm (IQR: 22.9 cm), and this bedding was removed and replaced a median 20.8 times per year (IQR: 40). A single farm reported not bedding the maternity pen, while scraping the area twice daily (730 times per year). Only 18.2% of farms reported using a chemical disinfectant at the time of cleaning.

On a national basis, multiple animal calving pens are the most common across all farm sizes (USDA, 2016). It has been shown that 58.7%±1.8 of all producers using pens of this type, although this proportion rises for medium (69.1% ±2.7) and large (77.1% ±2.0) farms to levels which are largely comparable to those observed in the present study.

Group housing of cows during the perinatal period has potential benefits for the cow, by reducing the number of moves between pens, preserving the stability of the social group, and encouraging higher feed intake (Cook and Nordlund, 2004) while impacting labor efficiency and cow monitoring for producers (Bewley et al., 2001). Despite these benefits, group housing of cows in the perinatal period presents significant risks for the neonatal calf, particularly through pathogen exposure from the cows and their fecal material (Bewley et al., 2001). Calf birth in a multiple-animal maternity pen also increases the risk of enteric (Garber et al., 1994) and respiratory (Lundborg, 2004) disease. Group maternity pens are also associated with lower concentrations of plasma immunoglobulin (Cook and Nordlund, 2004; Michanek and Ventorp, 1993), which leaves the calf less protected from the pathogens present in the calving area. The significance of risks posed to the neonate by housing multiple cows in the maternity pen has led to the recommendation that individual maternity pens be used whenever possible (Mee, 2008).

While monitoring of the calving area is critical to providing good care for the neonate, excessive human presence around the maternity pen is associated with an increase in dystocia and assisted births, and it is recommended that the area only be checked 4-8 times per day (every 3-6 hours from the onset of stage one of calving; Dufty, 1981). 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 an average of 13.2±10.7 times per day (or once every 1.8 hours). Although stillbirth records were not available, the relatively high level of calving supervision may be problematic for cows and calves on farms using automated feeders. Further, observation cameras (which limit the human presence in the calving area) were in use on just 14.7% of farms, with the remainder not using any special tools to monitor the calving area.

The birth process can be traumatic for calves, particularly following a prolonged or assisted birth (Mee, 1991; Schuijt and Taverne, 1994). Detection of issues such as respiratory-metabolic acidosis, or other issues causing low vigor, can be detected through the testing of calf reflexes, head-righting behavior, and the time taken to achieve key postures such as sternal recumbence or standing (Mee, 1991; Schuijt and Taverne, 1994; Szenci, 2003). After birth, 61.8% of farms in the present study reported using special techniques to stimulate weak calves, although only 40.6% of farms had a standard operating procedure for assessing calf vigor. Most farms (76.5%) left the calf to be cleaned and dried by the mother, 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 farms (28 of 36 farms reporting), with iodine treatment by far the most popular disinfectant and used on 92.9% of farms that performed umbilical disinfection. Of the remaining farms, 1 used a chlorohexidine product whereas the other used isopropyl alcohol. Despite its popularity, umbilical cord care is not well researched; however, umbilical disinfection is generally regarded as drying out the umbilical tissue which further prevents infection (Quigley et al., 1996). It has been shown that the risk of mortality was lower in calves treated with chlorohexidine than those treated with iodine or not treated (Waltner-Toews et al., 1986c). Future restriction in producer access to iodine (Mee, 2008) may shift usage toward treatment with chlorohexidine or other products.

Separating the cow and calf immediately after birth minimizes the impact of postnatal bonding, and 24.2% of farms report separating the animals within an hour of parturition (rising to 56.2% removal up to 6 hours; USDA 2016). In the present study the maximum length of time a calf was allowed to stay with the mother was 24 hours, although this occurred on only 4 farms. In the remainder of facilities, calves were removed after an average of 1.7 hours (range: 0-6 hours), which is broadly comparable to the length of time to separation observed nationally.

Colostrum Management

Colostrum management is generally regarded as being one of the most important factors impacting dairy calf morbidity and mortality, regardless of housing system (Godden, 2008). Automated feeder farms in the current study reported delivering an average of 3.67±0.75L (range: 2-6) of colostrum in the first feeding after birth, with the primary delivery method being bottle feeding (16/34 farms responding; 47.1%), followed by esophageal tubing (14 farms; 41.2%) and a minority (3 farms; 8.8%) allowing calves to suck from the dam or allowing suckling and using a bottle (1 farm; 2.9%).

Colostrum management on farms using automated feeders appears to differ from the general dairy population in some key areas. The amount of colostrum fed to calves on automated feeder farms in the current study was higher than reported nationally for the United States – 68.6% of farms reported delivering a first feeding of colostrum with a volume of 4L, compared to just 21.8% feeding a similar amount nationally (representing 42% of heifer calves; USDA 2016). The relatively high reported amount of colostrum delivered in the first feeding mirrors recommendations for colostrum management techniques which support short term health and long term productivity (Morin et al., 1997; Faber et al., 2005).

The method of delivering the colostrum also differed between automated farms and the typical American dairy, with both esophageal tubing of colostrum and allowing the calf to suckle from the dam being used by a much higher proportion of operations than has been reported nationally (tubing: 8.1%, nursing: 6.3%; USDA 2016). The method of colostrum feeding can impact immune transfer in calves, with bottle feeding and esophageal tubing both typically achieving acceptable results (Adams et al., 1985; Kaske et al., 2005). Failure of passive transfer is more common in calves that receive colostrum from suckling the dam (Besser et al., 1991), so the relatively high proportion of automated feeder farms relying on this method indicates an area that may yet be improved. Method of feeding colostrum was not related to farm size in the present study.

The great majority of farms (97.1%) used colostrum only from the first milking after birth, although the provenance of this colostrum varied. Fresh colostrum from the mother only was the primary colostrum source on 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 farms. Fresh individual colostrum is also the most popular source nationally (used on 88.6% of operations) while pooled colostrum is less popular on automated feeder farms than the wider USA (16.4% of operations USDA, 2016). Pooling colostrum is typically not recommended, as it may have a diluting effect on overall colostrum quality (Weaver et al., 2000)

Using tools (i.e. colostrometer, refractometer) is regarded as being generally effective in assessing colostrum quality (Pritchett et al., 1994), but these tools were used to measure colostrum quality on only 35.3% of farms, while 52.9% 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 farms. Despite its reported popularity, relying on visual evaluation of colostrum is not regarded as a reliable method of evaluating colostrum quality (Maunsell et al., 1999).

Measurement of serum total protein (STP) using light refractometry has been shown to have good correlation (R^2=0.72) with serum concentration of IgG and is a useful tool for gauging immune transfer at a group or herd level (Godden, 2008). Serum protein samples should be collected from calves at 1-7 days of age on a minimum of 12 calves (McGuirk and Collins) with concentration endpoints of 5.0-5.2 g/dL representing the most accurate estimates of adequate immune transfer (Calloway et al., 2002, Weaver et al., 2000). Only 8.8% of farms reported testing for serum total protein (STP) on every calf as a method of monitoring the success of immune transfer, although this testing rate is higher than the rate reported nationally (2.1%; USDA 2010). STP testing was used as a tool occasionally or in the case of an issue on 52.9% of farms and was not used at all on the remaining 38.2%.

Recommendations typically set minimum successful passive transfer at STP levels of 5.0-5.2 g/dL (Weaver et al., 2000; Calloway et al., 2002). A total of 925 calves were sampled on 35 farms for STP analysis, with an overall average of 5.44± 0.72 g/dL. Of the calves sampled, 205 (22%) returned STP values less than 5.0, while 311 (33.6%) were below 5.2 g/dL. By farm average STP was 5.44 g/dL±0.39, but 5 farms (14.3%) averaged below

5.0 and 9 farms (25.7%) averaged below 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 displayed IgG levels indicative of insufficient passive transfer (USDA 2010).

The importance of colostrum management is indisputable, but establishment of a resilient immune system is likely to be even more important when group housing dairy calves. Overall, operations using automated feeding systems appeared to be following only 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

In shifting from other systems, 23 farms (60.5%) retrofitted existing structures that had previously housed older animals, with the remaining 15 (39.5%) building completely new facilities to house calves and the automated feeding system. Natural ventilation (barns featuring adjustable curtain walls on at least one side) was the most popular type for housing calves, used on 19 (50%) of the farms, followed by barns with mechanical ventilation (solid wall structures featuring one or more exhaust fans) which was used on 15 farms (39.5%). A smaller proportion of facilities were built into tunnel ventilated barns (3 farms; 7.9%) or outdoor facilities (sheltered plastic domes; 1 farm, 2.6%).

Proper ventilation is an important factor in controlling the airborne pathogen load, and thus the incidence of respiratory disease, in calf facilities. Natural ventilation and negative pressure ventilation are popular systems used in the housing of adult animals but, because of the need to balance the intake of clean air with the need to prevent drafts, are very difficult to apply year round in a calf facility – because of this, it is often recommended that calf facilities feature at least some positive pressure ventilation in order to provide clean, fresh air to calves year-round (Nordlund, 2008). These recommendations were well reflected across automated feeder farms regardless of barn type, with positive pressure tube ventilation in use on 33 farms (86.8%) compared to 5 farms (13.2%) without it. It should be noted that, while 32 (97%) of the facilities using ventilation tubes were delivering fresh air from outside of the barn, 1 (3%) tube ventilation system was recirculating air from inside the calf area. When categorized by new vs. retrofitted construction preferences for ventilation type was more marked. A higher proportion of retrofitted calf housing featured solid walls and mechanical ventilation systems (13 farms; 56.5%) than curtain-walled, naturally ventilated systems (7 farms; 30.4%). All of the tunnel ventilated barns were retrofits and 2 of the 3 also held older animals in addition to preweaned calves.

High levels of environmental ammonia are linked to irritation of the respiratory tract (Kiorpes et al., 1988) with ideal levels below an upper limit of 25 ppm. Only 1 operation (2.6% of total) exceeded these recommended ammonia levels, with ammonia largely undetected and never exceeded 25 ppm on the remaining 37 (97.4%) farms. Light varied between farms, but lighting conditions never limited the visibility of animals.

Calves have a thermoneutral zone between 0-23°C and environmental temperatures outside this range can have marked effects on calf growth, behavior, and welfare (Silanikove, 2000). Exposure to extreme conditions causes thermic stress, a state which increases morbidity and mortality, lowers rate of weight gain, and negatively impacts performance and long term survival (Virtala et al., 1996; Donovan et al., 1998; Snowder et al., 2006). Cold stress has also been linked to a reduced rate of colostrum absorption in newborn calves (Olson et al., 1980). 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.

Table 1 contains the daily average, minimum and maximum recorded temperatures on all farms categorized by calendar season. Seasons were defined from the onset of study to December 20, 2012 (Fall 1), December 21, 2012-March 20, 2013 (Winter 1), March 21, 2013-June 20, 2013 (Spring 1), June 21, 2013-September 20, 2013 (Summer 1), September 21, 2013-December 20, 2013 (Fall 2), December 21, 2013-March 20,2014 (Winter 2), and March 21-May 20, 2014 (Spring 2).. Daily mean temperatures (DMT; the average of all temperature readings in a 24 hour period) were below 0° C during both Winter 1 (-0.85° ±4.07) and Winter 2 (-3.28° ±4.96), while daily mean minimum temperatures fell below zero during Fall 1 (-1.30° ± 2.33), Winter 1 (-4.76° ±5.85) and Winter 2 (-7.68° ±6.69). DMT was over 23° during Summer 1 (26.89° ±1.55). When comparing temperature by ventilation type (Table 2), only tunnel ventilated barns never experienced a seasonal average DMT that fell below 0°, while no ventilation type experienced a seasonal average DMT above 23°.

Farms temperatures regularly fell outside of the thermoneutral zone of calves (0-23°C; Wathes et al., 1983) – across farms, the DMT fell below this range 127±56.7 days and above this range 35.4±10.0 days. Across all facilities, farms recorded a DMT outside the thermoneutral zone on 34% ±10.4 of days measured during the study. The peak daily temperature was above the thermoneutral zone 36.7%±6.7 of the time and the low daily temperature was outside this zone 38.5%±13.6 of the time. The DMT was outside the thermoneutral zone in mechanically ventilated barns 30.2%±10.4 of the time, compared to 39.7%±5.1 in naturally ventilated barns, 15.1%±7.1 of tunnel ventilated barns and 39.0 in outdoor igloos (single farm). Farms using tube ventilation had a DMT outside the thermoneutral zone 34.5%±10.0 of the time, compared to 31.9%±14.6 in farms without a ventilation tube.

Bedding and Pen Cleaning

Although temperatures regularly fall outside of the calf's critical temperature, bedding can provide a mechanism to support thermoregulation (Panivivat et al., 2004; Nordlund, 2008). Indeed, if bedding is of an appropriate type and depth, the presence of this substrate can effectively widen the critical temperature range for animals in that facility (Webster, 1984). Pens in this study typically featured a bedding substrate of some type, although this was not always the case. Straw was the most common bedding material, used in 435 of the 558 pens (78%) in which bedding characteristics were measured. Other bedding materials included cornstalks (68 pens; 12.2%), wood shavings (29 pens; 5.2%), soybean straw (8 pens; 1.4%), and sand (3 pens; 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 (15 pens; 2.7%). Bedding depth was 16.3 (± 7.1) cm, and ranged from 2.5 cm 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.

Wetness of bedding can impact the effectiveness of the substrate as a tool for thermoregulation, but excessively wet bedding did not appear to be a major issue on automated feeder farms. Bedding wetness was tested in 547 pens (2,188 individual tests at 4 per pen). The great majority of 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 0-4.2) of a possible maximum of 16 per pen (4 measurements with a maximum value of 4 each).

The calf pen may act as a chronic vector for infectious pathogens, so practices which minimize this impact are critical to maintaining calf health (Maunsell and Donovan, 2002). In addition to impacting the thermal environment of the calf, the regular addition of clean, dry bedding has been reported as an effective method for separating calves from enteric pathogens on the pen floor (McGuirk, 2008) and has been shown to reduce risk of infection (Mohammed et al., 1999). Producers reported changing the bedding in automated feeder pens 1.2±1.0 times per month.

The cleaning and disinfecting of pens between calf groups is also recommended as a management practice to maintain biosecurity and disrupt disease cycles (Maunsell and Donovan, 2008) and disinfecting the floor of the calf pen has been shown to reduce the risk of infection by, and shedding of, pathogenic agents (Hamnes et al., 2006; Castro-Hermida et al., 2006). Despite the availability and efficacy of multiple sanitizing agents (Quilez, et al., 2005; Omidbakhsh and Sattar, 2006; Patterson et al., 2005), just 55.6% of operations reported the regular washing and disinfecting of the pens between groups and 44.4% did not perform any sanitation at this stage.

Insects

Dairy farms provide environments which encourage the existence of fly populations (Schmidtmann, 1991). These fly species may compromise sanitation efforts, and provide an annoyance and health risk to animals (Bruce and Decker, 1947), and can act as a vector for pathogenic organisms like *Cryptosporidium parvum* (Graczyk et al., 1999). Insect pests were reported as an issue in the group housing area on 58.3% of farms, compared to 41.7% without major pest issues. Insecticide spray was used to control fly populations on 67.6% of farms, whereas 27.3% of producers used a feed product with larvicide as an ingredient. Non-chemical pest control measures were reported on 41.9% of farms.

Calf Grouping

The majority of farms reported that calves were kept individually for a short period following birth in order for calves to develop the physical and immunological capacity to cope with group housing; only 9 farms (25.7%) on the present study reported grouping calves at 1 day of age or earlier. Calf age at grouping was 5.1±3.9 days, ranging from 0-14 days. 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). Observation of calves in semi-natural scenarios indicates that they are likely to be behaviorally best prepared for life in a group setting at around 2 weeks of age (Vitale et al., 1986; Le Neindre, 1989; Woodgush et al., 1984). These behavioral developments include interacting with novel adult animals and moving with the herd, which are not requirements for calves on automated feeding systems. If calves have a well-established immune system and are strong enough to gain regular access to critical resources in a group setting, the waiting for 14 days may not be necessary. More research is required to determine how the age at introduction to group housing impacts calf health and welfare.

Previous studies have found that group size (animals per pen) has a significant effect on calf health and performance, although the exact relationship is not necessarily clear. It has been shown that keeping calves in larger groups is associated with a generally detrimental impact on health outcomes and mortality (Losinger and Heinrichs, 1997; Svensson et al., 2003). The group size measured on farms in the present study was 17.6± 9.8 animals (range 5.9-60.5). On the management questionnaire, producers reported an ideal group size of 19.9±9.4 animals per pen and a maximum tolerable group size of 26.2±11.6 animals. Producer perceptions towards group size are driven by a number of factors, such as balance between calf health, space, and economic concerns as well as expectations set by the machine manufacturers. With the average stocking density measured on these farms being lower than the limits reported by producers and manufacturers, it appears that automated feeding system operators are careful not to exceed these upper limits.

The size of pens within these facilities ranged from 15.5 m^2 all the way to 237 m^2, although these sizes represent the extremes. The farm with the largest pen size also had the largest average group size (60.5 calves), although again this size was not typical. The per-farm pen size for group housed calves was 71±36 m^2. Pen size is intuitively related to the number of calves being housed, although this is not always the case. Pen space allowed per calf was 4.6±2.0 m^2. The minimum space allowed per calf was just 1.6 m^2, whereas the maximum was 11.9 m^2. Stocking density in a given space was a significant factor impacting the pathogen load in calf facilities (Nardell et al., 1991; Wathes et al., 1983) and a lower stocking density has been shown to reduce respiratory infection (Bach et al., 2008). An association has also been found between stocking density and calf diarrhea (Bendali et al., 1999). Because overstocking is detrimental to calf health, it is often recommended that calves be allowed a minimum amount of space of 2.3-2.8 m^2 (FASS, 2010) and this minimum limit was met in 93.1% of pens in the current study.

Older calves are a known source of infection for younger animals (Radostits et al., 1994), and minimizing the age difference between calves in a group is likely to magnify the health benefits of keeping calves in smaller groups. The age difference between the oldest and youngest animals in a pen was 3.1± 2.0 weeks, and ranged from 0.3-10 weeks. Weaned and unweaned animals were kept together in the same pen on 61.1% of farms, whereas 38.9% of producers removed animals on the day of weaning. The fact that almost twice as many farms are keeping weaned calves with unweaned calves is a source of concern.

Although the measurements taken represent a static example of calf group size, in reality group sizes tend to be significantly more dynamic with calves continually joining and leaving the group upon reaching certain age limits. Only 17.6% of producers utilized an all-in/all-out stocking system in which calf groups are relatively static once the pen has been filled. Much more common (82.4% of farms) was a dynamic grouping system in which calves are added and removed from the automated feeder as individuals or in small groups. These continuous flow systems effectively increase the group size that a calf is exposed to during the preweaning period and are likely to increase the risk of infection from other group members. All-in/all-out systems are recommended for their ability to reduce this exposure and to allow producers to fully clean and sanitize calf areas between groups (Wells et al., 2002) but because of farm size and economic considerations are yet to become common on automated feeder systems.

Feeding Plans

Most dairy calves receive a limited liquid diet over the course of the preweaning period, equivalent to approximately 10% of body weight until they reach an age of 4-10 weeks (Rushen et al., 2008a). This amount is significantly less than calves would consume if fed ad libitum, and tests with unlimited systems have shown calves drinking almost double the amount fed to conventionally raised animals (Jasper and Weary, 2002; Hepola, 2003). Allowance of a larger amount of milk has been shown to significantly improve preweaning growth rate (Khan et al., 2007; Huuskonen and Khalili, 2008), feed efficiency (Diaz et al., 2001) and a continued weight advantage in the post-weaning period (Jasper and Weary, 2002). Longer term observation has indicated that calves fed on a higher plane of nutrition may improve lactation once that animal reaches adulthood (Drackley et al., 2007; Soberon et al., 2012).

A common concern among producers is that feeding a larger amount of milk can negatively impact calf health, particularly by causing or lengthening episodes of diarrhea (Quigley et al., 2006). The majority of studies show that the incidence of diarrhea is not increased when feeding more milk (Jasper and Weary, 2002; Chua et al., 2002) and in some cases is even reduced (Khan et al., 2007), whereas feeding a higher plane of nutrition has positive impacts on immune function (Ballou, 2012). Reluctance of traditional calf raisers to adopt a practice of feeding more milk may also be related to labor costs or time, as it would require the delivery of more feedings per day.

The capability of automated feeding systems to deliver more milk, and more feedings, to calves is reflected in the relatively high milk allowances observed on the majority of farms in the present study. When introduced to the automated feeder, calves were started at a daily allowance (Figure 1) of 5.4±2.1L (range 3-15L) of milk or milk replacer. This rose to a peak amount of 8.3±2.0L (range 5-15L). It took 18±11.4 days (range 0-44d) for calves to reach the peak milk allowance. Milk replacer was the most popular liquid diet for calves on automated feeders, and was fed on 26 farms (68.4%) compared to a whole milk supplemented with nutrient balancer on 9 farms (23.7%) and a whole milk alone on 3 farms (7.9%).

While the amount of milk being fed is higher than in most traditional systems, there is some concern that the diets being delivered to calves are not mixed precisely to operator 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. Fat content of the liquid diet was 2.8%±0.7 (range 1.2-4.0), protein content was 3.3%±0.7 (range 1.9-5.1), and total solids were 12.2% (±1.9; range 11.1-18.0; n=73). For only those farms using milk replacer, fat content was 2.4%±0.5 (range 1.2-3.7), protein was 3.1%±0.7 (range 1.9-5.1), and total solids were 12.0%±2.2 (range 7.0-18). Farms feeding supplemented whole milk had fat content of 3.4%±0.6 (range 1.7-4.0), protein of 3.8%±0.4 (range 3.2-4.6), and total solids of 12.8%±1.1 (range 10.3-14.3). Farms using whole milk alone had fat content of 3.5%±0.3

(range 3.0-3.9), protein of 3.4%±0.3 (range 3.0-3.9), and total solids of 12.0%±0.5 (range 11.0-12.6). 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, 29 farms (76.3%) fed a medicated liquid diet with just 9 (23.7%) feeding a non-medicated diet. Feeding of a medicated liquid diet was more prevalent on farms feeding milk replacer, being used by 26 (89.7%) of these farms, when compared to just 3 (33.3%) of farms feeding a supplemented or non-supplemented whole milk.

When weaning calves that have been fed large amounts of milk, there is concern for reduction in the intake of solid feed during the pre-weaning period (Khalili et al., 1992) and weight loss once milk has been discontinued (Budzynska and Weary 2008; Jasper et al., 2008), effects which may reduce the growth benefits of accelerated feeding programs (Huuskonen and Khalili, 2008). Abrupt weaning of calves can also stimulate unwanted behaviors like cross-sucking (Nielsen et al., 2008). It has been shown that gradually weaning calves can mitigate many of these negative effects (Khan et al., 2007) with a weaning period of 10 days appearing to be most effective (Sweeney et al., 2010). While traditional systems make managing a gradual weaning program difficult, the process is relatively simple to administer in automated feeders. This was reflected in the generally gradual weaning period in farms on the study, which lasted 12.9±7.7 days (range 3-42) from first reduction to complete removal from a liquid diet.

Age at weaning also impacts performance, and it is sometimes recommended that calves be weaned early in order to save time, labor, and cost of feed (Owen and Larson, 1982), although it has been shown that calves which start weaning very early (19 days of age) may be unable to compensate for growth deficiencies with increased starter intake (Sweeney et al., 2010). The average age of weaning in the US is 58.8 days (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±6.9 days of age (range 32-60) and time on the feeder of 39.3±6.3 days (range 20-59). Calves were completely cut off from the feeder at 56.8±9.0 days of age (range 40-85.5) and 52.1±7.5 days (range 40-79) on the feeder.

Feeder Cleaning Management and Bacterial Contamination

Many of the important pathogens affecting dairy calves can survive in milk and, indeed, the intake of contaminated milk can be a major source of infection for dairy calves (Lorenz et al., 2011). Both milk replacer and pasteurized whole milk carry a relatively small risk for contamination when storage, delivery, and feeding are well managed, but contamination of feeding tools is possible and presents a risk to calves in any housing system (McGuirk, 2008). Automated feeders are designed with certain cleaning tools and procedures integrated into the system, but there is not significant research determining the effectiveness of these procedures. In addition to this, some cleaning procedures require the operator to manually initiate the process on the feeder controller, a fact which is often not known by operators at the time of installation. It is recommended that bacterial contamination of milk fed to calves be limited to a maximum of 100,000 colony forming units (cfu)/mL in standard plate counts (SPC) and to 15,000 cfu/mL for coliform bacteria (McGuirk and Collins, 2004).

Farm average bacterial counts were calculated from up to 5 samples per farm from both the automated feeder's mixing tank and from the tube end just before the nipple. The median for coliform count was 10,430 cfu/mL (IQR 233,111; range 45-28,517,000) in the feeder tube and 336 cfu/mL (IQR 28,689; range 0-25,621,330) in the mixing jar. The median for average standard plate count (SPC) was 2,566,867 cfu/mL (IQR 15,860,194; range 6,668-82,825,000) in the feeder tube and 166,916 (IQR 2,066,782; range 125-59,396,100) in the mixing jar. When comparing the best and worst performing farms (Table 3) the differences in bacterial count between median and IQR of the top ten and bottom ten performing farms is 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 which meets recommendations for safe consumption.

It is possible that farm operators were not aware about the contamination of the liquid diet. A minority of 28.1% of farms (9 of the 32 farms responding to this question) reported ever using a bacterial analysis to monitor automated feeder sanitation, 37.5% (12 farms) did not monitor sanitation, and 31.3% (10 farms) reported using only a visual assessment to monitor sanitation. Visual observation is unlikely to give a good measure of bacterial contamination and other assessment and monitoring procedures (both type and schedule) should be investigated.

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 per day (range 1-4). Producers reported performing the circuit cleaning function (an automated cleaning of machine tubing that must be manually initiated) 3.4±3.6 times per week (range 0-14) with 11.4% of farms (4 of the 35 farms responding to this question) never running this function. Farmers reported changing and sanitizing the nipples from which the calves nurse 6.1±4.0 times per week (range 0.2-14). The tubes leading from the mixing unit to the nipple were manually cleaned 1.9±3.1 times per week (range 0-14), with 36.4% (12 of the 33 farms responding to this question) never cleaning the tubes. These tubes were replaced 19.3±23.0 times per year (range 1-104).

Unsurprisingly, significant relationships were detected between many of the milk sample bacterial counts, with contamination in one location (the feeder tube or mixing jar) increasing the likelihood of measuring contamination in another. Relationships were detected between SPC and coliform counts. The coliform sample from the feeder tube was related to that from the mixing jar ($R=0.30$, $P<0.0001$) and the same relationship was detected for the tube and mixer SPC samples ($R=0.48$, $P<0.0001$). Bacterial counts in the feeder tubing were typically higher than those in the mixing tank, which is reflective of the fact that the cleaning functions of this component are totally automated while those for the tubing are not. Despite this, it is clear that both sites can serve as reservoir for potentially pathogenic organisms.

Relationships were also detected between milk sample bacterial counts and the frequency of performing cleaning procedures reported by producers. The coliform count from the mixing jar was related to the frequency of automated mixer cleaning (r= -0.26, *P*=0.0007) as was the SPC of the mixing tank (r= -0.32, *P*<0.0001). The SPC from the feeder tubes 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*=0.0003). 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. Despite these early indicators, it is absolutely crucial that more research be done to focus on the factors that impact bacterial contamination, including farm cleaning procedures, and the environment in which the feeder is housed.

Calf Monitoring

It was rare for the individual supervising the calf area to have no other responsibilities on the farm, but 28.9% of farms reported having an employee (or family member) whose primary responsibility was to care for young animals. Because operators rarely have extensive time to dedicate to observing calves in group pens, automated feeders were designed to provide information on individual animals' amount of milk consumed 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 rely on one or more of them to identify potentially sick animals.

When using the automated feeder to monitor calf health, producers reported using the measurement of drinking speed to identify sick animals more (55.9% of producers) than any other data gathered by the machine. 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 producers. Neither the number of times the calf visits the machine (used by 5.9% of producers) nor the number of unrewarded visits to the machine (used by 2.9% of producers) were widely used. Almost half of producers (44.7%) did not use a specific behavioral measure to monitor calf health, relying instead on the automated feeder's default algorithms. Of those farms that focused on one or more specific measures of calf health (55.3% of farms), 52.4% focused on a single factor, 42.9% used 2 factors, and 4.8% used 3 factors.

Painful Procedures

Of farms in the current study responding to questions focused on physical alteration of calves (dehorning: 35 farms, castrating: 18 farms), dehorning of calves was reported on all farms. Thermal (hot iron) dehorning was the most common practice (57.1% of farms), followed by use of a caustic paste (28.6% of farms) and physical removal of the horn bud (14.3% of farms). These percentages are largely in line with national practices for raising dairy heifers, in which hot iron dehorning is the most popular, followed by caustic paste, and then physical removal (USDA 2010).

Dehorning/disbudding and castration are known to be painful procedures for calves, causing an increase in pain related behaviors and blood cortisol after the procedure (Faulkner and Weary, 2000; Doherty et al., 2007). These outcomes can be mitigated through the use of anesthetics and analgesics (Faulkner and Weary, 2000; Vickers et al., 2005), but because of cost, availability of drugs, and producer training are not widely popular. Regardless of dehorning method used, anesthetic and analgesic use was reported on a maximum of 21.5% of operations (USDA, 2010).

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

CONCLUSIONS

In general, producers using automated feeding systems to raise dairy calves are taking advantage of many features associated with increased productivity and animal welfare. Widespread disinfection of the navel after birth and rapid removal of the neonate from the calving pen help to reduce the immediate risk of infection post-partum. The feeding of relatively large amounts of milk during the preweaning period – as well as the typically gradual reduction in milk allowance during weaning – is consistent with recent research that indicates both proximate and long-term benefits to the practice. Provision of bedding and ventilation inside the calf barns helps to limit calf contact with pathogens both in the air and on the ground.

There are, of course, practices which represent areas for improvement for supporting calf health and welfare. Widespread use of multiple animal calving pens puts calves at risk of infection during the vulnerable postnatal period and limits the abilities of producers to clean and sanitize the area. The feeding of large amounts of colostrum follow industry recommendations for managing the transmission of passive immunity, but measurements of immune outcomes indicate that colostrum management continues to be a major issue. While space per calf in the pen is typically above current recommendations, the number of calves in each group is higher than previous studies have suggested is best. Although the liquid diet provides more volume than traditional calf raising methods, there are very real concerns about the consistency of diet formulation – particularly on farms feeding milk replacer – and about the potential for bacterial contamination in the automated feeding machine and tubing.

While this study does not evaluate the relative qualities of management between farms, it does indicate areas in which improvement is possible. Better management of colostrum and a focus on reducing potential negative factors in calf group dynamics (group size, age difference) would likely help automated feeder farms continue to improve. These and other factors would benefit from more intensive, controlled experimentation. 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.

Chapter 3

Risk factors for dairy calf morbidity in automated feeding systems in the upper Midwest USA

SUMMARYAutomated feeding systems are growing in popularity for dairy farms in America. The objective of this study was to investigate the health outcomes for calves in these systems and to identify risk factors for adverse health outcomes on 38 farms using automated feeders in the upper Midwest USA. Calves (n=10,179) were scored for attitude (score of 0-4, where 0=normal), ear (0-4), eye (0-3), and nasal health (0-3), as well as evidence of scouring (cleanliness score of hindquarters; 0-2). Rectal temperatures were taken in calves scoring a 2 or higher in any category and those with a temperature above 39.4°C were categorized as sick (n=550). Associations were determined between farm level variables and health scores to identify risk factors for higher (worse) scores. All scores were significantly associated with season of measurement, with fall and winter seasons increasing the risk of a high health score or sick categorization. High bacterial count measured in the milk or milk replacer was associated with a risk for higher attitude and ear score, and a higher risk of calves being categorized as sick. A higher peak milk allowance was associated with lower cleanliness score, while a longer period of time to reach peak milk allowance was associated with increased risk of a higher attitude, ear, eye and cleanliness scores, as well as categorization as sick. Higher fat content in the liquid diet was associated with an increased risk of high eye score. Less space per calf was associated with higher ear and eye scores, whereas larger group sizes were associated with a small increased risk of higher nasal score and small decreased risk of higher cleanliness score. Rectangular pen shape was associated with a decreased risk of higher

eye score. Absence of a positive pressure ventilation tube was associated with an increased risk of a calf being categorized as sick. These factors could be easily managed to improve health outcomes for dairy calves on automated feeding systems.

INTRODUCTION

The period between birth and weaning represents a time of high risk for dairy calves, with 7.8% of calves born alive dying during this period (USDA, 2010). Infectious disease is a particularly high risk for calves, with enteric and pneumonic infections being the most common cause of disease related death (Sivula et al., 1996; Tyler et al., 1999; Svensson et al, 2006), and these diseases are a cause of economic efficiency and long term production in the dairy industry (Kaneene and Hurd, 1990; Heinrichs et al., 2005). Because of the risk of spreading infection between animals, dairy calves in the United States are traditionally kept in individual pens or hutches in order to minimize physical contact (Callan and Gary 2002). Although some studies have found that calves kept individually have lower morbidity and mortality rates (Waltner-Toews et al., 1986b,c), these systems are coming under increasing pressure for restricting physical movement and social interaction (Dellmeier et al., 1985; Rushen et al., 2008b) and an increasing number of farm operations are shifting towards group housed systems.

Housing calves in groups increases the opportunity for social interaction and facilitates normal calf behaviors (Jensen et al., 1997; Chua et al., 2002), but presents its own challenges. It is not clear that these housing systems are inherently worse for calf health than individual housing. While some studies have recorded an increased rate of morbidity and mortality for group-housed versus individual calves (Webster et al., 1985a; Le

Neindre, 1993), more recent studies have shown either advantages to housing calves in groups (Hänninen et al., 2003) or no difference between the two systems (Losinger and Heinrichs, 1997). Further work has demonstrated that, while group housing itself may not cause increased health and mortality events in calves, group size is an important factor. Calves kept in larger groups appear to be at higher risk for infection than those in small groups (Svensson et al., 2003; Svensson and Liberg, 2006), although the inverse has also been shown (Kung et al., 1997). Ultimately, it appears that the differences between systems are more related to important management practices than the grouping of animals (Rushen et al., 2008b).

Automated feeding systems are becoming increasingly popular in the upper Midwest USA as a tool for managing calves in group-housed systems. These computer controlled feeding tools provide operators with individual calf data, flexibility in diet and weaning management, and have been shown to significantly impact manual calf-care labor (Kung et al., 1997; de Passilé et al., 2004; Kack and Ziermerink, 2010). While popular in Europe, these systems are relatively new to the USA and little is known about the manner in which they are employed on American dairy farms. A summary of key management practices, facility design characteristics, and environmental factors have been described in the previous chapter, but it is critical to better understand how these variables impact calf health. The objective of this study was to document the health status of calves in automated feeding systems, and to investigate the association of management factors with calf morbidity.

MATERIALS AND METHODS

This study was conducted on 38 randomly selected farms using automated feeders in Minnesota, NW Iowa, and Wisconsin. Farms reported a median calf population of 45 animals (range 7-300). During data collection, each farm was visited up to 8 times each, approximately every 60 days, between November 2012 and May 2014. Data were collected through a combination of direct observation of the calves and their environment, as well the completion of a questionnaire by the farm operator.

Measurements of barn and pen characteristics were recorded at the time of each visit. Barn characteristics included barn construction type (new or retrofitted), ventilation type (natural ventilation, mechanical ventilation), number and size of circulation fans, and traits of supplemental positive pressure ventilation tubes (diameter, outlet hole size, spacing and placement, and air inlet source). Pen characteristics included pen size, group size, space per calf, and bedding type and depth. Bedding wetness was scored was measured at 4 locations in each pen (0=dry – 4=very wet; Canadian Dairy Research Portal, 2011).

Thermal conditions were measured from a central location in each calf area using temperature-humidity loggers (Hobo A23 Pro Series, Hobo, Bourne, MA) which recorded temperature and humidity hourly throughout the 18 month study period. In order to maintain parsimony in the final models produced, calendar season was used as a comprehensive category incorporating temperature/humidity, photoperiod, and other environmental factors that vary significantly throughout the year. Seasons were defined from the onset of study to December 20, 2012 (Fall 1), December 21, 2012-March 20, 2013 (Winter 1), March 21, 2013-June 20, 2013 (Spring 1), June 21, 2013-September 20, 2013 (Summer 1), September 21, 2013-December 20, 2013 (Fall 2), December 21, 2013-March 20,2014 (Winter 2), and March 21-May 20, 2014 (Spring 2).

Calf health was evaluated within 2 calf pens on smaller farms (4 or fewer total pens; 33 farms) or in 3 pens (farms with 5 or more total pens; 5 farms) using a modified health scoring system (McGuirk, University of Wisconsin; Appendix D). This system scored calf attitude (attitude score) and ear position (ear score) on a 0-4 scale, with 0 representing a healthy, normal calf. An attitude score of 4 represented a dead calf. Ocular (eye score) and nasal discharge (nasal score) were evaluated on a similar 0-3 scale. Incidence of diarrhea was modified from the original scoring system, and was measured using an assessment (cleanliness score) of the calf hind quarters and scored on a modified scale from 0-2, with 0 representing a healthy calf, 1 a calf with abnormal fecal consistency, and 2 a calf with significant evidence of watery diarrhea. Rectal temperatures were taken on calves scoring a 2 or higher on any health score category, and calves with a temperature above 39.4°C were categorized as sick. All calf health scores were measured by a single observer over the course of the study. A total of 10,179 calves were scored over the course of the study but, because of missing values this total number was not always used. Number of observations is noted alongside each model.

Colostrum management quality (success or failure of passive transfer) was evaluated by measuring serum total protein (STP) in young calves. Blood samples were taken at the time of visit from every clinically normal calf (up to 12 animals per farm per visit) between 24 hours and 5 days of age. These samples were centrifuged and STP was measured from each sample using a hand held light refractometer (model HR-200 ATC, AFAB Enterprises, Eustis, FL).

Seasonal milk samples for bacterial analysis were gathered from both the automated feeder mixing jar (mixer) and the point of connection between the flexible dispensing tube or hose and the nipple (tube-end) up to 5 times from each farm for evaluation. These samples were immediately placed on ice and frozen as quickly as possible. All bacterial samples were analyzed for standard plate count (SPC) and coliform bacteria contamination at the University of Minnesota Veterinary Diagnostic Laboratory (Saint Paul, MN). Samples were categorized to delineate between those which fall under the recommended limits for SPC (<100,000 cfu/mL) and coliform contamination (<15,000 cfu.mL; McGuirk and Collins, 2004). Milk samples were also gathered twice (in summer and winter) for component (fat, protein, solids) analysis following a protocol identical to that for the mixer sample. All component analysis was conducted by AgSource Laboratories (Marshfield, WI).

Farm management practices were gathered via questionnaire and covered topics from calving and neonate management to colostrum management, postnatal procedures (castration/dehorning), calf housing and bedding management, stocking and moving of animals, calf feeding and weaning, management and cleaning of the automated feeder equipment, and barn pest control.

Statistical Analysis

Association between each of 131 variables and the separate health score outcomes (attitude, ear, eye, nasal, cleanliness, and sick) was evaluated using a univariate model for screening (PROC GLIMMIX; SAS Institute Inc., Cary, NC). Farm, cohort (visit number) within farm, and pen within cohort within farm were fitted as random effects. A multivariate model (GLIMMIX: SAS Institute Inc.) was built from those variables identified as meeting a given criteria (P<0.3) in the univariate analysis. Backwards elimination was used to eliminate variables from the multivariate model until all remaining variables were significant (P<0.05). In the multivariate models for attitude score, eye score, ear score, nasal score, and cleanliness score the error distribution was multinomial and a clogit link function was used. Because the sick category had only two outcomes (yes/no), the error distribution of this model was binomial and a logit link function was used.

RESULTS AND DISCUSSION

Health Score Frequencies

Table 4 shows the distribution frequencies for each of the health scores measured on farm. For all health scores, the majority of calves were scored as “0” or “normal,” although the proportion of calves identified as abnormal (score ≥ 1) or high abnormal (score ≥ 2) varied depending on the score. More calves were categorized as having abnormal cleanliness scores (a score above 0; 41.9% of animals) and high abnormal cleanliness scores (9.4% of animals) than any other health score. Just 2 calves were dead (attitude score of 4) in the pens observed. Of those calves that scored a 2 or higher on any health score category, 550 animals (5.4% of all animals scored) had a rectal temperature above 39.4°C, which is generally consistent with morbidity rates of group housed calves observed elsewhere (Le Neindre, 1993).

Univariate Analysis

A maximum of 15 variables in the univariate analyses met the criteria for inclusion in the multivariate models ($P<0.3$) for each of the separate health outcomes and are listed in Table 5. Certain variables were consistently significant across all health score categories, particularly the season of measurement, stocking characteristics (number of calves per group, space per calf), feeding strategy, and bacterial measurement category appeared in nearly every inclusive model. Highly related variables (e.g. bacterial count category in the tube and mixing tank) were reduced to a single representative variable.

Multivariate Analysis

Seasonal Patterns. Season of measurement was highly significant in every individual model (Table 6), and comparisons of seasonal effects indicate that certain seasons were consistently worse for health outcomes in calves than others. The winter of 2013-2014 (Winter 2) was associated with higher attitude scores than the spring and autumn (Fall 2) seasons of 2013 while Winter 1 was also associated with higher ear scores. Autumn 2013 (Fall 2) was associated with higher eye scores, and the winter of 2013-2014 (Winter 2) was associated with higher nasal scores, cleanliness scores, and more sick animals. It is important to note that when the 95% confidence intervals are considered, the clarity of relationship between season and health is somewhat reduced – wide confidence intervals for ear score, in particular, make it difficult to definitively conclude that Winter 1 was different from any season except Winter 2.

The relationships indicate that fall and winter scores were most typically associated with worse health outcomes, which is generally consistent with previous findings. Leech et al.

(1968) found that mortality rates were higher in calves during the winter than in summer and that calves born in winter were at greater mortality risk than those born in summer. Additional work in other locations (i.e., Michigan, California) has shown a similar trend of increased mortality in winter (Speicher and Hepp, 1973; Martin et al., 1975; Svensson et al., 2006), even when overall mortality rates remain low throughout the year (Waltner-Toews et al., 1986a). Changes in temperature and precipitation are known to have an impact on calf health and survival (Martin et al., 1975), but there are likely additional factors that play a part in these seasonal differences.

Management Factors

Feeding Characteristics. The multivariate models (Table 7) detected significant associations between several management factors and measured health outcomes in dairy calves. As noted in the univariate analysis, certain types of management factors were commonly observed as having a significant association with multiple health scores – dietary management, bacterial contamination of the automated feeder unit, and the grouping dynamics appear consistently important across most of the health scores.

It has been shown previously that the amount of milk fed to calves has significant impacts on health and development in the preweaning period. While feeding calves more milk in this period has been shown to positively impact growth rate (Khan et al., 2007; Huuskonen and Khalili, 2008), there are concerns that high milk allowances may be related to worsening of diarrhea (Quigley et al., 2006). The majority of studies, however, show that there is not an increased rate of enteric infection for calves fed high milk allowances (Jasper and Weary, 2002; Chua et al., 2002) and in some cases the rate of infection is reduced (Khan et al., 2007). Nutritional deficiency has a suppressing effect on immune function (Nonnecke et al., 2003; Ballou, 2012), so feeding more milk may positively impact the ability of a calf to combat infection. The present analysis showed an association between the peak milk allowed to calves and the apparent incidence of diarrhea (the cleanliness score). Each additional liter of milk allowed was associated with an 11.8% decrease (*P*=0.0009) in the likelihood of calves receiving a high score for cleanliness.

Additionally, the speed at which a feeding plan reached peak milk allowance appeared to be broadly important across almost all of the recorded health scores. Each additional day taken to reach the peak milk allowance was associated with an increase in the risk of calves receiving a higher attitude score (1.3% per unit increased risk; *P*=0.0238), ear score (2.2%; *P*=0.0392), eye score (2.2%; *P*=0.0392), and cleanliness score (1.9%; *P*=0.006), and in the likelihood of a calf being categorized as sick (2.5%; *P* =0.0016). There is relatively little work available comparing the pattern of liquid diet increases with health outcomes in dairy calves, but we do know that higher allowances in early life provide the calf with approximately twice the nutrient intake as those fed the traditional limited diet (Khan et al., 2011), which is likely to have similar immune function benefits to those seen in calves fed a high volume of milk throughout the preweaning period.

A relationship was found between the farm-average fat content of the liquid diet and calf health, with each additional percent of fat content associated with a 62.4% increase in the odds of a high eye score (*P*=0.0056). Previous work has shown no impact of milk replacer fat content on health outcomes in bull calves when carbohydrate levels were maintained at reasonable levels (Tikofsky et al., 2001). Feeding nutritionally concentrated liquids, those with high osmolality, are known to exacerbate enteric infections (Smith, 2009), but we would expect this relationship to be visible in the cleanliness score of calves in the current study rather than the eye score. As noted in the previous chapter, the variability of components in the liquid diet is considerable for calves raised on automated feeding systems. The lack of consistency, particularly on those farms feeding milk replacer (rather than a whole milk product), is likely indicative of management issues which were not measured in the present study. It is also worth noting that the average component analysis was conducted on 2 samples per farm, so a more in depth investigation of how nutritional concentration and variation impact calf health on automated feeding systems is merited.

The significant relationship between calf health and feeding management is broadly consistent with previous work – feeding calves a higher volume of liquid in the preweaning period appears to be one important factor in supporting positive health outcomes. More work is necessary to determine how milk intake patterns in the very early stages of life impact calf health, particularly how calves cope with rapid increases in milk allowance in the first few days on the feeder.

Bacterial Contamination. Feeding large amounts of milk benefits calf growth and health, but only if that milk is safe for consumption – contaminated liquid represents a major risk to calves (Lorenz et al., 2011). Current guidelines recommend that bacterial contamination of milk fed to calves be limited to a maximum of 100,000 colony forming units (cfu)/mL in standard plate counts (SPC) and to 15,000 cfu/mL for coliform bacteria (McGuirk and Collins, 2004). Samples collected with a bacterial count (SPC) above the limit were associated with multiple health scores, with a tube-end SPC above 100,000 cfu/mL increasing the odds of a higher attitude score by 20.7% (*P*=0.0329), a higher ear score by 31.8% (*P*=0.0103) and increasing the odds of a calf being categorized as sick by 81.5% (*P*<0.0001).

While milk replacer and pasteurized milk have relatively low risk for contamination under ideal conditions (McGuirk, 2008), the automated feeding system adds several new potential reservoirs of bacteria – in the mixing tank and tube, where liquid milk is frequently present most obviously, but also in the milk powder storage area and in/on the nipple from which calves nurse. Environmental temperature is an important factor influencing the rate of proliferation of bacterial cells, and increased contamination of colostrum has been detected in warmer months (Fecteau et al., 2002); automated feeders are often kept in heated rooms to avoid freezing, but a combination of this heat, a lack of ventilation in the feeder housing, and any errors in machine installation or maintenance that allow milk to pool in the feeder mixing tank or tubing could contribute to the development of bacterial colonies.

The majority of these feeders are designed to run an automated cleaning function in the mixing tank, while requiring user activation of processes or manual cleaning to maintain holistically sanitary conditions. There is a relationship between the frequency of cleaning and the bacterial content of milk samples taken from the feeder, but a lack of training and awareness by producers of how to properly maintain the machines, as well as failure to adequately monitor contamination, are likely to also impact contamination. For farms feeding liquid milk, the additional pasteurization, storage and refrigeration add steps to the process of providing an uncontaminated diet to preweaned calves.

Although many operations were providing calves with a diet that met recommendations for bacterial content, highly contaminated samples were taken from multiple sources (mixing tanks and tubes) on several operations in the present study (as described in the previous chapter). The relative frequency of contamination is cause for major concern regarding the amount of pathogenic intake by calves on automated feeders. More research is needed to better understand the relationship between cleaning practices (frequency, techniques, and products used) and feeder cleanliness, as well as between contamination of milk and calf health.

Group Management. The major concerns of housing calves in groups focus on the transmission of disease between animals. Earlier studies indicated that keeping calves in groups was related to increased morbidity (Le Neindre, 1993) and mortality rates (Webster et al., 1985a,b). Other work has found that keeping calves in groups can result in comparable growth to those raised individually (Chue et al., 2002), while group-housed calves actually experience lower incidence of health problems than individuals (Kung et al., 1997; Hänninen et al., 2003). There appears to be no relationship between the housing type and rate of infection by common pathogens (Losinger et al., 1995; Mohammed et al., 1999; Rugbjerg et al., 2003) and large scale work has not demonstrated an advantage of one housing type over another (Losinger and Heinrichs, 1997).

Although calves can be kept successfully in groups, it does appear that the size of group has an impact on health outcomes for these animals. Several studies have shown an increase in morbidity and mortality for calves kept in large groups compared to those kept individually or in smaller groups (Losinger and Heinrichs, 1997). In multiple

Swedish studies, calves kept in large groups (12-18 animals) had a higher incidence of respiratory disease and diarrhea than those kept in smaller groups (6-9 animals; Svensson et al., 2003; Svensson and Liberg, 2006).

The results of the present study do not clearly agree with this work, although higher number of calves in a group was associated with an increased risk of a higher nasal score. For each additional calf, the risk of a higher nasal score rose by 1.1% (P=0.044). The effect was reversed when considering the cleanliness score, however, and for each additional calf in the group there was an associated 1.3% decrease in the risk of a higher cleanliness score. As noted previously group size is not necessarily the most important variable affecting calf health, as other management decisions can alter health outcomes even in farms with large groups (Rushen et al., 2008b). It is important to keep in mind that the average group size in the current study was 17.8 calves and not many farms had very large groups of 25-30 calves. This might have limited our ability to detect a stronger relationship between group size and calf health.

In a group housing system calf health may be impacted as much by stocking density as by raw group size. In adult cattle a higher stocking density increases the pathogen load in a pen (Grooms and Kroll, 2015) and stocking density has been shown to have a greater effect on airborne pathogen density than ventilation (Wathes et al., 1983; Nardell et al., 1991). In the present study a stronger relationship was observed between space per calf and calf health scores than between group size – every additional square meter of space allowed per calf there was a 10.4% decrease in the odds of receiving a higher ear score (P=0.0055) and a 7.7% decrease in the odds of a higher eye score (P=0.0075). These results are consistent with previous work demonstrating that increased stocking density is associated with adverse health events in calves (Bendali et al., 1999).

Pen and Barn Traits. The impacts of stocking density are potentially intertwined with several other aspects of barn design. In this study an association was discovered between the eye score and the pen shape, in which a rectangular pen shape (pens at least 2.5 times longer than they are wide) was associated with a 53.7% decrease in the odds of a higher eye score (P=0.0107). Longer, narrower pens – particularly those with a positive pressure ventilation tube running above them – may benefit from a greater impact of ventilation on airborne pathogen density. The distance fresh air is able to travel from a ventilation tube is limited to 3-5m on either side (Nordlund, 2008), so in certain circumstances a narrower pen design may help to ensure that the entire calf pen is properly ventilated. A common interest of producers is the impact that pen shape might have on group dynamics, behavior and health – access to the automated feeder itself is of particular concern, with operators worried that dominant calves may monopolize resources. The impact of pen shape on calf play behavior has been examined (Mintline et al., 2012), but no work has addressed the relationship between pen shape resource access or health outcomes. It should be noted that the definition used here for pen shape is fairly reductive, which has the effect of inflating the odds ratio estimate somewhat more than would be observed with more categories of pen shape represented. Despite this, as group-housing pens increase in popularity, it would likely be beneficial to further explore the impacts that pen shape may have on health and behavioral factors, as well as on ventilation system effectiveness.

Regardless of pen shape, proper ventilation of calf housing areas is critical in the maintenance of sanitary facilities – the airborne pathogen load has a dramatic impact on calf health, and associations have been shown between the total cfu/m^3 and the prevalence of respiratory disease (Lago et al., 2006). Calf areas can be particularly difficult to properly ventilate, particularly in winter when the need to balance between air movement and cold stress in calves can result in poorly ventilated areas (Lago et al., 2006). Positive pressure ventilation systems are frequently recommended for both naturally and mechanically ventilated calf barns in order to ensure that sufficient fresh air is reaching the animals, even during times of inclement weather or temperature change (Nordlund, 2008). Our observations of automated feeder facilities is consistent with this recommendation, and barns which did not have a positive pressure ventilation system in use were associated with an 80.6% increase in the likelihood of a calf being diagnosed as sick (P=0.0251).

CONCLUSION

While managing calves on automated feeders may be challenging, the relative rarity of very sick calves observed on this study indicate that successful calf rearing is possible in these systems. This study identified several farm-level risk factors that are associated with worse calf health – aspects of the feeding plan, group size and stocking management, ventilation of the calf barn, and bacterial contamination of the liquid diet were all significantly associated with health scores. Because they appeared across several health score categories, it seems that particular attention should be paid to the bacterial contamination of calf diets and to the speed at which the diets reach their peak amount.

Encouragingly, all of these factors can be managed on farm in order to reduce the morbidity of calves on automated feeding systems.

While identifying these risk factors is a first step in understanding the intricacies of automated feeder use, it should be noted that more research is needed to better understand the causal relationships between the factors discussed and calf health outcomes. Of particular interest should be an investigation into the cleaning, calibration, and housing of the automated feeder. These factors impact the quality of diet presented to the preweaned calf, and are likely to show a significant impact on bacterial contamination of the liquid diet.

Chapter 4

Morbidity and mortality of dairy calves in automated feeding systems in the upper Midwest USA

SUMMARY

Automated calf feeding systems are increasing in use across the United States, yet information regarding health and mortality outcomes is limited. This study investigates the impacts of farm management practices, housing, and environmental factors on mortality in preweaned dairy calves. Farm records were surveyed for health treatment (26 farms) and mortality (23) on farms using automated feeding systems to raise calves in the upper Midwest USA. Mortality and treatment rates were calculated and relationships determined between these outcomes and farm-level factors collected during farm visits and through management questionnaires. Relationships (least square means estimates) between categorical factors of interest and mortality rate were calculated using the mixed procedure of SAS. Pearson's correlation was used for continuous variables. Average mortality of calves on farms using automated feeders was 3.85%/year (±3.70%) and 57% of farms (13/23) reported mortality rates below 3%/year. The maximum recorded mortality rate was 13.41%/year and the minimum was 0.24%/year. Farm serum total protein concentration was negatively associated with farm annual mortality rate (R= -0.50, *P*=0.02; mean STP=5.4g/dL ±0.74). Farms that disinfect the navels of newborn calves had lower mortality rate (LSM=2.97%, SE=0.80; 78% of farms) than farms that do not disinfect (LSM=7.32%, SE=1.59; *P*=0.03; 22% of farms). Trends were detected in the correlations between mortality rate and bacteria content (standard plate count) of milk gathered from the feeder tube (R=0.37, *P*=0.08; median=435,000 cfu/mL, IQR=4,156,500 cfu/mL) size of the dairy (number of calves on site; R= -0.41, *P*=0.08; mean=82.18 calves ±84.26) and age difference in calf groups (R=0.41, p=0.06; mean=3.07 weeks ±2.03). Farm treatment rate was associated with coliform bacterial content in the feeder tube (R=0.45, *P*=0.02; mean=6.61 ln[cfu/mL] ±4.35) and the age of calves at grouping (R=0.50, *P*=0.01; mean=5.1 days ±3.6), with trends detected for coliform bacterial content of the feeder mixing tank (R=0.37, *P*=0.07; mean=3.54 ln[cfu/mL] ±6.18) and age of weaning (R=0.37, *P*=0.07; mean=57.4 days ±9.6). Seasonal patterns indicated that winter was the season of highest treatment rate. Taken together these outcomes indicate that, while automated feeding systems can achieve mortality rates well below the national average, improvements are needed in fundamental calf care practices like colostrum management and preventing bacterial contamination of the liquid diet.

INTRODUCTION

American dairy farms typically keep calves in individual pens during the preweaning period. These individual housing systems are designed to minimize the risk of morbidity and mortality in calves by restricting the transmission of infection between animals (Callan and Gary, 2002), and individual housing has been associated with better health outcomes in these animals (Waltner-Toews et al. 1986b,c; Le Neindre, 1993). In restricting calf-to-calf contact, though, these systems also prevent social and locomotory behavior in calves (Dellmeier et al., 1985), and represent a major labor investment for farm operators (Nordlund, 2008).

The processes leading to death have a strongly negative impact on animal welfare (Mellor and Stafford, 2004). Mortality rates remain relatively high in dairy calves, despite the prevalence of individual housing systems (6.3% -Wells et al., 1996; 7.1%-Meyer et al., 2000; 7.8%-USDA, 2007; 8.1%-USDA, 2007), and public pressure and legislation are increasingly restrictive of the use of isolation-based housing systems (Rushen et al., 2008). A combination of animal, social and economic factors have seen a recent increase in the number of farms considering group housing as an option for preweaned animals.

Although early work indicated a significant health benefit to keeping calves in separate enclosures, more recent studies have found contradictory outcomes. Group housing systems have been shown to have no difference in morbidity and mortality (Losinger and Heinrichs, 1997) or even a reduction in negative health outcomes (Hänninen et al., 2003). Multiple studies have found no association between housing type and the chance of infection by *Cryptosporidium parvum* (Mohammed et al., 1999), *Salmonella* spp. (Losinger et al., 1995), or *Escherichia coli* (Rugbjerg et al., 2003). The potential for increased health issues may be related to group size, and higher morbidity and mortality rates have been detected in animals kept in large groups when compared to small groups (Svensson et al., 2003; Svensson and Liberg 2006). This relationship is not clear, however, as some work has shown lower rates of infection in calves kept in relatively large groups (Kung et al., 1997). Ultimately the differences in health outcomes may be more related to management than the housing itself (Rushen et al., 2008).

Computer controlled feeding systems (automated feeders) are one tool available to farm operators managing calves in group housing. These systems are designed to mix, heat, and deliver a liquid diet to calves in the preweaning period, record calf feeding behaviors, and provide the manager with information on individual calf health status. Automated feeders are increasing in popularity in the United States; however, information regarding feeder management is relatively limited. The objective of this study was to describe the patterns of calf morbidity and mortality on farms using automated feeding systems.

MATERIALS AND METHODS

A total of 64 dairy farms using automated feeding systems were identified in Minnesota, Wisconsin and NW Iowa, and from this list 38 farms were randomly selected for analysis of farm management and calf health. Building design and environmental factors were measured at the time of visit to each facility up to 8 times per farm, and management practices were gathered via questionnaire. A subset of 26 farms granted access to producer-kept calf treatment records for all or part of the study period between November 2012 and May 2014 and these records were used to estimate the incidence of illness on these farms. Calf treatment data included the farm identification, calf identification, calf birthdate, date of treatment, producer reported reason for treatment, treatment type, and outcome of the illness (recovery/death), although not all of these categories were recorded by each producer for every treatment. In order for treatment rate to more closely mirror the actual morbidity rate, treatments for calves within 14 days of the previous treatment were excluded from the data set to avoid duplicate treatments for the same illness.

Mortality events were collected from 23 farms because 3 farms in the subset did not record calf deaths. On the farms represented in the mortality data subset, periods of consistent record keeping averaged 353.4 ±137.3 days and a total of 231 mortality events were recorded.

The beginning round of visits (November 2012) and ending round of visits (March-May 2014) for this study did not cover an entire calendar season and were excluded from the analysis of seasonal effects. Seven farms were identified with the most comprehensive treatment records for the full seasons recorded, encompassing a total of 1,949 individual treatments (126 deaths) during Winter 2013 (12/21/2012-3/20/2013), Spring 2013 (3/21-6/20/2013), Summer 2013 (6/21-9/20/2013) and Fall 2013 (9/21-12/20/2013) and were used to compare seasonal patterns of treatment rate.

As noted in previous studies, producer kept records can be problematic in terms of reliability and accuracy (Vasseur et al., 2012) and are unlikely to be a particularly sensitive diagnostic tool. Treatment, especially, is not necessarily reflective of morbidity. Efforts were made to focus data collection and analysis on only those records which were taken reliably and thoroughly on each farm.

Statistical Analysis

All statistical analysis was conducted with SAS 9.3 (SAS Institute Inc., Cary, NC). Treatment and mortality rates were calculated for each farm by dividing total observed treatments/death loss by the estimated yearly calf population on that farm (farm average stocking rate*365 days/group turnover rate). Relationships between annual mortality rates/annual treatment rates and farm level factors of environment and management were calculated using the Pearson's correlation (PROC CORR; SAS Institute Inc.) for continuous variables and analysis of variance (PROC ANOVA: SAS Institute Inc.) for categorical variables.

On the seven farms with the most comprehensive records, the relationship between season and treatment rate/mortality rate was analyzed using a univariate model (PROC GLIMMIX; SAS Institute Inc.). The model used a Gaussian error distribution with an identity link function. Farm was fitted as a random effect. Least squares means were determined for treatment/mortality rate by season and were compared using Bonferroni contrast t-test.

Significance was set at a *P*-value <0.05, while trends are reported for relationships with a *P*-value <0.1.

RESULTS AND DISCUSSION

Mortality

Mortality record length varied between farms, as some farms withdrew from the study prematurely or stopped keeping adequate treatment records. On the farms represented in the mortality subset, periods of consistent record keeping averaged 353.4 days (S.D. ±137.3). Estimated yearly stocking rate was 339.9±235.7 animals per farm (range: 148-1179).

In the preweaning period all calves face several challenges, from the birthing process to administration of colostrum to pathogen exposure and other stresses. Because of this, the national calf mortality rate is near 7% (6.3% -Wells et al., 1996; 7.1%-Meyer et al., 2000; 7.8%-USDA, 2007; 8.1%-USDA, 2010) inclusive of all housing types. In the present study a total of 231 mortality events were reported across all farms. Farm annual mortality rate was 3.85% (±SD 3.70; range:0.24-13.41%). Only 3 of the 23 farms (13%) reported mortality rates above 7% and 13 farms (57%) reported mortality rates below 3%. This average mortality rate is comparable to those found in previous studies on group housed veal calves (3.01%; Le Neindre, 1993). In 142 (61.5%) of mortality events, the animal received at least one treatment prior to death. Administration of antibiotics (104 treatments; 73.2%) was the primary treatment type provided to calves that went on to die, followed by administration of a vitamin B supplement (23 treatments; 16.2%), provision of electrolytes (10 treatments; 7.0%), probiotics (4 treatments; 2.8%), and anti-inflammatory medication (1 treatment; 0.7%).

In addition to impacting production characteristics like growth and future lactation (Faber, 2005), failure of passive immune transfer has been shown to increase early life mortality in dairy calves (Wells et al., 1996). The link between passive immunity and mortality is especially relevant for calves in group-housed situations, and relationships were detected between mortality rates and farm averages for serum total protein (STP) of calves measured on these operations ($R= -0.50$, $P=0.02$). The recommended targets for successful passive transfer are 5.0-5.2 g/dL (Weaver et al., 2000; Calloway et al., 2002) and although the mean STP of 5.44±0.72 mg/dL on all calves measured in this study was above this limit, it is worth noting that 33.6% of all samples fell below the 5.2 g/dL limit and 22% below 5.0 g/dL. Additionally, 25.7% of farms had by-farm STP averages under 5.2 g/dL and 14.3% below 5.0 g/dL (Jorgensen et al., 2016). While the importance of passive immune transfer to calf health and survival is well accepted, colostrum management continues to be an issue nationwide with 19.2% failure of passive transfer (USDA, 2010).

Proper administration of colostrum is important, but benefits have been shown to applying other management practices in the immediate post-birth period. In the present study, farms that reported disinfecting the umbilicus had a lower mortality rate (LSM=2.97%, SE=0.80; 78% of farms) than farms that did not disinfect (LSM=7.32%, SE=1.59; P=0.03; 22% of farms). Disinfection of the umbilicus in the immediate post-natal period is generally recommended to producers and may play a role in the desiccation of umbilical tissue which reduces infection (Quigley et al., 1996).

The pen environment represents a reservoir of potential infectious pathogens (Maunsell and Donovan, 2008), and it has been demonstrated that disinfecting the floor of calf pens between animals has a significant reductive effect on levels of infection and the risk of shedding (Castro-Hermida et al., 2006; Hamnes et al., 2006). Automated feeder farms that reported disinfecting the pen between calf groups showed a lower (P=0.04) annual mortality rate (2.55 ± 0.94; 59% of farms) than those that did not disinfect (5.78 ± 2.55%, 41% of farms). Farm size is likely to play a role in the ability of farms to sanitize calf areas regularly – running calves in an all-in, all-out system provides managers with a normal period in which these areas can be cleaned, a management strategy which may not be accessible to producers with more dynamic grouping strategies.

Among the difficulties of keeping calves in groups is monitoring individual animals for adverse health states. Automated feeders provide young stock managers with data for each individual calf in the group including milk intake (per meal, daily), number of visits to the machine (rewarded, unrewarded), interruptions of a feeding bout, and drinking speed. Farms that reported using the drinking speed as an alarm for notification of calf morbidity had a lower (P<0.001) annual mortality rate (2.37 ± 0.83%; 74% of farms) than those that did not (6.57 ± 1.13%; 36% of farms). Calf drinking speed has been previously investigated in relation to digestion and physical growth (McInnes et al., 2015). The use of drinking speed as an alarm has been described (Cramer et al., 2016) but more work is required in order to clarify the efficacy of this metric as a diagnostic tool.

It has been previously reported that large group size places calves at increased risk for mortality, with "large" groups typically categorized as having a number of animals in, or above, the high single digits showing higher mortality (large>6 animals, Losinger and Heinrichs, 1997) and disease incidence (large = 6-30 animals, Svensson et al.; 12-18 animals, Svensson and Liberg, 2006) than those kept in smaller groups. Group size (and space per calf) were observed as having an association with health outcomes when investigating calf health scores (chapter 3), but this relationship was not observed when exploring the correlation between calf mortality rate and group size. The average group size of farms in the present study was 18.4±9.4 animals, with only 1 farm averaging a stocking rate (9.2 animals) less than 10 calves per group. The relatively large group sizes represented in this dataset reduce the ability to detect a relationship between group size and mortality, but the relatively large number of farms with low mortality rates may indicate that it is possible to be successful raising calves in these situations. It has been shown previously that it is possible to successfully keep calves in groups of 12-15 animals (Kung et al., 1997), which appears consistent with the present data. Ultimately, the impact of group size is not clearly defined in the literature, and it is likely that the success or failure of a system may depend more on other management factors (Rushen et al., 2008).

A trend was detected between the reported age difference of calves and farm mortality rate, indicating that wider age gaps may be problematic for calf mortality (R=0.41, *P*=0.06; mean=3.07±2.03 weeks; range: 2-70 days). Older calves are a known source of infection for younger calves (Radostitis et al., 1994), so keeping calf age difference as small as possible may be one factor that impacts farms' ability to successfully keep calves in slightly larger groups.

Early studies dispute the impact of farm size on calf mortality with mortality increasing as farm size increases (Oxender et al., 1973; Hartman et al., 1974) or decreasing as farm size increases (Jenny et al., 1973). In a more recent national survey (USDA, 2010) it was found that large farms (500 or more cows) had lower preweaning mortality (6.5%, SE=0.4) than medium (100-499 animals; 9.1%, SE=0.4) and small farms (fewer than 100 animals; 8.3% SE=0.4). In the present study, this trend appears to be consistent. Using the same farm size criteria, none of the farms reporting calf mortality could be categorized as small, but large farms still had a numeric advantage over medium farms with 2.09%±1.63) mortality versus 4.57% ±4.23, although the large variability in mortality rate on medium farms makes clear separation of farm size difficult. Only 2 of the farms reporting mortality were custom calf raisers, with one reporting markedly reduced mortality (0.50%) compared to the other (4.51%). A trend was detected between the number of calves on site and annual mortality rate (R= -0.41, *P*=0.08; mean=82.2 ±84.3 calves). There may be many benefits available to calves on large farms that are not available on medium or small farms, including trained labor force, better transition cow and calf care protocols, more calvings per day resulting in narrow age difference calf groups, etc.

A relationship was detected between the log bacterial standard plate count and farm mortality rate at the trend level in the present study (R=0.37, *P*=0.08; median=435,000 cfu/mL, IQR=4,156,500 cfu/mL). Exposure to pathogens is an inherent risk for negative health outcomes in dairy calves, and the ingestion of contaminated milk can be a major source of infection (Lorenz et al., 2011). Most appropriately stored milk and milk-replacer products face a low risk for contamination (McGuirk, 2008), which is certainly the case in automated feeding systems. High bacterial counts have been detected in samples taken from these feeders, and bacterial contamination of the milk product delivered to calves on automated feeders was shown to have a significant relationship with calf health outcomes (chapter 3).

No significant relationship was detected between mortality rate and season in the present study. Patterns of calf mortality are known to follow a seasonal pattern. Mortality in preweaned animals is higher in winter than in summer (Leech et al., 1968; Waltner-Toews et al., 1986a; Svensson et al., 2006), and calves born in winter are at greater risk for mortality (Leech et al., 1968). Seasonal changes in precipitation and temperature are likely to impact seasonal changes in mortality (Martin et al., 1975a) so it may be that keeping calves inside barns – as most farms with automated feeders do – has a mitigating effect on these changes. Because the group of farms that could be compared directly across four consecutive seasons was relatively small, there also may have been insufficient power to detect a seasonal difference.

As has been demonstrated, the relationships detected between annual mortality rate and environmental and management factors in this study are generally consistent with previous work measuring calf health in other husbandry systems. Indeed, many focus on fundamental calf care issues – such as colostrum management and navel disinfection – that are commonly problematic for farms regardless of housing type. The sample size for this analysis was somewhat limited, with 23 facilities reporting mortality, which certainly impacted the ability of the analysis to detect significant relationships. A broader study would likely result in those trends described above becoming significant, along with certain other relationships that were not detected. Despite the limitations of this dataset, it is clear that the improvement of some basic calf care procedures, particularly in respects to colostrum management and limiting pathogen loads in both the environment and diet, could positively impact mortality rates on farms using automated feeders.

Treatment Rate/Morbidity

A total of 5,926 individual treatment events were recorded on the 26 farms keeping health records considered adequate to investigate treatment rates. From an estimated population of 8,679 animals, farms treated animals at an overall rate of 0.68 times per individual animal present. The great majority of recorded treatments (5,177 treatments; 0.60 times/individual) were antibiotics, followed by electrolytes (330 treatments), nutritional or vitamin supplements (218 treatments), probiotics (44 treatments), physical therapies (e.g. release of gas from bloat; 15 treatments), and kaopectate (11 treatments). Farms failed to record treatment type for 131 treatments. These may be somewhat skewed by producer perceptions of what treatment types are worth recording – for instance, non-antibiotic treatments may not be recorded at the same rate as antibiotics.

Farms averaged a treatment rate of 0.72 treatments (± 0.38; range: 0.12-1.62) per calf. As previously discussed, 142 animals died despite receiving treatment.

Because a similar relationship was observed in the analysis of farm mortality rates, it was unsurprising that bacterial exposure was also associated with treatment rate. The log transformed count of coliform bacteria content (ln[cfu/mL]) in the automated feeder tube was positively associated with annual treatment rate (R=0.45, *P*=0.02; mean=6.61 ln[cfu/mL] ±4.35). A trend was also observed between the count of coliform bacteria in the feeder mixing jar and the annual treatment rate (R=0.37, *P*=0.07; median=2,300cfu/mL IQR=19,351.5 cfu/mL). Coliform bacteria are one among several potential pathogens in calves, but are frequently cited as a possible cause of infection in milk fed to preweaned calves (Stewart et al., 2005). Control of pathogens in the milk has been discussed both in this and another associated article (chapter 3) as having a major impact on the health outcomes for calves in automated feeding systems.

The age at which critical management practices are taken appears to be related to treatment rates on automated feeder farms. Many farms using automated feeding systems keep calves in separate enclosures for the first several days of life in order allow neonates to develop physically and immunologically before mixing with the other calves on the automated feeder. While this practice is intuitively sensible, the age of calves at grouping showed a positive association with treatment rate (R=0.50, *P*=0.01; mean=5.1 days ±3.6), a relationship which indicates an increased rate of treatment on farms grouping calves later. The underlying basis for this relationship is unclear but several factors could have an influence. After transitioning to group housing, the individual pens housing calves for the first few days of life may not receive the attention that group pens do, leading to a build-up of pathogens in these areas over time – calves may contact infectious pathogens in individual housing, but only become infectious and spread them to other animals upon grouping. Further investigation of the ideal age at which to place calves in groups would be beneficial.

A positive trend was also detected between the age at which farms wean calves and treatment rate (R=0.37, *P*=0.07; mean=57.4 days ±9.6). Weaning at any age can cause distress (Weary et al., 2007) and links have been identified between stress and immune suppression (Frank and Griffin, 1989). It has been shown previously that weaning calves at 7 weeks, rather than 3 or 5, resulted in a higher incidence of scours in calves housed both indoors and outdoors (Jorgenson et al., 1970).

Treatment rates differed between seasons (Table 8), with significantly higher treatment rates occurring during the winter period (mean= 103.9, SE=10.1) when compared to spring (mean=54.7, SE=10.1, *P*=0.0008) and summer (mean=71.1, SE=10.1, *P*=0.03). The autumn season (mean=76.8, SE=10.1) was not different from any other season, although a difference was detected between autumn and winter at the trend level (*P*=0.09). While there was no detected relationship between mortality and season, the seasonal patterns of treatment are consistent with the increase in adverse health outcomes and prescribed antibiotics observed during the winter period in previous work (Nonnecke et al., 2009). Adverse health outcomes and mortality have been observed in winter previously (Leech et al., 1968; Waltner-Toews et al., 1986a; Svensson et al., 2006), and winter was associated with worse health score outcomes (chapter 3). The impacts of winter are likely diverse, but include aspects of calf thermoregulation, barn ventilation, and air quality (Lago et al., 2006, Brscic et al., 2012).

CONCLUSION

Although there are concerns about the transmission of disease between calves kept in groups, the calf mortality values gathered in this study indicate that automated feeding systems can function at a level at or better than the national average for mortality. Treatment rates appeared to be high, but there is limited information on treatment rates for individually housed systems for comparison. Despite good performance on mortality rates, it is clear that fundamental aspects of calf care remain crucial to raising calves successfully on automated feeders. Adequate care of the neonate, excellent colostrum management, and limited exposure to pathogens – particularly those in the liquid diet – are all practices that must be followed in automated feeding systems. It is important to note that the relationships between these factors and mortality and treatment rates are associative only, and that further research is necessary to determine causality of these variables on calf health outcomes.

REFERENCES

Adams, G.D., L.J. Bush, J.L. Horner, and T.E. Staley. 1985. Two methods for administering colostrum to newborn calves. J. Dairy Sci. 68: 773-775.

Andrews, A.H. 2000. Calf pneumonia costs! BVCA 8: 109-114.

Ames, T.R. 1997. Dairy calf pneumonia: the disease and its impact. Vet. Clin. North Am. Food Anim. Pract. 13: 179-91.

Appleby, M.C., D.M.Weary, and B. Chua. 2001. Performance and feeding behaviour of calves on ad libitum milk from artificial teats. Applied Animal Behaviour Science 74:191–201.

Arthur G.H., D.E. Nokes, and H. Pearson. The development of the conceptus. 1996. In: Arthur GH, Nokes DE, Pearson H, (eds.). Pregnancy and parturition in veterinary reproduction and obstetrics. 7th edition. W.B. Saunders , Philadelphia. pp. 51–109.

Aschengrau, A. and G. Seage. 2008. Essentials of epidemiology in public health. Jones & Bartlett Learning, Sudbury, MA. pp. 147-157.

Bach, A., J. Ahedo, and A. Kertz. 2008. Using growth monitoring in heifer management and research [abstract]. J. Dairy Sci. 91: 602.

Baldwin, R. L. VI, K. R. McLeod, J. L. Klotz, and R. N. Heitmann. 2004. Rumen development, intestinal growth and hepatic metabolism in the pre- and postweaning ruminant. J. Dairy Sci. 87(E. Suppl.):E55–E65.

Ballou, M.A. 2012. Immune responses of Holstein and Jersey calves during the preweaning and immediate postweaned period when fed varying planes of milk replacer. J. Dairy Sci. 95: 7319-7330.

Barrington G.M., J.M. Gay, and J.F. Evermann. 2002. Biosecurity for neonatal gastrointestinal diseases. Vet. Clin. North Am. Food Anim. Pract.18: 7–34.

Bendali, F., M. Sanaa, H. Bichet, and F. Schelcher. 1999. Risk factors associated with diarrhoea in newborn calves. Vet. Res. 30(5): 509-522.

Besser, T.E., C.C. Gay, and L. Pritchett. 1991. Comparison of three methods of feeding colostrum to dairy calves. J. Am. Vet. Med. Assoc. 198: 419-422.

Bewley, J., R.W. Palmer, and D.B. Jackson-Smith. 2001. A comparison of free-stall barns used by modernized Wisconsin dairies. J. Dairy Sci. 84: 528-541.

Blom, J.Y. 1982. The relationship between serum immunoglobulin values and incidence of respiratory disease and enteritis in calves. Nord. Vet. Med. 34:276–284.

Blum, J. W. 2006. Nutritional physiology of neonatal calves. J. Anim. Physiol. Anim. Nutr. (Berl.) 90:1–11.

Blum, J. W., and C. R. Baumrucker. 2002. Colostral and milk insulinlike growth factors and related substances: Mammary gland and neonatal (intestinal and systemic) targets. Domest. Anim. Endocrinol. 23:101–110.

Bøe, K.E., and G. Færevik. 2003. Grouping and social preferences in calves, heifers and cows. Appl. Anim. Behav. Sci. 80: 175-190.

Boissy, A., G. Manteuffel, M.B. Jensen, R.O. Moe, B. Spruijt, L.J. Keeling, C. Winckler, B. Forkman, I. Dimitrov, J. Langbein, M. Bakken, I. Veissier, and A. Aubert. 2007. Assessment of positive emotions in animals to improve their welfare. Phys. & Behav. 92: 375-397.

Borderas, T. F., J. Rushen, M.A.G.von Keyserlingk, and A.M.B. de Passillé. 2009. Automated measurement of changes in feeding behavior of milk-fed calves associated with illness. J. Dairy Sci. 92: 4549-4554.

Brown, E. G., M. J. Vandehaar, K. M. Daniels, J. S. Liesman, L. T. Chapin, J. W. Forrest, R. M. Akers, R. E. Pearson, and M. S. Weber Nielsen. 2005b. Effect of increasing energy and protein intake on mammary development in heifer calves. J. Dairy Sci. 88:595–603.

Brscic, M., H. Leruste, L. F.M. Heutinck, E.A.M. Bokkers, M. Wolthuis-Fillerup, N. Stockhofe, F. Gottardo, B.J. Lensink, G. Cozzi, and C.G. Van Reenen. 2012. Prevalence of respiratory disorders in veal calves and potential risk factors. J. Dairy Sci. 95: 2753-2764.

Bruce, W.N., and G.C. Decker. 1947. Fly control and milk flow. J. Econ. Entomol. 40:530.

Budzynska, M., and D.M. Weary. 2008. Weaning distress in calves: effects of alternative weaning procedures. Appl. Anim. Behav. Sci. 112: 33-39

Butler, J.A., S.A. Sickles, C.J. Johanns, and R.F. Rosenbusch. 2000. Pasteurization of discard mycoplasma mastitic milk used to feed calves: thermal effects on various mycoplasmas. J. Dairy Sci. 83: 2285-2288.

Callan R.J., and F.B. Garry. Biosecurity and bovine respiratory disease. Vet. Clin. North Am. Food Anim. Pract. 2002 (18): 57–77.

Calloway, C.D., J.W. Tyler, R.K. Tessman, D. Hostelter, and J. Holle. 2002. Comparison of refractometers and test endpoints in the measurement of serum protein concentration to assess passive transfer status in calves. J. Am. Vet. Med. Assoc. 221 (11): 1605-1608.

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.

Collins, K.A., S.J. Kay, A.J. Grant, and A.J. Quick. 1979. The effect on social organization and milk production of minor group alterations in dairy cattle. Appl. Anim. Ethol. 5: 103-111.

Cook, N.B., and K.V. Nordlund. 2004. Behavioral need of the transition cow and considerations for special needs facility design. Vet. Clin. Food Anim. 20: 495-520.

Cramer, M.C., T.L. Ollivett, and A.L. Stanton. 2016. Associations of behavior-based measurements and clinical disease in preweaned, group-housed dairy calves. J. Dairy Sci. 99: 7434-7443.

Cruz, A.M., and J.M. Naylor. 1993. A retrospective study of frostbite injuries in calves (1982-1991). Can. Vet. J. 34: 306-308.

Daniels, K.M., A.V. Capuco, M.L. McGilliard, R.E. James, and R.M. Akers. 2009. Effects of milk replacer formulation on measures of mammary growth and composition in Holstein heifers. J. Dairy Sci. 92: 5937-5950.

Davis C.L., and J.K. Drackley. 1998. The development, nutrition and management of the young calf. Ames (IA): Iowa State University Press.

Day, M.L., K. Imakawa, A.C. Clutter, P.L. Wolfe, D.D. Zalesky, M.K. Nielsen, and J.E. Kinder. 1987. Suckling behavior of calves with dams varying in milk production. J. Anim. Sci. 65: 1207-1212.

Dellmeier, G.R., T.H. Friend, and E.E. Gbur. 1985. Comparison of four methods of calf confinement II: behavior. J. Anim. Sci. 60 (5): 1102-1109.

de Passillé, A. M. 2001. Sucking motivation and related problems in calves. Appl. Anim. Behav. Sci. 72: 175-187.

de Passillé, A. M. B., R. Christopherson, and J. Rushen. 1993. Nonnutritive sucking by the calf and postprandial secretion of insulin, CCK and gastrin. Physiol. Behav. 54: 1069–1073.

de Passillé, A.M.B., J.H.M. Metz, P. Mekking, and P.R. Wiepkema. 1992. Does drinking milk stimulate sucking in young calves? Appl. Anim. Behav. Sci. 34: 23-36.

de Passillé, A. M., J. Rushen, and M. Janzen. 1997. Some aspects of milk that elicit non-nutritive sucking in the calf. Appl. Anim. Behav. Sci. 53:167–173.

de Passillé, A. M., J. Rushen, and D. Weary. 2004. Designing good environments and management for calves. Adv. Dairy Tech. 16: 75–89.

de Paula Vieira, A., V. Guesdon, A.M. de Passillé, M.A.G. von Keyserlingk, and D.M. Weary. 2008. Behavioural indicators of hunger in dairy calves. Appl. Anim. Behav. Sci. 109: 180-189.

Diaz, M.C., M.E. Van Amburgh, J.M Smith, J.M. Kelsey, and E.L. Hutton. 2001. Composition of growth of Holstein calves fed milk replacer from birth to 105=kilogram body weight. J. Dairy Sci. 84: 830-842.

Doherty, T.J., H.G., Kattesh, R.J. Adcock, M.G. Welborn, A.M. Saxton, J.L. Morrow, and J.W. Dailey. 2007. Effects of a concentrated lidocaine solution on the acute phase stress response to dehorning in dairy calves. J. Dairy Sci. 90: 4232-4239.

Donovan, G.A., I.R. Dohoo, D.M. Montgomery, and F.L. Bennet. 1998. Calf and disease factors affecting growth in female Holstein calves in Florida, USA. Prev. Vet. Med. 33: 1-10.

Drackley, J.K., B.C. Pollard, H.M. Dann and J.A. Stamey. 2007. First-lactation milk production for cows fed control or intensified milk replacer programs as calves. J. Dairy Sci. 90: 779.

Dufty, J.H. 1981. The influence of various degrees of confinement and supervision on the incidence of dystokia and stillbirths in Hereford heifers. N.Z. Vet. J. 29: 44-48.

Faber, S.N., N.E. Faber, T.C. Mccauley, and R.L. Ax. 2005. Effects of colostrum ingestion on lactational performance. The Professional Animal Scientist 21: 420-425.

Faulkner, P.M., and D.M. Weary. 2000. Reducing pain after dehorning in dairy calves. J. Dairy Sci. 83: 1037-2041.

Fecteau, G., P. Baillargeon, R. Higgins, J. Paré, and M. Fortin. 2002. Bacterial contamination of colostrum fed to newborn calves in Québec dairy herds. Can. Vet. J. 43(7): 523-527.

Federation of Animal Science Societies. Dairy cattle. In: Guide for the care and use of agricultural animals in teaching and research. 3rd edition. Champagne, IL. Federation of Animal Science Societies 2010. P 74-88.

Godden, S. 2008. Colostrum management for dairy calves. Vet. Clin. North Am. Food Anim. Pract. 24:19–39.

Godden, S.M., S. Smith, J.M. Feirtag, L.R. Green, S.J. Wells, and J.P. Fetrow. 2003. Effect of on-farm commercial batch pasteurization of colostrum on colostrum and serum immunoglobulin concentrations in dairy calves. J. Dairy Sci. 86: 1503-1512.

Graczyk, T.K., M.R. Cranfield, R. Fayer, and H. Bixler. 1999. House flies (*Musca domestica*) as transport hosts of *Cryptosporidium parvum*. Am. J. Trap. Med. Hyg. 61(3): 500-504.

Grooms, D.L., and L.A.K. Kroll. 2015. Indoor confined feedlots. Vet. Clin. North Am. Food Anim. Pract. 31: 295-304.

Hamnes, I.S., B. Gjerde, and L. Robertson. 2006. Prevalence of *Giardia* and *Cryptosporidium* in dairy calves in three areas of Norway. Vet. Parasitol. 140: 204-216.

Hartman, D.A., E.W. Everett, S.T. Slack, and R.G. Warner. 1974. Calf mortality. J. Dairy Sci. 57: 576-578.

Hasegawa, N., A. Nishiwaki, K. Suguwara, and I. Ito. 1997. The effects of social exchange between two groups of lactating primiparous heifers on milk production, dominance order, behavior, and adrenocortical response. Appl. Anim. Behav. Sci. 51: 15-27.

Heinrichs, A.J., B.S. Heinrichs, O. Harel, G.W. Rogers, and N.T. Place. 2005. A prospective study of calf factors affecting age, body size, and body condition score at first calving of dairy heifers. J. Dairy Sci. 88: 2828-2835.

Hepola, H. 2003. Milk feeding systems for dairy calves in groups: effects on feed intake growth and health. Appl. Anim. Behav. Sci. 50: 71-82.

Hill, T. M., H. G. Bateman, J. M. Aldrich, and R. L. Schlotterbeck. 2010. Effect of milk replacer program on digestion of nutrients in dairy calves. J. Dairy Sci. 93:1105–1115.

Huuskonen, A., and H. Khalili. 2008. Computer controlled milk replacer feeding strategies for group reared dairy calves. Livest. Sci. 113: 302-306.

Jasper, J., M. Budzynska, and D.M. Weary. 2008. Weaning distress in dairy calves: acute behavioural responses by limit-fed calves. Appl. Anim. Behav. Sci. 110: 136-143.

Jasper, J. and D.M.Weary. 2002. Effects of ad libitum milk intake on dairy calves. J. Dairy Sci. 85: 3054-3058.

Jenny, B.F., G.E. Gramling, and T.M. Glaze. 1981. Management factors associated with calf mortality in South Carolina dairy herds. J. Dairy Sci. 64: 2284-2289

Jensen, M.B. 2003. The effects of feeding method, milk allowance and social factors on milk feeding behaviour and cross-sucking in group housed dairy calves. Appl. Anim. Behav. Sci. 80 (3): 191-206.

Jensen, M.B., and L. Holm. 2003. The effect of milk flow rate and milk allowance on feeding related behavior in dairy calves fed by computer controlled milk feeders. Appl. Anim. Behav. Sci. 82: 87-100.

Jensen, M.B., L. Munksgaard, L. Mogensen, and C.C. Krohn. 1999. Effects of housing in different social environments on open-field and social responses of female dairy calves. Acta Agric., Scand. Section A-Animal Sci. 49: 113-120.

Jensen, M.B., K.S. Vestergaard, C.C. Krohn, and L. Munksgaard. 1997. Effect of single versus group housing and space allowance on responses of calves during open-field tests. Appl. Anim. Behav. Sci. 54: 109-121.

Jorgenson, L.J., N. A. Jorgensen, D.J. Schingoethe, M.J. Owens. 1970. Indoor versus outdoor calf rearing at three weaning ages. J. Dairy Sci. 53: 813-816.

Jung, J., and L. Lidfors. 2001. Effects of amount of milk. In: Lidfors, L., K. Svennersten-Sjaunja, and I. Redbo (eds.). Suckling: applied animal behavior sciences vol. 72 pp.201-213.

Kack, M. and J. Ziemerink. 2010. Benefits, function and operation of computer-controlled calf feeders. In: First North American Conference on Precision Dairy Management 2010, Toronto, Canada.

Kaneene, J.B., and H.S. Hurd. 1990. The national animal health monitoring system in Michigan. III. Cost estimates of selected dairy cattle diseases. Prev. Vet. Med. 8(2): 127-140.

Karzes, J. Dairy replacement programs: cost and analysis. In: Dairy calves and heifers: integrating biology and management. NRAES Conference. Syracuse, NY. 2005. pp. 10-23.

Kaske, M., A. Werner, H.-J. Schuberth, J. Rehage, and W. Kehler. 2005. Colostrum management in calves: effects of drenching vs. bottle feeding. J. Anim. Physiol. Anim. Nutr. 89: 151-157.

Khalili, H., S. Crosse, and T. Varvikko. 1992. The performance of crossbred dairy calves given different levels of whole milk and weaned at different ages. Anim. Prod. 54(2):191-195.

Khan, M.A., H.J. Lee, W.S. Lee, H.S. Kim, K.S. Ki, T.Y. Hur, G.H. Suh, S.J. Kang, and Y.J. Choi. 2007. Structural growth, rumen development, and metabolic and immune responses of Holstein male calves fed milk through step-down and conventional methods. J. Dairy Sci. 90:3376–3387.

Khan, M.A., H.J. Lee, W.S. Lee, H.S. Kim, S.B. Kim, S.B. Park, K.S. Baek, J.K. Ha, and Y.J. Choi. 2008. Starch source evaluation in calf starter: II. Ruminal parameters, rumen development, nutrient digestibilities, and nitrogen utilization in Holstein calves. J. Dairy Sci. 91:1140–1149.

Khan, M.A., D.M. Weary, and M.A.G. von Keyserlingk. 2010. Invited review: Effects of milk ration on solid feed intake, weaning and performance in dairy heifers. J. Dairy Sci. 94: 1071-1081.

Kiel, N.M., L. Audige, and W. Langhans. Is Intersucking in dairy cows the continuation of a habit developed in early life? J. Dairy Sci. 84 (1): 140-146.

Kiorpes, A., D. Butler, R. Dubielzieg, K. Beck. 1988. Enzootic pneumonia in calves: clinical and morphologic features. Comp. Cont. Educ. Pract. Vet. 10: 248-258.

Kondo, S., and J.F. Hurnik. 1990. Stabilization of social hierarchy in dairy cows. Appl. Anim. Behav. Sci. 27: 287-297.

Kung, L., S. Demarco, L.N. Siebenson, E. Joyner, G.F.W. Haenlein, and R.M. Morris.1997. An evaluation of two management systems for rearing calves fed milk replacer. J. Dairy Sci. 80: 2529–2533.

Lago, A., S.M. McGuirk, T.B. Bennett, N.B. Cook, and K.V. Nordlund. 2006. Calf respiratory disease and pen microenvironments in naturally ventilated calf barns in winter. Journal of Dairy Science 89: 4014-4025.

Leech, F.B., W.D. Macrea, and D.W. Menzies. 1968. Calf wastage and husbandry in Britain 1962-1963. Anim. Dis. Surveys Re. No. 5, Her Majesty's Stationery Office, London.

Le Neindre, P. 1989. Influence of rearing conditions and breed on social behavior and activity of cattle in novel environments. Appl. Anim. Behav. Sci. 23: 129-140.

Le Neindre, P. 1993. Evaluating housing systems for veal calves. J. Anim. Sci. 71: 1345-1354.

Lidfors, L.M. 1993. Cross-sucking in group-housed dairy calves before and after weaning off milk. Appl. Anim. Behav. Sci. 38: 15-24.

Lidfors, L. and L. Isberg. 2003. Intersucking in dairy cattle – review and questionnaire. Appl. Anim. Behav. Sci. 80: 207–231.

Loberg, J. and L. Lidfors. 2001. Effect of milkflow rate and presence of a floating nipple on abnormal sucking between dairy calves. Appl. Anim. Behav. Sci. 72: 189–199.

Lorenz, I., J.F. Mee, B. Earley, and S.J. More. 2011. Calf health from birth to weaning. I. General aspects of disease prevention. Ir. Vet. J. 64: 10-18.

Losinger, W. C. and A.J. Heinrichs. 1997. Management practices associated with high mortality among preweaned dairy heifers. J. Dairy Res. 64: 1–11.

Losinger, W.C., S.J. Wells, L.P Garber, H.S. Hurd, and L.A. Thomas. 1995. Management factors related to salmonella shedding by dairy heifers. J. Dairy Sci. 78:2464–2472.

Lundborg, K. 2004. Housing, management and health in Swedish dairy calves. Acta Universitatis Agriculturae Sueciae. Veterinaria 168:1-52.

Lundborg, G.K., E.C. Svensson, and P.A. Oltenacu. 2005. Herd-level risk factors for infectious diseases in Swedish dairy calves aged 0-90 days. Prev. Vet. Med. 68: 123-143.

Martig, J., P.H. Boss, J. Nicolet, and F. Steck. 1976. Etiology and predisposing factors in respiratory disease of milk-fattened veal calves. Livestock Prod. Sci. 3:285-295.

Martin, S.W., C.W. Schwabe, and C.E. Franti. 1975a. Dairy calf mortality rate: influence of management and housing factors on calf mortality rate in Tulare County, California. Am. J. Vet. Res. 36: 1111-1114.

Martin, S.W., C.W. Schwabe, and C.E. Franti. 1975b. Dairy calf mortality rate: the association of of daily meteorological factors and calf mortality. Can. J. Com. Med. 39: 377-388.

Maunsell, F., and G.A. Donovan. 2008. Biosecurity and risk management for dairy replacements. Vent. Clin. North Am. Food Anim. Pract. 24: 155-190.

Maunsell, F.P., D.E. Morin, P.D. Constable, W.L. Hurley, and G.C. McCoy. 1999. Use of mammary gland and colostral characteristics for prediction of IgG1 concentration and intramammary infection in Holstein cows. J. Am. Vet. Me. Assoc. 214: 1817-1823.

McGuirk, S.M. 2008. Disease management of dairy calves and heifers. Vet. Clin. North Am. Food Anim. Pract. 24: 139-153.

McGuirk S.M., and M. Collins. 2004. Managing the production, storage and delivery of colostrum. Vet. Clin. North Am. Food Anim. Pract, 20(3):593–603.

McInnes, R., D. McInnes, R. Papworth, and A. McIntyre. 2015. Influence of teat flow rate in commercial milk feeding systems on calf digestion and performance. J. App. Nutr. 3: e11.

McMartin, S., S. Godden, L. Metzger, J. Feirtag, R. Bey, J. Stabel, S. Goyal, J. Fetrow, S. Wells, and H. Chester-Jones. 2006. Heat treatment of bovine colostrum I: effects of temperature on viscosity and immunoglobulin G level. J. Dairy Sci. 89: 2110-2118.

Mee, J.F. 1991. Bovine perinatal mortality and parturient problems in Irish dairy herds. PhD Diss. National University of Ireland 1-365).

Mee, J.F. 2004. Managing the cow at calving time. Vet. Clin. North Am. Food Anim. Pract 20: 521-546.

Mee, J.F. 2008. Newborn dairy calf management. Vet. Clin. North Am. Food Anim. Pract. 24 (1):1-17.

Mellor, D.J., and K.J. Stafford. 2004. Animal welfare implications of neonatal mortality and morbidity in farm animals. Vet. Journal 168: 118-133.

Meyer, C.L., P.J. Berger, and K.J. Koehler. 2000. Interactions among factors affecting stillbirths in Holstein cattle in the United States. J. Dairy Sci. 83: 2657-2663.

Meyer, M. J., A. V. Capuco, D. A. Ross, L. M. Lintault, and M. E. Van Amburgh. 2006. Developmental and nutritional regulation of the prepubertal bovine mammary gland: II. Epithelial cell proliferation, parenchymal accretion rate, and allometric growth. J. Dairy Sci. 89:4298–4304.

Michanek, P., and M. Ventorp. 1993. Passive immunization of new-born dairy calves on three farms with different housing systems. Swed. J. Ag. Res. 23: 37-43.

Moallem, U., D. Werner, H. Lehrer, M. Zachut, L. Livshitz, S. Yakoby, and A. Shamay. 2010. Long-term effects of ad libitum whole milk prior to weaning and prepubertal protein supplementation on skeletal growth rate and first-lactation milk production. J. Dairy Sci. 93:2639–2650.

Mohammed, H. O., S.E. Wade, and S. Schaaf. 1999. Risk factors associated with *Cryptosporidium parvum* infection in dairy cattle in southeastern New York State. Vet. Parasit. 83:1–13.

Morin, D.E, G.C. McCoy, and W.L. Hurley. 1997. Effects of quality, quantity, and timing of colostrum feeding and addition of a dried colostrum supplement on immunoglobulin G1 absorption in Holstein bull calves. J. Dairy Sci. 80: 747-753.

Nakanishi, Y., T. Kawamura, T. Goto, and R. Umetsu. 1993. Comparative aspects of behavioral activities of beef cows before and after introducing a stranger at night. J. Faculty Agric. Kyushu University 37: 227-238.

Nakanishi, Y., Y. Mutoh, R. Umetsu, Y. Masuda, and I. Goto. 1991. Changes in social and spacing behavior of Japanese Black cattle after introducing a strange cow into a stable herd. J. Faculty Agric. Kyushu University 36: 1-11.

Nardell, E.A., J. Keegan, S.A. Cheney, and S.C. Etkind. 1991. Airborne infection: theoretical limits of protection achievable by building ventilation. Am. Rev. of Resp. Dis. 144(2): 302-306.

Nielsen, P.P., M.B. Jensen, and L. Lidfors. Milk allowance and weaning method affect the use of a computer controlled milk feeder and the development of cross-sucking in dairy calves. Appl. Anim. Behav. Sci. 109: 223-237.

Nonnecke, B.J., M.R. Foote, J.M. Smith, B.A. Pesch, and M.E. Van Amburgh. 2003. Composition and functional capacity of blood mononuclear leukocyte populations from neonatal calves on standard and intensified milk replacers. J. Dairy Sci. 86: 3592-3604.

Nordlund, K.V. 2008. Practical considerations for ventilating calf barns in winter. Vet. Clin. Food. Anim. 24: 41-54.

Olson, D.P., C.J. Papasian, and R.C. Ritter. 1980. The effects of cold stress on neonatal calves. I. Clinical condition and pathological lesions. Can. J. Comp. Med. 44: 11-18a.

Omidbakhsh N., and S.A. Sattar. 2006. Broad-spectrum microbicidal activity, toxicologic assessment, and materials compatibility of a new generation of accelerated hydrogen peroxide-based environmental surface disinfectant. Am. J. Infect. Control 34(5):251–7.

Owen, F.G., and L.L. Larson. 1982. A simplified liquid feeding program for calves. J. Dairy Sci. 65: 1350-1356.

Oxender, W.D., L.E. Newman, and D.A. Morrow. 1973. Factors influencing calf mortality in Michigan dairy herds. J. Am. Vet. Med. Assoc. 162: 458-462.

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(4): 597-602.

Pritchett, L.C., C.C. Gay, D.D. Hancock, and T.E. Besser. 1994. Evaluation of the hydrometer for testing immunoglobulin G 1 concentrations in Holstein colostrum. J. Dairy Sci. 77: 1761-1767.

Quigley III, J.D., C.S.T. Nyabadza, G. Benedictus, and A. Brand. 1996. Monitoring replacement rearing: objectives and materials and methods. Herd Health and Production Management in Dairy Practice. A. Brand, J.P.T.M. Noordhuizen, and Y.H. Schukken, eds. Wageningen Press, Waageningen, the Netherlands, pp. 75-102.

Quigley, J.D., T.A. Wolfe, and T.H. Elsassert. 2006. Effects of additional milk replacer feeding on calf health, growth, and selected blood metabolites in calves. J. Dairy Sci. 89: 207-216.

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 parcum oocysts. J. Appl. Environ. Microbiol. 71(5): 2479-2483.

Radostitis, O.M., K.E. Leslie, and J. Fetrow. 1994. Herd Health: Food Animal Production Medicine (second ed.), vol. 1, W.B. Saunders Company, Philadelphia, PA.

Raeth-Knight, M., H. Chester-Jones, S. Hayes, J. Linn, R. Larson, D. Ziegler, B. Ziegler, and N. Broadwater. 2009. Impact of conventional or intensive milk replacer programs on Holstein heifer performance through six months of age and during first lactation. J. Dairy Sci. 92:799–809.

Rugbjerg, H., E.M. Nielsen, and J.S. Andersen. 2003. Risk factors associated with faecal shedding of verocytotoxin-producing *Escherichia coli* O157 in eight known-infected Danish dairy herds. Prev. Vet. Med. 58:101–113.

Rushen, J., A.M. de Passillé, M.A.G. von Keyserlingk, and D.M. Weary. 2008a. Feeding and nutrition. Pages 211-228 in The Welfare of Cattle. C. Phillips, ed. Springer.

Rushen, J., A.M. de Passillé, M.A.G. von Keyserlingk, and D.M. Weary. 2008b. Housing for growing animals. Pages 181-210 in The Welfare of Cattle. C. Phillips, ed. Springer.

Schmidtmann, E. 1991. Suppressing immature house and stable flies in outdoor calf hutches with sand, gravel, and sawdust bedding. J. Dairy Sci. 74: 3956-3960.

Schuijt, G., and M.A.M. Taverne. 1994. The interval between birth and sternal recumbency as an objective measure of the vitality of newborn calves. Vet. Rec. 135: 111-115.

Shen, Z., H. M. Seyfert, B. Lohrke, F. Schneider, R. Zitnan, A. Chudy, S. Kuhla, H. M. Hammon, J. W. Blum, H. Martens, H. Hagemeister, and J. Viogt. 2004. An energy rich diet causes rumen papillae proliferation associated with more IGF type 1 receptors and increased plasma IGF-1 concentrations in young goats. J. Nutr. 134:11–17.

Silanikove, N. 2000. Effects of heat stress on the welfare of extensively managed domestic ruminants. Livest. Prod. Sci. 67: 1-18.

Sivula, N.J., T.R. Ames, W.E. Marsh, and R.E. Werdin. 1996. Descriptive epidemiology of morbidity and mortality in Minnesota dairy heifer calves. Prev. Vet. Med. 27(3): 155-171.

Smith, G.W. 2009. Treatment of calf diarrhea: oral fluid therapy. Vet. Clin. Food Anim. 25: 55-72.

Snowder, G.D., L.D. Van Vleck, L.V. Cundiff, and G.L. Bennet. 2006. Bovine respiratory disease in feedlot cattle: environmental, genetic, and economic factors. J. Anim. Sci. 84: 1999-2008.

Soberon, F., E. Raffrenato, R.W. Everett, and M.E. Van Amburgh. 2012. Preweaning milk replacer intake and effects on long-term productivity of dairy calves. Journal of Dairy Science 95 (2): 783-793.

Sowerby, M.E., and C.E. Polan. 1978. Milk production response to shifting cows between intraherd groups. J. Dairy Sci. 61: 455-460.

Speicher, J.A., and R.E. Hepp. 1973. Factors associated with calf mortality in Michigan dairy herds. J. Am. Vet. Med. Assoc. 162: 436-466.

Stewart, S., S. Godden, R. Bey, P. Rapnicki, J. Fetrow, R. Farnsworth, M. Scanlon, Y. Arnold, L. Clow, K. Mueller, and C. Ferrouillet. 2005. Preventing bacterial contamination and proliferation during the harvest, storage, and feeding of fresh bovine colostrum. J. Dairy Sci. 88: 2571-2578.

Stull, C.L., and S.P. McDonough. 1994. Multidisciplinary approach to evaluating welfare of veal calves in commercial facilities. J. Anim. Sci. 72: 2518-2524.

Svensson, C., and P. Liberg. 2006. The effect of group size on health and growth rate of Swedish dairy calves housed in pens with automatic milk-feeders. Prev. Vet. Med. 73: 43-53.

Svensson, C., A. Linder, and S.O. Olsson. 2006. Mortality in Swedish dairy calves and replacement heifers. J. Dairy Sci. 89: 4769-4777.

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.

Sweeney, B. C., J. P. Rushen, D. M. Weary, and A. M. B. de Passillé. 2010. Duration of weaning, starter intake, and weight gain of dairy calves fed large amounts of milk. J. Dairy Sci. 93:148–152.

Szenci, O. 2003. Role of acid-base disturbance in perinatal mortality of calves: a review. Vet. Bull. 73: 7R-14R.

Thickett, W.S., D. Mitchell, and B. Hallows. 1986. Calf Rearing. Farming Press, Ipswich, UK.

Tikofsky, J.N., M.E. Van Amburgh, and D.A. Ross. 2001. Effect of varying carbohydrate and fat content of milk replacer on body composition of Holstein bull calves. J. Anim. Sci. 79: 2260-2267.

Tozer, P.R. and A.J. Heinrichs. 2001. What affects the costs of raising replacement dairy heifers: a multiple component analysis. J. Dairy Sci. 84:1836-1844.

Tyler, J.W., D.D. Hancock, J.G. Thorne, C.C. Gay, and J.M. Gay. 1999. Partitioning the mortality risk associated with inadequate passive transfer of colostral immunoglobulins in dairy calves. J. Vet. Int. Med. 13: 335-337.

Unshelm, J., U. Andreae, and D. Smidt. 1982. Behavioural and physiological studies which are relevant to the welfare of young calves. In: J.P. Signoret (ed.). Welfare and husbandry of calves. Martinus Nijhoff, The Hague, pp. 47-69.

USDA. 2007. USDA Dairy 2007, part I: reference of dairy cattle health and management. Practices in the United States, 2007. USDA-APHIS-VS, CEAH. Fort Collins, CO. Accessed July 1, 2016. https://www.aphis.usda.gov/animal_health/nahms/dairy/downloads/dairy07/Dairy07_ir_CalfHealth.pdf

USDA. 2010. Dairy 2007, heifer calf health and management practices on U.S. dairy operations. USDA-APHIS-VS, CEAH. Fort Collins, CO. Accessed July 1 2016. https://www.aphis.usda.gov/animal_health/nahms/dairy/downloads/dairy14/Dairy14_dr_PartI.pdf

USDA. 2016. Dairy 2014. Dairy cattle management practices in the United States, 2014. USDA-APHIS-VS- CEAH-NAHMS. Fort Collins, CO.

Van Donkersgoed J., C.S. Ribble, L.G. Boyer, and G.G. Townsend. 1993. Epidemiological study of enzootic pneumonia in dairy calves in Saskatchewan. Can. J. Vet. Res. 57:247–54.

Vasseur, E., F. Borderas, R.I. Cue, D. LeFebvre, D. Pellerin, J. Rushen, K.M. Wade, and A.M de Passillé. 2010. A survey of dairy calf management practices in Canada that affect animal welfare. J. Dairy Sci. 93: 1307-1315.

Veissier, I., A. Boissy, S. Russel, A.M. de Passillé, J. Rushen, and K. Van Reenen. 2000. Calves' responses to repeated social regrouping and relocation. In: Ramos, A., L.C. Pinheiro Machado Filho, and M.J. Hötzel (eds.). Proceedings of the 34th International Congress of the ISAE, Florianopolis, Brazil, pp. 72.

Veissier, I., A.M. de Passillé, G. Després, J. Rushen, I. Charpentier, A.R. Ramirez de la Fe, and P. Pradel. 2002 Does nutritive and non-nutritive sucking reduce other oral behaviors and stimulate rest in calves? J. Anim. Sci. 80: 2574-2587.

Veissier, I., V. Gesmier, P. Le Neindre, J.Y. Gautier, and G. Bertrand. 1994. The effects of rearing in individual crates on subsequent social behavior of veal calves. Appl. Anim. Behav. Sci. 41: 199-210.

Vickers, K.J., L. Neil, L.M. Kiehlbauch, and D.M. Weary. 2005. Calf response to caustic paste and hot-iron dehorning using sedation with and without local anesthetic. J. Dairy Sci. 88: 1454-1459.

Villarroel, A., D.A. Dargatz, M. Lane, B.J. McCluskey, and M.D. Salman. 2007. Suggested outline of potential critical control points for biosecurity and biocontainment on large dairy farms. J. Am. Vet. Med. Assoc. 230: 808-819.

Virtala, A.-M.K., G.D. Mechor, Y.T. Gröhn, and H.N. Erb. 1996. The effect of calfhood diseases on growth of female dairy calves during the first 3 months of life in New York State. J. Dairy Sci. 79: 1040-1049.

Vitale, A.F., M. Tenucci, M. Papini, and S. Lovari. 1986. Social behavior of the calves of semiwild Maremma cattle, *Bos Primigenius Taurus*. Appl. Anim. Behav. Sci. 16: 217-231.

von Keyserlingk, M.A.G., L. Brusius, and D.M. Weary. 2004. Competition for teats and feeding behavior by group-housed dairy calves. J. Dairy Sci. 87: 4190-4194.

Waltner-Toews, D., S. Martin, and A. Meek. 1986a. Dairy calf management, morbidity and mortality in Ontario Holstein herds. II. Age and seasonal patterns. Prev. Vet. Med. 4: 125-135.

Waltner-Toews, D., S. Martin, and A. Meek. 1986b. Dairy calf management, morbidity and mortality in Ontario Holstein herds. III. Association of management with morbidity. Prev. Vet. Med. 4: 137-158.

Waltner-Toews, D., S. Martin, and A. Meek. 1986c. Dairy calf management, morbidity and mortality in Ontario Holstein herds. IV. Association of management with mortality. Prev. Vet. Med. 4: 159-171.

Wathes, C., C. Jones, and A. Webster. 1983. Ventilation, air hygiene and animal health. Vet. Rec. 113: 554-559.

Weary, D.M., J. Jasper, and M.J. Hötzel. 2008. Understanding weaning distress. Appl. Anim. Behav. Sci. 110: 24-41.

Weaver, D.M., J.W. Tyler, D.C. VanMetre, D.E. Hostelter, and G.M. Barrington. 2000. Passive transfer of colostral immunoglobulins in calves. J. Vet. Intern. Med. 14(6): 569-577.

Webster, J. 1984. Calf husbandry, health and welfare. Collins, London, UK, pp. 71-97.

Webster, A. J. F., C. Saville, B.M. Church, A. Gnanasakthy, and R. Moss. 1985a. The effect of different rearing systems on the development of calf behaviour. British Veterinary Journal 141:249-264.

Webster, A. J. F., C. Saville, B.M. Church, A. Gnanasakthy, and R. Moss. 1985b. Some effects of different rearing systems on health, cleanliness and injury in calves. British Veterinary Journal 141:472–483.

Wells, S.J., S. Dee, and S. Godden. 2002. Biosecurity for gastrointestinal diseases of adult dairy cattle. Vet. Clin. North Am. Food Anim. Pract.18: 35-55.

Wells, S.J., L.P. Garber, and G.W. Hill. 1996. Health status of preweaned dairy heifers in the United States. Prev. Vet. Med. 29: 185-199.

Wiepkema, P.R., D.M. Broom, I.J.H. Duncan, and G. van Putten. 1983. Abnormal behaviours in farm animals. Report of the commission of the European communities, pp.16.

Williams, P. E. V., and A. J. Frost. 1992. Feeding the young ruminant. Pages 109–118 in Neonatal Survival and Growth. Occasional Publ. No. 15. M. Varley, P. E. V. Williams, and T. L. J. Lawrence, ed. Br. Soc. Anim. Prod., Edinburgh, UK.

Wilson, L.L., J.L. Smith, D.L. Smith, D.L Swanson, T.R. Drake, D.R. Wolfgang, and E.F. Wheeler. 2000. Characteristics of veal calves upon arrival, at 28 and 84 days, and at end of the production cycle. J. Dairy Sci. 83(4): 843-854

Wolf, C.A. 2003. Custom dairy heifer grower industry characteristics and contract terms. J. Dairy Sci. 86:3016-3022.

Woodgush, D.G.M., S.G.C. Dennison, K. Carson, and K.A. Hunt. 1984. The early behavior of suckler calves in the field. Biol. Behav. 9: 295-306.

Appendix I -Tables

Table 1: Seasonal summary of daily average, minimum and maximum temperature recordings in °C (± S.D.) on all farms.

Season	Daily Avg. Temp. (±S.D.)	Daily Min. Temp. (±S.D.)	Daily Max. Temp. (±S.D.)
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)

Table 2: Seasonal daily average temperature (◦C ; ± SD) by ventilation type.

Season	Naturally Ventilated (n=19)	Mechanically Ventilated (n=15)	Tunnel Ventilated (n=3)	Igloo (n=1)
Fall 1	0.90 (±1.35)	2.42 (±1.58)	-	-
Winter 1	-2.90 (±1.80)	0.71 (±4.71)	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

Table 3: Comparison of median (+IQR) of average coliform and standard plate (SPC) bacterial count (cfu/mL) in milk samples from the automated feeder mixing jar and tube end on the 10 farms with highest and lowest counts.

	Tube Coliform (CFU/ml)	Mixer Coliform (CFU/ml)	Tube SPC (CFU/ml)	Mixer SPC (CFU/ml)
Median of Top 10 (Q1-Q3)	887 (206-1,211)	12 (3-15)	87,590 (32,603-134,940)	9,006 (2,308-9,392)
Median of Bottom 10 (Q1-Q3)	5,659,567 (1,198,059-14,344,063)	522,263 (64,564-20,001,213)	21,140,625 (18,644,538-71,642,610)	10,209,920 (3,204,500-43,673,293)

Table 4: Distribution frequencies of calf health scores for attitude, ear, eye, nasal, cleanliness, and sick.

Score	**Attitude Score**	**Ear Score**	**Eye Score**	**Nasal Score**	**Clean Score**	**Sick**	
4	2	3	-	-	-	550	Confirmed Temperature
3	5	14	39	7	-	9,628	No Temperature
2	283	235	515	212	958	-	
1	1,352	622	2,045	1,804	3,303	-	
0	8,537	9,304	7,579	8,155	5,918	-	
Total calves	10,179	10,178	10,178	10,178	10,179	10,178	
Calves scoring ≥ 1	16.1%	8.6%	25.5%	19.9%	41.9%	5.4%	Sick Animals
Calves scoring ≥ 2	2.8%	2.5%	5.4%	2.2%	9.4%	-	

Table 5: Univariate association of health score categories with farm level variables

Attitude Score		Ear Score		Eye Score		Nasal Score		Cleanliness Score		Sick (Yes/No)	
Var.	P-Value	Var.	P-Value	Var.	P-Value	Var.	P-Value	Var.	P-Value	Var.	P-Value
Season	<.0001	Season	<.0001	Season	<.0001	Season	<.0001	Season	<.0001	Season	0.0003
Vent. type	0.0133	Calves/ group	0.0005	Calves/ group	0.0008	Bed depth	0.0001	Start milk all.	0.0003	Days to peak milk	0.0025
Days to peak milk	0.0202	M2/ calf	0.0019	Pen shape	0.0116	Vent. Type	0.0053	Peak milk all.	0.0005	Tube SPC cat.	0.0065
Tube SPC cat.	0.0316	Vent. type	0.0075	M2/ calf	0.021	Total wean time	0.0132	Days to peak milk	0.0009	Vent tube	0.0495
Farm avg. STP	0.057	Tube SPC cat.	0.0372	Avg. total solids (%)	0.0245	Max. air speed in pen	0.0503	Liquid diet type	0.0018	Liquid diet type	0.1447
Vent tube	0.191	Vent tube	0.038	Avg. fat (%)	0.0326	Calves/ group	0.0611	Avg. fat (%)	0.0075	Tube colif. cat.	0.2447
M^2/ calf	0.2215	Total wean time	0.0571	Max. air speed in pen	0.0485	Mixer colif. cat.	0.068	Pen shape	0.0115		
Wean length	0.2751	Pen shape	0.0734	Vent. type	0.0581	Vent tube	0.0719	Mixer SPC cat.	0.0451		
Start milk all.	0.2833	Days to peak milk	0.0796	Wean. calves in pen	0.0825	Avg. fat (%)	0.0887	Calves/ group	0.047		
		Start milk all.	0.2013	Pen area	0.0917	Avg total solids (%)	0.1189	Pen area	0.0785		
		Calf mgr. on site	0.213	Avg. protein (%)	0.1174	Pen area	0.167	Med. diet	0.1063		
		Age range in pen	0.2288	Bed type	0.1374	Liquid diet type	0.1984	Avg. protein (%)	0.1701		
				Colost. Vol.	0.169						
				Days to peak milk	0.1996						
				Bed depth	0.2043						

Table 6: Association of health score categories with season of measurement (Odds ratio estimates and 95% confidence intervals). Values marked with “a” have 95% confidence intervals that do not overlap with the reference season (Winter 2).

		Attitude Score	Ear Score	Eye Score	Nasal Score	Cleanliness Score	Sick Score
Season		Estimate (95% CI)	Estimate (95% CI)	Estimate (95% CI)	Estimate (95% CI)	Estimate (95% CI)	Estimate (95% CI)
Fall 1	Winter 2	1.046	1.438	0.224 [a]	0.053 [a]	0.601 [a]	0.338 [a]
		(0.756-1.448)	(0.875-2.364)	(0.133-0.378)	(0.033-0.086)	(0.427-0.846)	(0.184-0.621)
Fall 2	Winter 2	0.738[a]	1.294	1.741	0.835	0.758 [a]	0.831
		(0.575-0.947)	(0.882-1.898)	(1.259-2.406)	(0.639-1.092)	(0.591-0.973)	(0.567-1.218)
Spring 1	Winter 2	0.585 [a]	0.994	0.422 [a]	0.216 [a]	0.428 [a]	0.421 [a]
		(0.452-0.756)	(0.667-1.481)	(0.298-0.598)	(0.163-0.287)	(0.332-0.551)	(0.277-0.641)
Spring 2	Winter 2	0.892	0.832	0.414 [a]	0.7 [a]	0.468 [a]	0.618
		(0.646-1.233)	(0.483-1.433)	(0.26-0.66)	(0.496-0.989)	(0.336-0.65)	(0.362-1.055)
Summer 1	Winter 2	0.799	0.858	0.99	0.252 [a]	0.539 [a]	0.508 [a]
		(0.622-1.026)	(0.57-1.291)	(0.711-1.378)	(0.191-0.333)	(0.418-0.694)	(0.338-0.764)
Winter 1	Winter 2	0.978	1.87	0.417 [a]	0.151 [a]	0.777	0.506 [a]
		(0.757-1.263)	1.259-2.778)	(0.289-0.602)	(0.112-0.205)	(0.597-1.011)	(0.329-0.776)
P-Value		<0.0001	0.0003	<0.0001	<0.0001	<0.0001	<0.0001

Table 7: Multivariate association of health score categories with farm level variables (odds ratio estimates and 95% confidence intervals). Odds ratios predict increase in health score per unit of increase in the factor of interest.

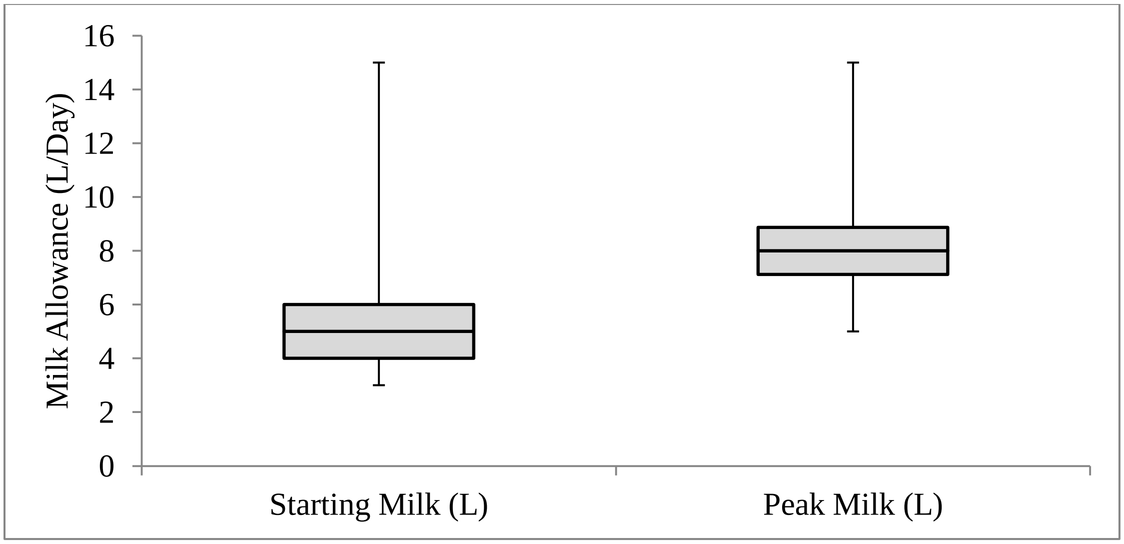
Health Score	**Variable**	**OR Estimate**	**P-Value**	**95% Confidence Limits**	
Attitude Score	Tube SPC (High/Normal)	1.207	0.0329	1.015	1.436
	Days to Peak Milk Allowance	1.013	0.0238	1.002	1.025
Ear Score	Stocking Density	0.896	0.0055	0.83	0.968
	Days to Peak Milk Allowance	1.022	0.0392	1.005	1.039
	Tube SPC (High/Normal)	1.318	0.0103	1.014	1.715
Eye Score	Pen Shape (Rect./Square)	0.463	0.0107	0.256	0.836
	Stocking Density	0.923	0.0075	0.87	0.979
	Average Fat (%) of Liquid Diet	1.624	0.0056	1.153	2.288
	Days to Peak Milk Allowance	1.022	0.0392	1.001	1.043
Nasal Score	Number of Calves/Group	1.011	0.0439	1	1.022
Cleanliness Score	Peak Milk Allowance	0.882	0.0009	0.819	0.95
	Days to Peak Milk Allowance	1.019	0.006	1.005	1.033
	Number of Calves/Group	0.987	0.0476	0.974	1
Sick (Yes/No)	Days to Peak Milk Allowance	1.025	0.0016	1.01	1.041
	Tube SPC (High/Normal)	1.815	<.0001	1.351	2.439
	Pos. Press. Ventilation Tube	1.806	0.0251	1.077	3.029

Table 8: Seasonal treatment rate (treatments/hundred animals) least squares means of 7 farms using automated feeders in the upper Midwest. Means with significant differences (P<0.05) are denoted by differing superscript letters.

Season	Least Squares Mean
Spring	54.70 [a]
Summer	71.10 [a]
Fall	76.80[a,b]
Winter	103.91 [b]

Appendix II –Figures

Figure 1: Milk allowance (L/day) at day 1 and peak milk allowance for calves on automated feeding systems (Median, IQR, Range)



Appendix III - Questionnaire

Producer Questionnaire
Management of Automated Feeding Systems

Date:

Producer Information

Farm ID Number:

Farm Information

Number of Milking Animals:

Number of Heifers (Post-weaning):

Number of Calves:

Breed:

DHI Herd Code/RAC Code:

Autofeeder (Make/Model/Number):

<u>Section 1 – Calving & the Neonate</u>

Area Management

How is the calving area managed?

1. Does calving occur in a separate calving pen (apart from the primary herd)?
    a. What are the dimensions of the calving area?

    b. What is the depth of bedding in the calving area?

    c. Is the calving area exposed to environmental conditions (e.g. wind, rain)?

    d. Do newborn calves have contact with any animals besides the mother?

2. How often is the calving area cleaned (daily, between births, etc.)?

    a. Is the calving area washed or disinfected between births?

3. Is the calving area ever used to house sick animals?

Birth Monitoring

How are pregnant/due cows monitored?

1. How often are cows checked in the 24 hour period before birth?
    a. Are any special tools used in monitoring (e.g. cameras)?

Newborn Calves

What happens to calves immediately following birth?

1. How soon after birth is the umbilicus disinfected?
    a. What product is used?
    b. What concentration?
2. Are newborn calves assessed for vigor?
    a. How are weak calves stimulated (e.g. cold shower)?
3. Are nasal, oral and pulmonary secretions cleared?
4. How is the calf dried after birth?

Section 2 – Colostrum Management

What are your procedures for delivering colostrum?

1. When calving occurs at a given time of day, how long after birth (hours) does the first feeding of colostrum normally occur?
    a. Morning (5-11 am)
        i. Within 2 hrs. of calving
        ii. 2-6 hrs.
        iii. 6-12hrs.
        iv. >12 hrs.
        v. When the calf sucks
    b. Afternoon 11 am -5 pm
        i. Within 2 hrs. of calving
        ii. 2-6 hrs.
        iii. 6-12hrs.
        iv. >12 hrs.
        v. When the calf sucks
    c. Evening (5 pm – 11 pm
        i. Within 2 hrs. of calving
        ii. 2-6 hrs.
        iii. 6-12hrs.
        iv. >12 hrs.
        v. When the calf sucks
    d. Night (11 pm – 5 am)
        i. Within 2 hrs. of calving
        ii. 2-6 hrs.

iii. 6-12hrs.
iv. >12 hrs.
v. When the calf sucks

2. How is the first feeding of colostrum delivered? (percentages should Total: 100 %)

   a. Nursing the dam? _______% of calves
   b. Hand feeding by nurse bottle?_______% of calves
   c. Hand feeding by bucket?_______% of calves
   d. Esophageal (tube) feeder?_______% of calves

3. How much colostrum (L) is routinely hand-fed or tubed to each calf in the first feeding? (1 liter = ~1 quart)

   a. 2 liters
   b. 3 liters
   c. 4 liters
   d. More than 4 liters

   Is this colostrum from the first milking after birth? (Y/N)

4. At the time of colostrum feeding, which type(s) of colostrum are fed?

1 = never used → 4 = always used

Commercial colostrum replacer Manufacturer:_______________________	1 2 3 4 (circle)
Fresh colostrum from dam only	1 2 3 4 (circle)
Fresh colostrum from another cow	1 2 3 4 (circle)
Pooled colostrum from the herd	1 2 3 4 (circle)
Frozen Colostrum	1 2 3 4 (circle)
Pasteurized colostrum	1 2 3 4 (circle)
Acidified/preserved colostrum	1 2 3 4 (circle)

5. Is colostrum quality evaluated before feeding?

   □Yes □ No

   If yes, how?

6. Is the passive transfer of immunity evaluated in newborn calves (blood test) to assess colostrum management on the farm?

   □ Yes / □ Occasionally / □ No

Section 3 – Postnatal Procedures

What surgical procedures do calves experience?

1. Are calves dehorned?
    a. At what age?
    b. What is the method of dehorning (physical, chemical, thermal)?
    c. Pain Management

Drug	Anesthetic (pain relief during procedure)	Analgesic (pain relief following procedure)
Yes/ No		

2. Castration
    a. At what age?
    b. What is the method of castration (surgical removal, burdizzo)?
    c. Pain Management

Drug	Anesthetic (pain relief during procedure)	Analgesic (pain relief following procedure)
Yes/ No		

Section 4 – Calf Housing

Where on the farm are calves housed? How is this housing maintained?

1. At what age are calves separated from their mothers?

2. At what age are calves incorporated into groups?

    a. How are calves moved to group pens?

3. Calf grouping
    a. How many calves are there per group?
    b. What is the average age difference between the oldest and youngest calves in a group?
    c. Are weaned calves kept with unweaned calves?

4. Is bedding present in the calf pen?
    a. What type of bedding?

    b. How frequently is bedding changed when the pen is occupied?

        i. Is bedding changed between calf groups?

        ii. Is the pen washed/disinfected between groups?

Section 5 – Feeding

What are the feeding plans for calves on the automated system?

1. At what age are calves started on the automated feeder?
2. Are calves added to a feeder pen as an all in/all out group or as individuals?

3. What milk diet are calves fed?
    a. Milk replacer (brand & type, %CP, %FAT)
    b. Raw waste milk
    c. Pasteurized waste milk
    d. Salable bulk tank milk
    e. Multiple sources (describe)

4. What is the composition of the replacer mixture (powder:water ratio)

5. Is total-solids content of the liquid measured?

6. Feeding Schedules
    a. How frequently are feeding allotments reset (e.g. every 12 hrs.)?
        i. When does each (12 hr.) feeding period begin?
    b. How much time is each calf allowed per individual meal?

7. How much liquid are calves allowed per day (or is it ad libitum)?
    a. What is the intake limit per calf?
    b. What is the reason for this limitation (e.g. company recommended)
    c. What are the differences between summer and winter rations?
    d. What changes are made to feeding amount/frequency as calves age?

8. Is antibiotic/medication delivered with the milk?

9. What thresholds are set to indicate calf health issues?
    a. Food intake (e.g. less than max, reduced rate)
    b. Change in unrewarded visits

10. If a calf does not consume the full allotment at a meal, is this milk disposed of or retained and fed to the next animal?
    a. Can calves access another calf's leftover milk even if their own allotment has been consumed?
11. When are water, starter feed, hay first offered to the calves?
    a. Feed type:
        i. Water
        ii. Starter Feed
            1. What is the nutritional composition of the starter?

2. How much is available to each calf per day?

   a. How does this change as the calf ages?

iii. Hay

b. Is there continuous access to solid food/water?
c. Is water/solid food intake measured per calf?
d. Is water/solid food intake limited?

Section 6 – Weaning

What is the farm's weaning plan?

1. At what age (days) does weaning begin?
2. At what age (days) does weaning end?
3. What is the rate of reduction for milk rations over this period?

Section 7 – Automated Feeder System

How is the automated feeding equipment set up and maintained?

1. What make/model is the system?
   a. How many nipples/feeding stations are there?
2. When was the system installed on the farm?
3. Cleaning
   a. How often is the mixing tank cleaned?
   b. How often is the rest of the machine cleaned?
   c. How often are tubes/lines replaced?
   d. How often are nipples replaced (or sanitized)?
4. How is sanitation of the machinery evaluated?

   a. Is bacterial growth measured using standard plate counts?
   b. Where are samples obtained from?

5. How often is basic maintenance performed?
6. Who has responsibility for feeder maintenance (worker, manager, etc.)?

7. How are software alarms (identifying sick calves) set up?
   a. Change in overall intake, change in feeding rate, etc.
8. Who is responsible for care of calves (owner, family member, manager, employee)?

   a. Is this person responsible for other tasks on the farm?
      i. Which tasks?

9. What challenges have arisen since the conversion to automated feeding?

Section 8 – Pest Control

What pest (fly) control measures are taken on the farm?

- Are insect pests an issue on the farm?
- What measures are taken to control pest populations?
    - What chemicals are used?
        - How frequently?
    - Non chemical measures?

Section 9 - Cow & Calf Vaccinations

What vaccination schedules are cows and calves on?

- Which vaccinations do cows receive and when/how frequently?

Vaccine	Age at first Inoculation	Frequency of Inoculation

- Which vaccinations do calves receive and when/how frequently?

Vaccine	Age at first Inoculation	Frequency of Inoculation

Section 10 – Reasons for Transition to Automated Feeding

What were your motivations for installing automated feeding equipment?

Which of the following reasons factored in to your decision to switch to an automated feeding system?

Labor	Less time spent performing menial tasks	Low---1----2----3----4----5----6----7----8----9----10---High
	Reduction in cost of labor	Low---1----2----3----4----5----6----7----8----9----10---High
	Improved labor conditions	Low---1----2----3----4----5----6----7----8----9----10---High
	Other (please specify):	Low---1----2----3----4----5----6----7----8----9----10---High
Production Considerations	Improved calf data	Low---1----2----3----4----5----6----7----8----9----10---High
	Indicators of health issues	Low---1----2----3----4----5----6----7----8----9----10---High
	Natural diet changes (e.g. more gradual weaning procedure)	Low---1----2----3----4----5----6----7----8----9----10---High
	Improved growth rate (ADG)	Low---1----2----3----4----5----6----7----8----9----10---High
	Other (please specify):	Low---1----2----3----4----5----6----7----8----9----10---High
Behavioral Issues	Calves can move freely	Low---1----2----3----4----5----6----7----8----9----10---High
	Social interaction reduces issues at future mixing.	Low---1----2----3----4----5----6----7----8----9----10---High
	Other (please specify):	Low---1----2----3----4----5----6----7----8----9----10---High
Animal Welfare	Reduced disease incidence	Low---1----2----3----4----5----6----7----8----9----10---High
	Animals able to express social/play behaviors	Low---1----2----3----4----5----6----7----8----9----10---High
	Closer to natural feeding behavior	Low---1----2----3----4----5----6----7----8----9----10---High
	Other (please specify):	Low---1----2----3----4----5----6----7----8----9----10---High

Automated Feeder Unit
Cleaning Procedures Details

Farm ID:

Feeder Make/Model:

Additional Pumps (feeding stations):

Medical Dispenser/Supplement Hopper:

Is the medical dispenser in use? What is it dispensing?

<u>Automated Cleaning Functions</u>

1. How many times per day is the automated cleaning program scheduled to run?

2. What times does the auto-clean program run?

3. Is the manual circuit-cleaning function used?

4. How often is the circuit-cleaning function used?

5. How much water is used in the circuit-cleaning function?

6. Is the feeder set up to dispense water from the nipple ("clean teat")?

7. Is detergent used in the automated cleaning procedures? What type? What Concentration?
   Is acid used in the automated cleaning procedures? What type? What Concentration?

<u>Manual Cleaning Procedures</u>

1. How often are the nipples removed from the feeder and cleaned?

2. What is the procedure for cleaning the nipples (chemicals, duration, etc.)?

3. How often are the nipples disposed of and replaced with new nipples?

4. How often are the exterior tubes (from feeder to nipple) removed from the feeder and cleaned?

5. What is the procedure for cleaning the tubes (chemicals, duration, etc.)?

6. How often are the tubes disposed of and replaced with new nipples?

7. How often are interior tubes/valves cleaned?
8. What is the procedure for cleaning interior tubes/valves
9. How often is the room/area housing the automated feeder unit cleaned?
10. Is the room/area housing the automated feeder heated?
11. What is the condition of the room/area housing the feeder unit?

Have **ANY** cleaning procedures changed during the course of this study? What was changed and when were these changes implemented?