Adoption, Use, and Management of Automated Milk Feeders for Group-housed Dairy Calves

by

Catalina Medrano Galarza

A Thesis
presented to
The University of Guelph

In partial fulfilment of requirements
for the degree of
Doctor of Philosophy
in
Population Medicine

Guelph, Ontario, Canada

© Catalina Medrano Galarza, May, 2018
ABSTRACT

ADOPTION, USE, AND MANAGEMENT OF AUTOMATED MILK FEEDERS FOR GROUP-HOUSING DAIRY CALVES

Catalina Medrano Galarza  
University of Guelph, 2017  
Co-Advisors:  
Dr. Derek B. Haley  
Dr. Stephen J. LeBlanc

This thesis investigated the adoption of automated milk feeders (AMF) and the prevalence and effects of management practices used to raise calves in groups with AMF on Canadian dairy farms. I used three study designs: a survey, a longitudinal observational study, and a controlled trial.

The survey of 670 dairy farmers across Canada helped determine the prevalence of various calf management and feeding practices and compared these between farms using manual milk feeding (MMF) and AMF systems. The factors influencing producers to switch to AMF were also investigated. Sixteen-percent of respondents used an AMF. These farms were larger, used more automation, provided more milk to calves, and grouped calves at an earlier age compared with MMF farms. The key motivators for adoption of AMF were to raise better calves, provide higher milk allowances, reduce labour, and improve working conditions, while the key barriers were costs regarding investment in the equipment and group-housing facilities.

In the observational study, 17 farms in southern Ontario feeding milk with AMF to group-housed calves were visited 4 times over one year, to identify management factors associated with the prevalence of calf diarrhea (CD) and bovine respiratory disease (BRD). Overall calf-prevalence of CD and BRD were 23% and 17%. The use of calving pens for additional purposes, calf pens located in barns where older cattle were present, and inadequate quality of bedding (adding fresh bedding every ≥ 7 days, and allowing manure-saturated bedding to accumulate) were associated with increased within-pen disease prevalence.

The controlled trial investigated the effect of the age of introduction of calves to a group pen with an AMF (< 1 (early) vs. 5 days of age (conventional)) on learning to use the AMF,
growth, and the requirements for labour. Early introduction resulted in decreased total labour for milk feeding, despite the fact that early-introduced calves took longer to learn to use the AMF than conventional introduction. Average daily gain was not affected by age of introduction, but the risk of having a severe case of diarrhea was higher for early-introduced calves.
For my parents

Ricardo and Stella
ACKNOWLEDGEMENTS

Behind this thesis are many people and living beings who contributed to make it possible; and no matter how big their contribution was, they were all part of this long and fun journey. First, I would like to thank the Colombian Administrative Department of Science, Technology and Innovation – Colciencias for financially supporting my graduate studies.

Secondly, I would like to thank my co-advisors, Drs. Derek Haley and Stephen LeBlanc, and advisory committee, Drs. Trevor DeVries, Andria Jones-Bitton, and Jeff Rushen. Derek, thank you for accepting me as a student and for giving me the opportunity to come to the University of Guelph and be part of its best department - PopMed. Thank you for the confidence you had in me, and for being so patient. Thank you also for finding the best co-advisor and advisory committee to work with and to guide me; without them, it would have been very difficult. Thank you Stephen, for all your patience and guidance. I feel very fortunate to have had you as my co-advisor and that you always helped me every time I felt lost and for always being there to provide advice, and no matter what… you always had a smile on your face. It really made a difference the way you went through all my papers to help me correct my mistakes and improve my writing to finally complete a nice thesis. I would also like to thank Trevor for his guidance, for always having his office open to give advice and for giving feedback to papers in record time (no one had beat you!). Andria, I have to thank you for re-introducing me to the science of epidemiology and to be able to say now that I do enjoy it. I am thankful that you were the one in my committee who was always so thorough on your comments and corrections, but also the one that I felt was always making sure I was doing ok and always safe. Finally, Drs. Jeff Rushen and Anne Marie de Passillé, thank you for always trusting my capabilities, helping me dream bigger, and directing my way towards Guelph.

I would also like to thank Dr. Marcia Endres for her contributions to this thesis. Marcia, timing was not in my favor to be your student back in 2012, but destiny was determined to make it happen. This time not as your direct student, but having you as a collaborator all along the way. Thank you for all your help and advice, muito obrigada!

This work was also possible thanks to the participation and kindness of the Canadian dairy producers who answered the survey and those who allowed us to go into their farms. Thank you and your families and staff for all your help during our farm visits.
I would also like to thank all the staff of the Department of Population Medicine, specially Linda Kraemer and Sally Maclachlan for all their help and support during my years at *PopMed*, for making things much easier, and for organizing all the fun activities at the department because that made it feel that we all belong to the *PopMed* family. I would also want to thank all the managers and staff at the Research and Innovation Centre – Elora Dairy, Gail Ritchie, and the veterinarians Drs. Jeff Rau, Charlotte Winder, Stephen LeBlanc, and Todd Duffield, for all your help and support during my last months of data collection.

I also want to thank William Sears and Dr. Peter Physick-Sheard. To William, I am very grateful for all his stats support and patience, and for being so funny and never ever grumpy regardless of the question I had. Dr. Peter Physick-Sheard, thank you for your kindness and for always trying to improve my pronunciation and my public speaking… I hope it improved a bit.

Throughout these 4 years I have met awesome students - from Epi I and II study groups (Lindsay, Jil, Joana, and Daniella), from Behaviour group (specially, Aitor, Ivy, and Hillary), from Dr. Lee Neil’s Lab (Melissa, Carly, and Lauren), from the Dairy Lab (José, Elise, Amanda, Charlotte, Dave, Emma, Tanya, Stephanie, Maggie, Allison, Marianne, Clem, Alex, Rita, Osvaldo, and all the cow people), and all the volunteers (specially Mohammed, Heidi, Amanda, Pauline, and Larissa) who helped me during data collection times, and all the beautiful people living in “The Royal City” and surroundings - from Garcia-Baquero and Echeverry-Buemberguer’s houses, my frisbee team, and my apartment building. I want to thank all of them for being always there to give advice about research or life matters, and to have fun and celebrate. I need to say that an advantage of being far from home and being an international student is that it creates stronger bonds with very special people.

Family, love, and pets is all you need! Without my parents Ricardo and Stella, my sisters Camila and Juliana, my nephew Yaco, my nieces Martina and Federica, my darling half Nelson, and all my family I would not have made it. Being far from you was not easy, but definitely, God, Pepe 🐏, and all your love and support, gave me the encouragement and the strength to accomplish my goals… *los amo y adoro!* Also, I was very lucky to have here in Ontario, my cousin Cia and her family… thank you for all your love and for looking after Pepe and I! … *Love y’all!*
STATEMENT OF WORK

The funding for this project was provided by Dairy Farmers of Canada and Agriculture and Agri-Food Canada (Ottawa, ON, Canada) as part of the Dairy Research Cluster 2 program. The funding for tuition fees was provided by the Colombian Administrative Department of Science, Technology and Innovation – Colciencias (Bogota, Cundinamarca, Colombia).

All approvals for research involving human participants (Chapter 2, 3, and 4) and animal utilization protocols (Chapter 4 and 5) were obtained by Dr. Derek Haley and Catalina Medrano Galarza, and approved by the University of Guelph Research Ethics Board and Animal Care Committee, respectively.

Catalina Medrano Galarza and Dr. Derek Haley were responsible for study design for Chapters 2 and 3. Drs. Jeff Rushen, Anne Marie de Passillé, and Derek Haley were responsible for the proposed study design when applied for the Dairy Research Cluster 2 grant regarding part of the objectives of Chapter 4, but Catalina Medrano Galarza was responsible for the final study design implemented in Chapter 4, with advice from the advisory committee and Dr. Marcia Endres (University of Minnesota). Catalina Medrano Galarza was responsible for study design and protocol development for Chapter 5. Overall, all advisory committee members provided advice on study designs for all chapters.

Laboratory determination of total bacteria and coliform counts for Chapter 4 was performed by the Animal Health Laboratory, University of Guelph (Guelph, ON, Canada).

Statistical guidance for Chapters 2, 3, 4, and 5 was provided by William Sears and Drs. Stephen LeBlanc, Andria Jones-Bitton, and Trevor DeVries. Dr. David Pearl provided advice for some sections of Chapter 5 as well.

Preparation of the thesis in entirety was done by Catalina Medrano Galarza. The preparation included data collection (with the help of volunteers), data entry, data management, statistical analyses, writing, and manuscript preparation. Drs. Stephen LeBlanc, Trevor DeVries, Andria Jones-Bitton and Derek Haley provided editing assistance for all chapters. Drs. Jeff Rushen and Anne Marie de Passillé provided editing assistance for Chapter 4 and 5. Dr. Marcia Endres provided editing assistance for Chapters 4 and 5.
# TABLE OF CONTENTS

**ACKNOWLEDGEMENTS** .......................................................................................................................... v

**LIST OF TABLES** ................................................................................................................................. xii

**LIST OF FIGURES** ................................................................................................................................. xiv

**LIST OF APPENDICES** ......................................................................................................................... xvi

**LIST OF ABBREVIATIONS** ................................................................................................................... xviii

## CHAPTER 1. Review of literature .............................................................................................................. 1

1.1 INTRODUCTION ................................................................................................................................. 1

1.2 MILK ALLOWANCES: SHORT- AND LONG-TERM IMPACTS ......................................................... 3
  1.2.1 Impacts on Calf Growth and Health ........................................................................................ 3
  1.2.2 Impacts on Affective States ................................................................................................... 8
  1.2.3 Impacts on Calves’ Natural Living .......................................................................................... 10
  1.2.4 Impacts on Future Performance ............................................................................................ 11

1.3 MILK FEEDING METHODS ................................................................................................................. 12
  1.3.1 Impacts on Calf Growth and Health ..................................................................................... 12
  1.3.2 Impacts on Affective States .................................................................................................. 15
  1.3.3 Impacts on Natural Living .................................................................................................... 17

1.4 INDIVIDUAL AND GROUP HOUSING ............................................................................................... 18
  1.4.1 Impacts on Calf Health ......................................................................................................... 18
  1.4.2 Impacts on Affective States and Natural Living ..................................................................... 23

1.5 MANAGEMENT AND PERFORMANCE OF GROUP-HOUSED AUTOMATICALLY-FED CALVES ................................................................................................................................. 25
  1.5.1 Calf Health and Performance on Commercial Dairy Farms using Automated Milk Feeders ................................................................................................................................................................................................. 26
  1.5.2 Management Aspects of Group Housing with Automated Milk Feeders from Experimental Trials ................................................................................................................................................................................................. 29
     1.5.2.1 Age of introduction to the group pen ............................................................................... 29
     1.5.2.2 Adaptation to the automated milk feeder ....................................................................... 31
     1.5.2.3 Group sizes .................................................................................................................... 33

1.6 ADOPTION OF TECHNOLOGY ON FARMS ...................................................................................... 34
  1.6.1 Adoption of Automatic Milking Systems ............................................................................... 35
  1.6.2 Adoption of Precision Technologies ..................................................................................... 36

1.7 CONCLUSIONS AND RESEARCH OBJECTIVES ............................................................................ 37

1.8 REFERENCES ...................................................................................................................................... 39
CHAPTER 2. A survey of dairy calf management practices among farms using manual and automated milk feeding systems in Canada .......................................................... 56

2.1 ABSTRACT ........................................................................................................ 57
2.2 INTRODUCTION ................................................................................................. 58
2.3 MATERIALS AND METHODS ........................................................................ 59
  2.3.1 Sample Size Estimation ............................................................................... 59
  2.3.2 Collection and Description of Data ............................................................... 60
  2.3.3 Data Management and Analysis .................................................................. 61
2.4 RESULTS ............................................................................................................ 63
  2.4.1 General Description of Producers and Farms ............................................... 63
  2.4.2 Factors Associated with Having an Automated Milk Feeder ....................... 63
  2.4.3 Newborn Calf and Colostrum Management ............................................... 63
  2.4.4 Housing of Calves During the Milk-fed Period ........................................... 64
  2.4.5 Calf Feeding During the Milk-fed Period .................................................... 66
    2.4.5.1 Type of milk fed ...................................................................................... 66
    2.4.5.2 Daily milk allowance .............................................................................. 66
    2.4.5.3 Solid feed and water ............................................................................... 68
    2.4.5.5 Weaning .................................................................................................. 68
  2.4.6 Personnel in Charge of Calves Care ............................................................. 69
2.5 DISCUSSION ...................................................................................................... 70
2.6 CONCLUSIONS ................................................................................................. 74
2.7 ACKNOWLEDGEMENTS .................................................................................. 75
2.8 REFERENCES .................................................................................................... 76

CHAPTER 3. Producer perceptions of manual and automated milk feeding systems for dairy calves in Canada ................................................................. 86

3.1 ABSTRACT ........................................................................................................ 87
3.2 INTRODUCTION ................................................................................................. 87
3.3 MATERIALS AND METHODS ........................................................................ 88
3.4 RESULTS ............................................................................................................ 90
  3.4.1 General Description of Producers and Farms ............................................... 90
  3.4.2 Factors Influencing Decision-making Regarding Milk Feeding System for Calves .. 90
  3.4.3 Perceived Advantages and Disadvantages of Automated and Manual Milk Feeding Systems ............................................................ 92
    3.4.3.1 Advantages of automated milk feeding systems ................................... 92
    3.4.3.2 Advantages of manual milk feeding systems ....................................... 92
LIST OF TABLES

Table 1.1: Percentage of farms using specific calf management practices in the United States. National Health Monitoring Systems, covering 75 to 95% of the total dairy operations in this country from 1991 to 2014 ................................................................. 51

Table 1.2: Published research addressing the effects of higher milk allowances on growth and disease of dairy calves ................................................................. 52

Table 1.3: Published controlled trials addressing the effects of higher milk allowances on behaviours indicative of negative and positive affective states in dairy calves ................................ 53

Table 1.4: Published research addressing the effects of group housing on growth and disease of dairy calves in dairy calves ................................................................. 54

Table 1.5: Published controlled trials addressing the effects of group housing on behaviours and cognitive performance in dairy calves ................................................................. 55

Table 2.1: Percentage (95% CI) of participant farms using automated milk feeders (AMF, n= 105) and manual milking feeding (MMF, n = 565) systems for raising dairy calves from an online questionnaire completed by 670 dairy producers in Canada ................................................................. 80

Table 2.2: Number of milking cows on farms using automated milk feeders (AMF) and manual milking feeding (MMF) systems for raising dairy calves from an online questionnaire completed by 670 dairy producers in Canada ................................................................. 81

Table 2.3: Percentage (95% CI) of farms using automated milk feeders (AMF, n = 105) and manual milking feeding (MMF, n = 565) systems for raising dairy calves from an online questionnaire completed by 670 dairy producers in Canada ................................................................. 82

Table 2.4: Final logistic regression models evaluating factors associated with having an automated milk feeder for raising milk-fed dairy calves with geographic region as fixed effects to adjust for region effects1 ......................................................................................... 83

Table 2.5: Age at access to solid feed and water, age at weaning, and length of weaning period reported by farms using automated milk feeders (AMF) and manual milk feeding (MMF) systems from an online questionnaire completed by 670 dairy producers in Canada ................................................................. 84

Table 4.1: Calf health scoring system used to classify health status in calves housed in group pens and fed through automated milk feeders in 17 dairy farms in southern Ontario .......... 138

Table 4.2: Calf-level prevalence of diarrhea and respiratory disease from 17 dairy farms raising calves with automated milk feeders in southern Ontario for each of the 4 visits (one per season) to the farms ........................................................................................................ 139
Table 4. 3. Within herd- and within pen-level prevalence of calf diarrhea and respiratory disease by visit (seasonal) from 17 dairy farms raising calves in group housing with automated milk feeders in southern Ontario .................................................................................................................. 140

Table 4. 4. Final generalized linear regression models of groups of factors associated with within-pen prevalence of calf diarrhea on farms (n = 17) raising calves in group pens with automated milk feeders in southern Ontario visited 4 times, seasonally, over 1 year period, and the least squares means of the adjusted prevalence (AP) ........................................................................................................................................ 141

Table 4. 5. Final generalized linear regression models of group of factors associated with within-pen prevalence of bovine respiratory disease on farms (n = 17) raising calves in group pens with automated milk feeders in southern Ontario visited 4 times, seasonally, over 1 year period, and the least squares means of the adjusted prevalence (AP) ........................................................................................................................................ 143

Table 5. 1. Calving- and colostrum-related factors, sex, birth weight, introduction time and number of calves in the group pen for Holstein calves assigned to conventional introduction (5 days of age) or early introduction (< 24 hours after birth) to a group pen with an automated milk feeder (AMF) ........................................................................................................................................ 171

Table 5. 2. Univariable exact logistic regression models describing the effect of introduction to the group pen with an automated milk feeder < 24 hours after birth (early) or at 5 days old (conventional) on the risk of having diarrhea at least once < 60 days of age ........................................................................ 172
LIST OF FIGURES

Figure 2. 1. Distribution of daily amount of milk offered to calves by week of age during the first 4 weeks of life and the peak amount offered before starting weaning for farms with automated milk feeders (AMF) or with manual milk feeding (MMF) systems. Median = line within the box; 25th and 75th percentiles = box part of the plot; and 10th and 90th percentiles = end of the whiskers. ................................................................. 85

Figure 3. 1. Distribution of respondents (with 95% CI) from an online questionnaire completed by 670 dairy producers (Jan-15 to May-15) by region (Western provinces = British Colombia, Alberta, Saskatchewan, and Manitoba [n = 153]; Ontario [n = 322]; and Quebec and Atlantic provinces = New Brunswick, Prince Edward Island, Nova Scotia, and Newfoundland and Labrador [n = 195]) compared with National industry data (n = 11,683; CDIC, 2015). ............ 103

Figure 3. 2. Level of importance reported by 105 producers with automated calf milk feeders for a list of potential factors influencing their decision to switch from manual milk feeding systems to automated milk feeders to raise calves (responses from an online questionnaire; Canada, January 2015 to May 2015). .................................................................................................................. 104

Figure 3. 3. Factors influencing producers’ decision to switch from manual milk feeding systems to automated milk feeders to raise calves, and how these factors relate to each other (arrows). Factors of influence (thinner circles) are grouped into main themes (represented by thicker circles). The themes are derived from the responses to closed-ended questions (Likert scales) regarding decision-making statements and the analysis of the 16 responses to open text comment boxes in an online survey with 105 respondents using automated calf milk feeders. ............... 105

Figure 3. 4. Level of importance reported by 558 producers for a list of potential factors influencing their decision to continue using manual milk feeding systems to raise calves (responses from an online questionnaire; Canada, January 2015 to May 2015). AMF, automated milk feeding systems .................................................................................................................................................. 106

Figure 3. 5. Factors influencing producers’ decision to continue using manual milk feeding systems to raise calves, and how these factors relate to each other (arrows). Factors of influence (thinner circles) are grouped into main themes (represented by thicker circles). The themes are derived from the responses to closed-ended questions (Likert scales) regarding decision-making statements and the analysis of the 150 responses to open text comment boxes in an online survey with 565 respondents using manual milk feeding systems. AMF, automated milk feeder. ....... 107

Figure 3. 6. Level of agreement reported by 97 producers using automated milk feeders with a list of statements regarding potential advantages and disadvantages that automated feeders brought to their farms (responses from an online questionnaire; Canada, January 2015 to May 2015). .................................................................................................................................................. 108

Figure 3. 7. Level of agreement reported by 548 producers using manual milk feeding systems (MMF) with a list of statements regarding potential advantages and disadvantages that MMF
brought to their farms (responses from an online questionnaire; Canada, January 2015 to May 2015). MR, milk replacer.

Figure 4. 1. Scatterplot of within pen prevalence of bovine respiratory disease (BRD) and calf diarrhea (CD) on farms (n = 17) raising calves in group pens with automated milk feeders in southern Ontario visited 4 times, seasonally, over 1 year period.

Figure 4. 2. Association between within-pen prevalence of calf diarrhea (error bars are 95% CI) and the interaction between seasonal visit and total bacteria counts (TBC) in milk samples taken from the mixing jar of automated milk feeders used to feed calves housed in groups on 17 dairy farms in southern Ontario. The TBC were considered acceptable or not acceptable if counts were < 100,000 cfu/mL or ≥ 100,000 cfu/mL, respectively. *Significant difference: P < 0.05.

Figure 5. 1. Layout of experimental rooms and pens to house calves randomly assigned to either 1 of 2 treatments: early (< 24 hours of age) or conventional introduction (5 days of age) to the group pen with an automated milk feeder (AMF) with a “continuous flow” stocking approach.

Figure 5. 2. Kaplan-Meier survival analysis graph: Time interval (in hours) between the first training session to use the automated milk feeder (AMF) and the first voluntary (unassisted) visit to the AMF with > 1 L milk intake, indicative of successful learning) for the 60 calves randomly assigned to early (< 24 hours of age) or conventional introduction (5 days of age) to the group pen with an AMF. Wilcoxon test: P = 0.002; Log Rank test: P = 0.24.

Figure 5. 3. Mean daily milk intake (± SE) across the 5 stages of the milk feeding period (from 1 to 60 days of age) for 60 calves introduced to a group with an automated milk feeder at 5 days of age (conventional introduction) and before 24 hours of age (early introduction). Milk allowance for each milk feeding stage: Start = 9 L/d; Ad libitum = up to 36 L/d; Step down period = gradual reduction from 12 to 9 L/d; Plateau prior to weaning = 9 L/d; and weaning: gradual reduction from 9 to 2 L/d. *P < 0.05, +P < 0.1.
## LIST OF APPENDICES

**Appendix 2. 1.** Survey to compare management and feeding practices of milk-fed calves when fed manually vs. by automated milk feeders. ................................................................. 192

**Appendix 2. 2.** Summary of newborn and colostrum management practices by farms with automated milk feeders (AMF) and farms using manual milking feeding (MMF) systems for raising dairy calves derived from an online questionnaire completed by 670 dairy producers in Canada ......................................................................................................................... 227

**Appendix 2. 3.** Summary of housing practices of calves during the milk feeding period by farms with automated milk feeders (AMF) and farms using manual milking feeding (MMF) systems for raising dairy calves derived from an online questionnaire completed by 670 dairy producers in Canada ......................................................................................................................... 228

**Appendix 2. 4.** Summary of milk feeding practices of calves during the milk feeding period by farms with automated milk feeders (AMF) and farms using manual milking feeding (MMF) systems for raising dairy calves derived from an online questionnaire completed by 670 dairy producers in Canada ......................................................................................................................... 229

**Appendix 4. 1.** Imaginary “W” track (red line) used as a guide to select the 8 test-sampling spots (red crosses) for the wetness paper towel scoring system, dry matter of top bedding estimation, and bed deepness measurement across the group pen .............................................................................. 230

**Appendix 4. 2.** Management of un-weaned calves, group housing, and automated milk feeders at the farm; Questionnaire 1 ........................................................................................................ 231

**Appendix 4. 3.** Management of un-weaned calves, group housing, and automated milk feeders at the farm; Questionnaire 2 ........................................................................................................ 239

**Appendix 4. 4.** Distribution of independent variables regarding calving and newborn management potentially associated with within-pen prevalence of calf diarrhea and bovine respiratory disease measured during 4 seasonal visits to a maximum of 35 pens (no. of pens: fall 2015 = 34, winter 2016 = 35, spring 2016 = 33, and summer 2016 = 35) across 17 farms in southern Ontario raising calves in group pens with automated milk feeders (137 observations in total at the pen level) ........................................................................................................... 241

**Appendix 4. 5.** Distribution of explanatory variables regarding the milk feeding plan potentially associated with within-pen prevalence of calf diarrhea and bovine respiratory disease measured during 4 seasonal visits to a maximum of 35 pens (no. of pens: fall 2015 = 34, winter 2016 = 35, spring 2016 = 33, and summer 2016 = 35) across 17 farms in southern Ontario raising calves in group pens with automated milk feeders (137 observations in total at the pen-level) ............. 242
Appendix 4. 6. Distribution of explanatory variables regarding calibration and cleaning practices of the automated feeder potentially associated with within-pen prevalence of calf diarrhea and bovine respiratory disease measured during 4 seasonal visits to a maximum of 35 pens (no. of pens: fall 2015 = 34, winter 2016 = 35, spring 2016 = 33, and summer 2016 = 35) across 17 farms in southern Ontario raising calves in group pens with automated milk feeders (137 observations in total at the pen-level) ................................................................. 243

Appendix 4. 7. Distribution of explanatory variables regarding pen management and calf barn features potentially associated with within-pen prevalence of calf diarrhea and bovine respiratory disease measured during 4 seasonal visits to a maximum of 35 pens (no. of pens: fall 2015 = 34, winter 2016 = 35, spring 2016 = 33, and summer 2016 = 35) across 17 farms in southern Ontario raising calves in group pens with automated milk feeders (137 observations in total at the pen-level) ........................................................................................................ 244

Appendix 4. 8. Distribution of explanatory variables regarding bacteria counts in milk (sampled from the mixing jar and at the end of the hose [where it connects to the teat]) potentially associated with within-pen prevalence of calf diarrhea and bovine respiratory disease measured during 4 seasonal visits to a maximum of 35 pens (no. of pens: fall 2015 = 34, winter 2016 = 35, spring 2016 = 33, and summer 2016 = 35) across 17 farms in southern Ontario raising calves in group pens with automated milk feeders .................................................................................. 246

Appendix 4. 9. Number of automated milk feeders (AMF), pens with AMF, and number of feeding stations per pen among 17 farms in southern Ontario raising dairy calves in group pens with AMF visited 4 times, seasonally, over 1 year period ......................................................................................................................... 247
LIST OF ABBREVIATIONS

ADG – Average daily gain
AMF – Automated milk feeder(s) or Automated milk feeding
AMS – Automatic milking system
BRD – Bovine respiratory disease
BW – Body weight
CCK – Cholecystokinin
CD – Calf diarrhea
CDIC – Canadian Dairy Information Centre
CI – Confidence interval
CP – Crude protein
DIM – Days in milk
DM – Dry matter
MMF – Manual milk feeding
NFACC – National Farm Animal Care Council
OR – Odds ratio
PFT – Precision farming technologies
USDA – United States Department of Agriculture
TBC – Total bacteria counts
TCC – Total coliform counts
TMR – Total mixed ration
CHAPTER 1

REVIEW OF LITERATURE

1.1 INTRODUCTION

The way dairy calves are raised during the milk feeding period in North America has been consistent for decades (Table 1.1; USDA, 1994, 1996, 2002, 2007, 2016). The latest National Animal Health Monitoring System study conducted in the United States (USDA, 2016), which represented 77% of dairy farms in that country, showed that the majority of farms separated calf and dam within 24 hours after calving (82%), housed calves individually (85%), fed them approximately 4 L/d of milk in two meals a day (56%) via an open bucket (72%), and weaned them at an average age of 9 weeks. Although there is no Canadian national survey on calf management practices, similar practices to those in the United States have been reported for the province of Quebec (Vasseur et al, 2010), where approximately 50% of the dairy producers in Canada are located (CDIC, 2017). Vasseur et al. (2010) surveyed a representative sample of 155 dairy farms in Quebec and found that separation from the dam occurred by 24 hours after birth on 93% of farms, 88% of farms housed calves individually, and calves were fed a median of 5.5 L/d via an open bucket (92%) up to one week before weaning, which happened at a median age of 7 weeks.

These practices contrast with the way calves would behave if raised in semi-natural conditions and with their dams. Under these conditions, calves are raised in a herd, normally suckling milk 5 to 8 times a day (Phillips, 2002) and consume about 20% of their body weight (BW) in milk per day (at least 8 L/d for an average Holstein calf; Flower and Weary, 2001). Calves would also be naturally weaned at the age of 7 to 14 months (Reinhardt and Reinhardt, 1981; Reinhardt, 2002). This feeding pattern is well developed from birth and, thus, may be considered an important component of a calf’s nature; what Rollin (1994) would call, “the calfness of a calf”.
Nonetheless, there are reasons behind the use of conventional practices on dairy farms. By housing and feeding calves individually, the risk of disease spread can be reduced by minimizing direct contact between calves, and monitoring health and intake can be more practical when calves are separate (Callan and Garry, 2002; Stull and Reynolds, 2008). In addition, these conventional practices allow for early weaning by promoting early solid feed intake, which is achieved by restricting milk intake, consequently reducing rearing costs (Khan et al., 2011). These conventional practices are meant to maximize efficiency and productivity, and to ensure health though not necessarily welfare in all its aspects (von Keyserlingk et al., 2013). Additionally, milk-restricted diets have been supported by the old belief that calves who consume too much milk will have scours (e.g. Andrews et al., 2004).

On the other hand, agriculture changes as culture and society evolve (Fraser, 2010). After industrialization, society shifted moral concerns towards the protection of the powerless, including farm animals (Anderson, 2011). Especially during the last two decades, public pressure has driven a change in how research organizations, industry, and governments address animal farming procedures (Anderson, 2011), focusing on a more socially-sustainable farming that involves improving animal welfare (von Keyserlingk et al., 2013). Despite the fact that the adoption of best practices and passing of legislation to protect farm animals is slow, changes are occurring. In 2009, the Canadian National Farm Animal Care Council facilitated the development of the Code of Practice for the Care and Handling of Dairy Cattle with the participation and consensus of scientists, industry, government agencies, and the general public. This Code provides producers with a series of requirements and recommended best practices. A highlight of the Code from the “unweaned calves” section is that producers are recommended to “offer calves a minimum total daily intake of 20% of BW in milk until 28 days of age, … and to provide milk via a teat to satisfy the calf’s motivation to suck” and to “house calves individually or in well managed groups of less than 10 calves” (NFACC, 2009). However, there is presently no enforcement of the requirements and recommendations of this Code. On the other hand, the Code of practice specifically developed for veal calves (NFACC, 2017) does state that “calves must be housed in groups as young as possible and no later than 8 weeks of age”, and enforces this requirement to be effective by December 31, 2020.
Public pressure, codes of practice, and scientific findings on best management practices to ensure welfare (Ventura et al., 2015) are causing a change in how calves are managed and fed on farms. The goal is that calves should be allowed to drink more milk and should be able to socialize with other calves while maintaining good welfare. However, finding feasible ways of achieving this without increasing physical labour on farms can be challenging. Computer-controlled automated milk feeders (AMF) have been developed to facilitate the increase of daily milk allowance and the management of group-housed calves, while retaining the benefits of feeding calves individually and decreasing labour (de Passillé et al., 2004; Käck and Ziemerink, 2010; Jensen and Weary, 2013).

Taking into consideration the three approaches of animal welfare science - health and functioning, affective states, and natural living (Fraser, 2008) - this review will focus on the welfare implications of milk allowances and the different methods of feeding milk to calves, and of housing systems (individual and group housing) for raising calves, as they are factors that possibly have triggered the adoption of AMF (Kung et al., 1997). Finally, this review will summarize the literature available regarding the management and performance of calves on farms using AMF and group-housing systems, and the adoption of technology on dairy farms.

1.2 MILK ALLOWANCES: SHORT- AND LONG-TERM IMPACTS

1.2.1 Impacts on Calf Growth and Health

Dairy producers in North America typically have a restricted milk feeding plan for their un-weaned calves, providing them only 10% of BW in milk per day (Jasper and Weary, 2002). Poor nutrition during calfhood has been found to have negative long-lasting effects (Bach, 2012), and only when requirements for maintenance are met, will remaining nutrients support growth (Drackley, 2008). Researchers from diverse countries (e.g., Woodward, 1923; Diaz et al., 2001; Borderas et al., 2009a; Terre et al., 2009; Miller-Cushon et al., 2013) have shown that feeding a larger amount of milk (i.e., > 10% of BW) to calves has no detrimental effect on health as had been believed (e.g., calves that consume too much milk will have scours; Andrews et al., 2004);
on the contrary, it helps to have better weight gains as described below (summarized in Table 1.2).

When calves are able to drink at least 20% of BW in milk, they double their nutrient intake (Borderas et al., 2009a; Khan et al., 2011; Miller-Cushon et al., 2013), as dry matter intake (DMI, primarily from milk) increases from 1 – 1.5% to at least 2 – 3% of BW (Diaz et al., 2001). In young calves, nutrients will be mainly obtained from milk (or milk replacer), as they are born as monogastric, and not from starter rations as older calves do as they become ruminants (Drackley, 2008; Khan et al., 2011). An early attempt in the 20th century, with a small scaled controlled experiment (4 calves per treatment group; Woodward, 1923), showed that feeding just 14% of BW in milk resulted in an average daily gain (ADG) of 0.43 kg compared to feeding 20% of BW in milk or milk ad libitum (average consumed 12.1 L), which resulted in a daily gain of 0.57 and 0.67 kg, respectively, with no differences in the occurrence of diarrhea. However, Woodward concluded that “satisfactory gains” were made by feeding 14% of body weight, which, at that time, was a predictable and sensible choice in order to achieve efficiency. That author also concluded that producers could feed more milk to calves, if available, without fear of causing scour.

More recent research has shown similar results regarding better calf growth when feeding milk ad libitum compared to 10% of BW in milk to individually-housed calves. Compared to restricted feeding, Appleby et al. (2001) found ad libitum feeding to result in a 2.4 and 1.4 times difference on ADG during the first 14 days of life (0.85 vs. 0.36 kg/d) and during the third and fourth weeks (0.79 vs. 0.58 kg/d), respectively. Similarly, Jasper and Weary (2002) and Miller-Cushon et al. (2013) found differences on ADG during the pre-weaning period (ad libitum-fed calves: 0.78 and 1.2 kg/d, respectively, vs. restricted-fed calves: 0.48 and 0.6 kg/d, respectively), with no differences afterwards. Nonetheless, Jasper and Weary (2002) concluded that the advantage on weight gained obtained by ad libitum-fed calves was maintained at least up to 9 weeks of age, which could improve future reproductive performance (see Section 1.2.4). In addition, another controlled trial (Terre et al., 2009), although comparing restricted-fed calves (i.e., 4 L/d of milk) with calves being fed between 6 to 7 L/d during the pre-weaning period, showed subtle but significant differences on ADG (0.8 vs. 0.9 kg/d) between feeding treatments, with no further differences once weaning started.
Similar results have been obtained when controlled trials compare milk feeding levels among group-housed calves. For example, Borderas et al. (2009a) compared ad libitum milk feeding and feeding 12 L/d with only feeding 4 L/d of milk, and found that the overall ADG across the first 6 weeks of life was higher for ad libitum-fed calves and calves fed 12 L/d compared to restricted-fed calves (0.88 vs. 0.66 kg/d; and 0.73 vs. 0.43 kg/d, respectively). Additionally, a recent study (Rosenberger et al., 2017) showed the gradual increase on ADG achieved during the pre-weaning period by feeding > 10% of BW of milk to calves, from 0.58 kg/d when feeding 6 L/d to 0.88 kg/d when feeding 12 L/d; however, once calves were weaned, ADG during 13 days post-weaning no longer differed (1.27 vs. 1.26 kg/d, respectively).

It is important to mention that lack of differences in growth during the post-weaning period between restricted-fed calves and calves fed higher milk allowances might be influenced by the method of weaning used or the age at which calves were weaned, especially for those under higher milk allowance. Nevertheless, weight advantage of calves fed higher milk allowances will persist (Jasper and Weary, 2002). Regarding the method of weaning, Khan et al. (2011) showed that a step-down weaning process (i.e., gradually reducing milk feeding rate from 20 to 10% of BW over a 5 day-period starting at 26 days of age, then maintaining the 10% rate for 15 days more followed by a 5 day-period for gradually wean the calves) helped reduced problems related to lower starter intake of calves drinking high milk allowances (20% of BW in milk). In addition, Sweeney et al. (2010) found that a gradual weaning period over 10 days improved starter intake during and after weaning for calves being fed 12 kg/d of milk compared to abrupt weaning, 4, and 22 days weaning period. Regarding age at which calves drinking high milk allowances (i.e., 12 L/d) were weaned, de Passillé et al. (2011) found that delaying it from 47 to 89 days of age helped reduce stress and the drop in energy intake and growth as a consequence of calves not eating enough starter at the time of weaning to be able to compensate for the lack of milk in their diets. Similarly, Eckert et al. (2015) found that calves (allowed to drink 8 L/d) weaned at 57 days vs. 43 days of age had higher growth rates (which were sustained at 90 and 150 days) and reduced signs of stress (more time lying down and less vocalizations).

Benefits of higher milk allowances on calf health are not straightforward as are the benefits for calf growth. Researchers had concluded that there are not negative implications of feeding more milk to calves, yet no research has specifically concluded that there is a clear
(cause-effect) improvement on calf health. Diarrhea occurrence has not been impacted by feeding more milk to calves in controlled trials. Appleby et al. (2001) found no difference in the incidence of diarrhea between calves fed 10% of BW vs. calves fed milk ad libitum, with the only significant differences happening on the third week of life, where diarrhea lasted longer among restricted-fed calves (mean of 2.8 days) compared with ad libitum-fed calves (mean of 0.8 days). However, Appleby et al. attributed this improvement to the method of feeding, which differed between treatments (i.e., teat for ad libitum-fed calves vs. bucket for restricted-fed calves). The authors concluded that sucking from a teat stimulates the esophageal groove to close and triggers the release of digestive hormones with important roles in the absorption of nutrients (de Passillé et al., 1993). On the other hand, Jasper and Weary (2002), with a similar study design, did not find any differences in diarrhea days between treatment groups. In addition, Borderas et al. (2009a) and Rosenberg et al. (2017) found that there were no differences in the incidence of diarrhea or respiratory disease between milk feeding treatment levels among group-housed calves. A problem with all these studies is that they have small sample sizes (≤ 14 calves per treatment group). Thus, this relatively small sample size could have limited their analysis and increased the probability of having Type II error.

Other researchers, using bigger sample sizes (between 30 and 40 calves per treatment group), although still lacking power, have found similar results to the findings described above. Terre et al. (2009) did not find differences in calf disease frequency measures between treatments (4 L/d vs. 6-7 L/d). On the other hand, Bach et al. (2013) compared feeding individually-housed calves 6 L/d with feeding 8 L/d, and found that during the pre-weaning period (< 52 days of age) there were no differences in the incidence of diarrhea (52 vs. 45%) and bovine respiratory disease (BRD; 12% for both groups) between feeding treatments. However, the incidence of relapses of BRD was higher for calves fed lower milk volumes during the same period (60% vs. 0%). Once calves were grouped at weaning, there were no differences in calf health. One constraint of this study is that half of the calves enrolled were recruited after 16 days of age, a period where calves at a higher risk of experiencing diarrhea, and the authors do not provide information on milk feeding levels prior to enrolment. The authors did state that the randomization should remove any potential effects of previous experiences; nevertheless, experiments comparing effects of early nutrition on calf health should ideally enrolled animals from birth. Furthermore, other researchers have shown that higher milk allowances do not cause
diarrhea but softer feces. Davis Rincker et al. (2011) found that calves fed milk replacer at 2.1% of BW in a dry matter (DM) basis had higher fecal scores (where 1 was firm and 5 was watery feces) compared to calves fed milk replacer at 1.2% of BW in a DM basis (3.2 vs. 3 fecal score) and had longer days with loose feces (2.7 vs. 2.4 days); however, days with medication or fever did not differ between feeding treatments. In addition, Diaz et al. (2001) concluded that calves fed milk replacer with higher DM content (i.e., 3% and 4% of BW compared to 1% of BW) had higher fecal scores but as a reflection of the amount of feed and water consumed, not as a result of disease. On the other hand, an observational cross-sectional study in the Midwest United States (Jorgensen et al., 2017; described in more detail in section 1.5.1) found a negative association between the peak daily milk allowance and the odds of a calf being classified as having a higher hind-end dirtiness score of the perineal region, underside of the tail, and tailhead (i.e., 3-point scale where 0 = clean, 1 = evidence of loose or abnormal fecal consistency, and 2 = significant evidence of watery diarrhea). The latter was used by the authors as an indirect measure of calf diarrhea. However, there is little research available that has validated the agreement between hide dirtiness score and actual presence of diarrhea. A recent study (Graham et al., 2018) showed only fair agreement between fecal consistency and hind-end dirtiness.

Based on all the research described above looking at calf growth and health, it is fair to ask the question: is it worth doubling milk daily allowances if, once calves are weaned, weight gain might be similar to what one can achieve using restricted milk diets? Is it worth increasing milk allowance if its benefits on calf health are not straight forward? To answer these questions only from a health, performance, or cost point of view is not easy because other elements such as affective states and calf future performance (see following sections) are key parts of this puzzle. A Canadian observational study using data of 1,588 calves from birth until 90 to 120 days of age from 16 different farms (McCorquodale et al., 2013) could indirectly help to give a direction to answer those questions. McCorquodale et al. (2013) examined factors associated with calf survival, and found that heavier calves (> 44 kg) during the first week of life had lower risk of mortality. The authors stated that heavier calves had more resources to fight disease and continue gaining weight, and although this research does not directly evaluate feeding more milk to calves, it indirectly supports the practice of feeding more milk to calves to improve growth, which ultimately will be reflected on calf health and survival.
1.2.2 Impacts on Affective States

Restrictive milk feeding programs not only have negative implications for dairy calves’ physical health, but also for their affective states (summarized in Table 1.3). Calves under restricted feeding suffer from negative states, such as hunger and frustration (von Keyserlingk et al., 2009). Feeling hungry is a negative state caused by a prolonged lack of food and is associated with a strong desire to eat (De Paula Vieira et al., 2008). Restricted milk-fed calves are able to consume just half of the volume they would if fed ad libitum (Appleby et al., 2001; Miller-Cushon et al., 2013). Additionally, this restricted volume is normally split in only two meals per day, unlike the natural feeding pattern of a calf (Jasper and Weary, 2002). On the other hand, restricted milk-fed calves consume almost twice as much starter than calves fed higher amounts of milk (Appleby et al., 2001; Jasper and Weary, 2002; Terre et al., 2009; Bach et al., 2013; Miller-Cushon et al., 2013), and have even been reported to consume more bedding material (Diaz et al., 2001). The reason behind this difference in feeding behaviour is that calves allowed to drink more milk are satiated, and thus feel less hungry (Khan et al., 2011).

Calves express hunger by increasing the number and frequency of vocal calls, as well as the time spent standing (Thomas et al., 2001). The latter is caused by the motivation to find food, sacrificing other activities such as resting or playing. Restricted milk-fed calves on teats spend more time standing around the teat performing non-nutritive sucking when milk is not provided, compared to ad libitum-fed calves (De Paula Vieira et al., 2008; Borderas et al., 2009a; Miller-Cushon et al., 2013). Similarly, Herskin et al. (2010), in a controlled trial, found that the duration of non-nutritive sucking was higher in calves experiencing increased hunger (284 s) compared to calves experiencing reduced hunger (121 s) and control calves (173 s). In Herskin et al. (2010), the level of hunger calves experienced prior to be fed was manipulated by either feeding the normal milk ration the night before (3 L) plus feeding an extra of 1.5 L prior the routine morning feeding time (reduced hunger level), feeding half ration the night before without feeding the extra milk prior morning feeding (increased hunger level), or feeding the normal ration at night without the extra milk prior morning feeding (control).

Hyperphagia, which is defined as “an abnormal great desire for food or excessive eating” (Oxford Dictionary, 2018), has been used as an indicator of hunger in food-restricted
mice (Hambly et al., 2007). When calves are on a restricted diet, when milk is delivered (twice a day) they drink the entire ration (usually 2 L) at a faster speed than ad libitum-fed calves (Miller-Cushon et al., 2013). Long intervals between meals generate higher milk intake at the next meal (Senn at al., 2000). In addition, De Paula Vieira et al. (2008) found that ad libitum-fed calves only drink, at each meal, an average of two thirds as much as a restricted-fed calf, with no differences in meal duration, confirming that restricted-fed calves perform hyperphagia when milk is delivered.

The alteration of the natural feeding behaviour in restricted-fed calves might aggravate the feeling of hunger, which may trigger frustration, and the reduction in feeding time may result in constant hunger (de Paula Vieira et al., 2008). In humans, frustration is a negative emotion experienced as a result of not being able to do something, and might involve aggression (Oxford Dictionary, 2018). Hungry dairy calves suffer from frustration. Aggressive behaviours, such as displacements and pushing, are characteristic of restricted milk-fed calves in group-housing pens, where competition for the food source is higher. For example, Jensen and Holm (2003) found that restricted-fed calves that were also fed at reduced flow rate (0.5 L/min) showed a higher frequency of displacements (i.e., causing a calf occupying the feeder to leave as a consequence of butting, rest heading, or entering the occupied feeder) in a 24-hour observation period (median of 8 displacements) compared to calves fed double the amount of milk with a reduced flow rate as well (median of 4 displacements). Similarly, de Paula Vieira et al. (2008) found that restricted-fed calves performed 7 times the frequency of displacements (i.e., a calf pushed or butted a calf occupying an AMF) performed by ad libitum-fed calves (7.5 vs. 1 displacements/day). In addition, Herskin et al. (2010) found that calves subjected to increased hunger had a higher frequency of butting (14 butts during 40 min observation) compared to calves experiencing reduced hunger (7.8 butts). The frustration experienced by restricted-fed calves is also evident when the frequency of unrewarded visits to the AMF (i.e., visits to the milk feeder without milk ingestion) is quantified. De Paula Vieira et al. (2008) showed that calves allowed to drink 10% of BW in milk (4.2 to 4.8 L/d) had a frequency of 24 unrewarded visits per day compared to only 2 unrewarded visits per day performed by ad libitum-fed calves. Restricted-feeding would result in a higher occupancy of the feeder and an endless cycle of displacements, which could cause an increased risk of cross-sucking (i.e., one calf sucking a pen mate) due to the competition to access the milk source (Jensen and Holm, 2003).
On the other hand, allowing calves access to more than 10% of BW in milk or ad libitum milk could bring benefits to the development of calves, not only by avoiding the feeling of hunger, but by triggering the performance of play behaviour. Play behaviour has been suggested as an indicator of good welfare of juvenile animals (Napolitano et al., 2009), as they perform play behaviour once their basic needs for maintenance of life (e.g., food and shelter) are satisfied (Fagan, 1981). Play behaviour evidences “the absence of fitness threats” (Fraser and Duncan, 1998; Held and Špinka, 2011). In calves, play behaviour refers to locomotor activities such as running, galloping and kicking; it can happen individually or in a group (social play). Researchers have found that when dairy calves have access to high milk allowance (12 L/d, Krachun et al., 2010; 9 L/d, Duve et al., 2012), the duration of play running increases compared to calves fed lower amounts of milk (6 L/d, Krachun et al., 2010; 5 L/d, Duve et al., 2012) during the first month of life. Isolated calves have an increase in play behaviour when milk allowance is changed from conventional (5 L/d) to a larger allowance (9 L/d), showing the benefits on the experience of positive mental states (Duve et al., 2012).

1.2.3 Impacts on Calves’ Natural Living

In semi-natural conditions, calves suck their dams over the course of the day following a circadian rhythm. Suckling activity occurs most frequently at sunrise (0500 - 0600 h); followed by a peak at sunset (1700 – 2100 h) and a smaller peak from 1000 to 1300 h (Odde et al., 1985). Additionally, calves would normally suck milk about five to eight times a day; these meals last around 10 to 15 minutes (Phillips, 2002; de Passillé and Rushen, 2006). As calves get older, suckling bouts become shorter and decline in number to three to five per day (Phillips, 2002). Restricted milk-fed calves typically receive only 2 meals per day, usually around 0800 and 1700 h (Jasper and Weary, 2002), consuming their entire portion at the time of milk delivery. Whereas feeding a larger amount of milk allows calves to have a more natural feeding schedule, feeding peaks would be still dependent on fresh milk delivery (Miller-Cushon, et al., 2013). Similar to calves that suck from their dam, ad libitum-fed calves start their feeding activity at dawn and finish it at dusk, with paused meals (every 4 hours on average) throughout the day, but with feeding activity very rarely occurring at night (Senn et al., 2000; Borderas et al., 2009a).
1.2.4 Impacts on Future Performance

Research in the last decade has shown that reproduction and milk production during the first lactation is positively influenced by nutrition during the early stages of a calf’s life. Davis Rincker et al. (2011) found that feeding calves a higher milk allowance (milk at 2.1% of BW and 24.3% crude protein (CP) content in the starter on a DM basis) reached puberty at a younger age (270 vs. 301 days) and calved earlier (14 days earlier) than calves under a conventional, restricted milk allowance (milk at 1.2% of BW, and 19.9% CP in the starter). Additionally, Davis Rincker et al. (2011) found that conventionally-fed calves tended to lose more weight two years later, during early lactation (change in BW at 150 days in milk (DIM): restricted-fed calves during the pre-weaning period: -10.6 kg; calves with higher milk allowance: 6.6 kg).

Many intrinsic and extrinsic factors play a role in milk production, including genetic variation and nutrition. Davis Rincker et al. (2011) also found that after correcting for genetic variation, 305-day milk yield tended to be higher for calves that received a higher plane of nutrition during the milk-feeding period compared to those under restricted diets (10,128 vs. 9,712 vs kg). Similarly, data collected from two New York (United States) dairy farms (Soberon et al., 2012) feeding milk replacer at specific rates to double calves’ birth weight by 60 days of age (farm 1: 2 to 2.5% of BW on a DM basis; Farm 2: 0.9 kg of milk replacer per day), showed a positive correlation between first-lactation milk yield and pre-weaning ADG. The pre-weaning ADG (range) for each farm was 0.82 kg/d (0.10 to 1.58 kg/d) and 0.66 kg/d (0.32 to 1.27 kg/d), respectively. The authors found that for every additional 0.1 kg of pre-weaning ADG, milk production during the first lactation increased 97 kg, accounting for approximately 22% of the variation in milk yield. Based on these findings, Soberon et al. (2012) concluded that the pre-weaning period is a window to positively impact the future milk production of a calf as a milking cow, and that improvements on the liquid feed to increase ADG should start at birth and last at least 5 weeks. These findings are supported by two recent meta-analysis. Soberon and Amburgh (2013) did a meta-analysis to evaluate the effects of nutrient intake from milk or milk replacer and pre-weaning ADG on first-lactation milk yield. The authors found that calves receiving more nutrients during the pre-weaning period were 2 times more likely to produce more milk than calves under a restricted milk diet. Additionally, Soberon and Amburgh (2013) showed that for every additional 0.1 kg of pre-weaning ADG, milk production during the first lactation increased
155 kg. The effect of starter intake was not able to be quantified, and the authors recognized that nutrient intake from starter would enhance the outcome. Similarly, Gelsinger et al. (2016) did a meta-analysis to evaluate the effects of nutrient intake (from milk and starter) and pre-weaning ADG on first-lactation milk yield. Even though Gelsinger et al. (2016) found that the majority of the variation in milk yield was explained by study (i.e., specific management factors had a greater effect than pre-weaning nutrition and ADG), they found that that for every additional 0.1 kg of pre-weaning ADG, milk production during the first lactation increased 130 kg. Additionally, Gelsinger et al. (2016) found that ADG between 0.3 and 0.5 kg/d had minimal effects on future milk production, but when ADG went from 0.5 to 0.9 kg/d, the effects of pre-weaning growth rate on milk yield increased.

1.3 MILK FEEDING METHODS

There are different ways of feeding milk to dairy calves that are not left to suck the dam. These feeding methods can be divided into manual and automated. Manually milk-fed calves are mainly fed by open buckets or artificial teats (e.g., teat buckets, teat bottles or multiple teat milk bars), and this requires more physical labour. Automated milk feeders (AMF) are computer-controlled devices that allow producers to feed multiple calves through an artificial teat. AMF were initially developed to feed more milk to group-housed calves with the possibility of controlling the amount of milk offered to each individual calf, which cannot be controlled if milk is fed with a trough or milk-bar (Hepola, 2003). It is perceived that AMF for group-housed calves imply less physical labour (de Passillé et al., 2004).

1.3.1 Impacts on Calf Growth and Health

When sucking from its dam, the calf’s neck is lowered and the head is raised; this position helps the esophageal groove to close, allowing milk to go straight into the abomasum (Hafez and Lineweaver, 1968; Phillips, 2002). In contrast, when buckets are used, the head-down position that calves adopt to be able to reach milk does not allow an adequate closure of the groove, and milk can go directly into the rumen, which is unprepared to digest milk (Phillips,
2002). Based on this, one could think that bucket feeding for calves could have negative effects on calf health, but research on this topic is limited and has shown contradictory results.

In 1968, Wise and LaMaster compared individually-housed calf responses to open-bucket and nipple-pail feeding systems to feed milk at different rates (10% of BW, 14 to 18% of BW, and ad libitum), and found no differences in BW and incidence of diarrhea between feeding systems, and concluded that both systems were equally effective, which was similar to previously-reported results (Kesler et al., 1956). Similarly, Veissier et al. (2002) compared bucket vs. teat feeding among individually- and group-housed calves, and found no differences in health (number of treatment days: 3.1 vs. 2.5 days) and growth (ADG: 1.29 kg/d for both treatment groups). On the other hand, Appleby et al. (2001) found that bucket-fed calves had a greater number of days with diarrhea compared to teat-fed calves (2.87 vs. 0.84 days); however, this was confounded by milk allowances (restricted and ad libitum, respectively). Despite this confounder, the authors stated that the difference in diarrhea days was due to the lack of suckling bucket-fed calves experienced. In addition, Hammell et al. (1988) reported that increasing the volume of milk fed is not sufficient to ensure better calf performance, but that the method of feeding is also important. They found that ad libitum bucket-fed calves had a shorter feeding time (17.7 min/day vs. 44.2 min/day), drank less milk (8.0 L/day vs. 11.9 L/day) and had lower body weight gain (0.5 kg/day vs. 0.8 kg/day) than ad libitum teat-fed calves.

Allowing calves to suck has been shown to be associated with a better digestion process. Wise et al. (1976) showed that sucking from a teat (either from a cow or from a teat-bucket) slowed down the rate of milk ingestion compared to when milk was ingested by drinking (i.e., open-bucket feeding), allowing milk to be mixed with saliva and have a greater exposure to pre-gastric esterases (e.g., lipase), which are known to contribute to the digestion of fats and proteins. Additionally, Wise et al. (1976) also showed that the digestion of fats and proteins was greater when calves sucked milk than when calves drank it from a bucket. Furthermore, de Passillé et al. (1993) found that when bucket-fed calves were allowed to suck a dry teat after milk ingestion, concentrations of insulin and cholecystokinin (CCK) in the portal vein were higher compared to concentrations from calves not allowed to suck after milk ingestion. Insulin and CCK are associated with the metabolism of carbohydrates, fats, and proteins; and increased
levels of these hormones are associated with satiety and reducing the feeling of hunger (de Passillé et al., 1993).

Feeding by bucket is still very common in North America and Europe (Vasseur et al., 2010; Staněk et al., 2014; USDA, 2016). The use of this feeding method seems to be a matter of convenience, as cleaning and sanitizing of open buckets is perceived to require less labour (Wise and LaMaster, 1968). For example, in the Czech Republic, 41% of producers use buckets to feed milk to calves (Staněk et al., 2014), and in North America the usage is even higher (e.g. in Quebec, 92% of farms use buckets; Vasseur et al., 2010). On the other hand, combining the benefits of feeding by an artificial teat and the tendency for more automated dairy farming (Singh et al., 2014), AMF bring along potential benefits for calves’ health.

Automated milk feeders allow producers to offer larger amount of milk to each calf by providing small meals several times a day, independent of labour availability (de Passillé et al., 2004; Käck and Ziemerink, 2010). Producers may have difficulty identifying sick calves when calves are housed in large groups (Svensson and Jensen, 2007); but AMF can be used to predict illness before the onset of clinical signs as these devices record (and store if connected to a computer with a specific software) calf individual feeding behaviour. For example, Svensson and Jensen (2007) followed group-housed calves up to weaning, from one Swedish and one Danish dairy farm feeding between 5.6 to 8 L/d of milk with an AMF, to determine the relationship between clinical status and feeding behaviour. The authors found that diseased calves had a lower number of unrewarded visits to the AMF (mean of 15.8 visits/d) compared to healthy calves (19.8 visits/d), which reflected a reduction in appetite due to illness. In addition, Borderas et al. (2009b) found that changes in behaviour due to illness were also dependent on milk allowances. Sick calves fed high milk allowances (≥ 12 L/d) had a reduction in milk intake and in the frequency of visits to the AMF, and had longer visits to the AMF on the days following disease detection compared to healthy calves fed high milk allowances. Meanwhile, sick calves fed low milk allowances (4 L/d) had shorter visits to the AMF on the day of disease detection and on the following 3 days compared to healthy calves fed low milk allowances. Borderas et al. (2009b) concluded that differences in changes in behaviour between calves being fed low and high milk allowances was mainly due to the stronger motivation for ingesting milk among restricted-fed calves (due to the experienced hunger), which limited the effect of disease on milk
intake. In a recent observational study, Knauer et al. (2017) followed 176 sick calves and matched-healthy controls, and found that 2 to 3 days prior to treatment day (i.e., day when producer identified and treated a sick calf), sick calves started drinking slower, and by treatment day, drinking speed was 0.18 L/min slower compared to healthy calves. In addition, drinking speed took around 10 days to go back to baseline levels. When looking at milk intake, Knauer et al. (2017) found that sick calves drank 1.2 L less than healthy calves on the day of treatment, and the effect persisted for 10 days after. Changes in drinking speed and milk intake were more pronounced among calves experiencing diarrhea compared to calves with BRD or depressed/feverish calves. These three studies illustrate that feeding behaviour recorded by AMF could be a useful tool to help producers identify disease onset when calves are housed in groups based on individual calf behavioural changes.

1.3.2 Impacts on Affective States

Sucking has profound effects on juvenile mammal behaviour. Nutritive sucking triggers calmness in rats (Blass, 1994). In human infants, sucking also plays an important role in the modulation of behavioural-mental states by prompting feelings of calmness, and controlling arousal state when facing over-stimulating environments (Bruner, 1973; McCain, 1995). Dairy calves are highly motivated to suckle when they taste milk (de Passillé et al., 1992; de Passillé, 2001). However, bucket-fed calves do not have the opportunity to suck (Jensen, 2003); therefore, after milk intake, they start “sucking” objects (non-nutritive sucking) or other calves (non-nutritive cross-sucking) trying to cope with the lack of a teat and fulfill the desire to suck (de Passillé, 2001; Margerison et al., 2003). This postprandial non-nutritive sucking tends to last between 10 and 15 minutes, decreasing over time (Weber and Wechsler, 2001). Specifically, cross-suckling is defined as a calf sucking on body parts of other calf (e.g. ears, navel/umbilical cord, udder region, and scrotum) (de Passillé, 2001; Lidfors and Isberg, 2003), and is categorized as a detrimental undesired behaviour (Weber and Wechsler, 2001). In an observational study, Mahmoud et al. (2016) found that 39% of calves involved in cross-suckling developed abscesses in their ears and navel. In addition, a positive correlation between cross-sucking in un-weaned calves and intersuckling (i.e., specifically sucking the udder of heifers or cows with the intention of sucking milk) in heifers after weaning has been described in literature (Keil and Langhans, 2001; reviewed in Lidfors and Isberg, 2003). In fact, farms with intersucking heifers were 7.8
times more likely to have intersucking among cows (Keil et al., 2001). Czech, German, and Slovak research from the 80’s and 90’s has shown that intersucking is associated with economic losses due to reduced milk yield and mastitis (reviewed in Lidfors and Isberg, 2003). In addition, Vaughan et al. (2016) found that the incidence of mastitis during first lactation was higher among cross-sucked calves (31%) compared with not cross-sucked calves (17%), but differences were not significant, which could have resulted from a lack of power due to small sample size (16 and 23 animals per group).

Initiatives to help calves to satisfy their motivation to suck have been a priority for researchers for years. Veissier et al. (2002) showed the benefits of providing a dry teat to bucket-fed calves after milk has been consumed. Having a teat around the pen, where calves could discharge the desire to suck, helped them reduce cross-sucking and the calves had a shorter latency to lie down and rest than when teats were not available. However, these effects were less evident compared to actually allowing calves to suck milk from a teat. Feeding milk through a teat allows calves to have longer meals and more pauses within meals, which is positively associated with feeling satiated and reducing non-nutritive sucking (Haley et al., 1998; de Passillé, 2001; Veissier et al., 2002).

Automated milk feeders are an alternative method for feeding calves through a teat, mainly while calves are group-housed, although they also exist for individually-housed calves (not discussed in this review). Some producers are reluctant to use AMF because the high risk of cross-sucking in group pens (Ude et al., 2011). de Passillé et al. (2004) reported that cross-sucking in automatically-fed calves is controlled if sufficient time to suck is allowed and that controlling competition is a key factor. Competition could be reduced when milk allowance (Jensen and Holm, 2003; De Paula Vieira et al., 2008) and flow rate (Jensen and Holm, 2003) are increased from 10 to 20% of BW, and from 0.5 to 1.6 to L/min, respectively. In addition, occupancy of the AMF can be reduced by decreasing the number of meals per day, from 8 to 4 meals/day, which will allow calves to have larger intakes per meal (in this case 1.6 vs. 0.8 L/meal), decreasing sensation of hunger and frustration (Jensen, 2004, 2007).

On the other hand, when a large group size within a pen is used, the level of competition increases (big calves push small ones out of the feeder, Hepola, 2003). Commercially, one feeder
(with one milk station) can feed up to 30 calves, but having such a large group size leads to displacements and aggression around the feeder (Jensen, 2003). Jensen (2004) found that groups of 24 calves per pen had higher levels of competition compared to groups of 12 calves. Total daily duration of rewarded visits to the AMF was shorter (18 min/24 hours) and drinking speed was faster (0.4 L/min) among calves housed in groups of 24 compared to calves housed in groups of 12 (visits duration: 23 min/24 hours; drinking speed: 0.3 L/min). Jensen (2004) concluded that calves housed in groups of 24 animals per pen were subjected to social constraint. From a health and growth perspective, the ideal group size should not be over 10 calves (Svensson and Liberg, 2006); larger groups should also be avoided because young calves will have less ability to compete for milk access and have a higher risk of being sucked from older calves (Jensen, 2003). However, the group size can be bigger as long as the age variation is small and adequate space in the pen for each calf is provided (Magnusson, 1993 cited by Hepola 2003).

Researchers have also tried to modify AMF or use enrichment to try to decrease cross-sucking among calves. Weber and Wechsler (2001) succeeded in decreasing frequency of cross-sucking after milk ingestion by adding a gate at the rear of the AMF feeding stall to control access and displacement, allowing calves to stay longer at the feeder after milk ingestion, and increasing duration of non-nutritive sucking on the teat. Similarly, Ude et al. (2011), using the same type of modification of the feeder, but adding a side door that led to a separate area (post feeding) where dry teats were available, found that a lower proportion of calves that had access to the dry teats’ area showed cross-sucking (17%) compared to calves that had no access to the dry teats (58%).

1.3.3 Impacts on Natural Living

Natural suckling involves both calf and cow. When suckling, different behaviours take place to induce milk release, such as mutual calls, butting of the udder, and sucking (Lidfors et al., 1994). When milk is offered through a bucket, calves lose the opportunity to express their natural feeding behavioural repertoire. Suckling becomes a simple act of drinking milk, with an unnatural position and speed (Appleby et al., 2001; Phillips, 2002).

Providing milk through teats allows calves to suck, adopt a more natural position, and perform butting towards the teat (Nielsen, 2008). Automated milk feeders combine the benefits
of a teat with the advantages of computerized systems, ideally providing fresh milk or milk replacer several times a day (Käck and Ziemerink, 2010), more closely resembling natural sucking for calves. Using AMF, calves can be fed more naturally; starting with small and frequent milk meals, then declining to larger and less frequent meals (Nielsen, 2008; Jensen, 2009).

Of course, good management practices are required when using AMF. Although calves are naturally raised in a herd with more calves around (Phillips, 2002), the level of competition in group housing can affect their behaviour and outweigh the benefits that automated feeders offer. When there is a large age variation in a group of calves, feeding patterns of newly introduced calves are altered, changing their feeding schedule to avoid displacements at the feeder (Jensen, 2003). Newly-introduced calves tend to visit the feeder between midnight and 0500 h, contrary to their natural schedule, when calves that have been in the group for more than 14 days are sleeping and resting (Schlichting 1990 cited by Jensen 2003).

1.4 INDIVIDUAL AND GROUP HOUSING

In North America, calves are commonly raised in individual housing, and direct contact with other calves normally occurs only after calves are weaned (USDA, 1994). The European Union, through the Council Directive 2008/119 EC, prohibits the use of individual housing for calves after the age of eight weeks. Similarly, the new Canadian Code of practice for veal calves (NFACC, 2017) will (from 2020) also forbid the use of individual housing beyond eight weeks of age, but this code does not apply to dairy calves. Most previous research on the impacts of housing mainly focused on health and performance (Table 1.4), but recent research has considered effects on affective states, cognitive abilities of calves, and adaptation during weaning (Table 1.5).

1.4.1 Impacts on Calf Health

Research on the impacts on calf health and performance of housing calves individually or in groups from an early age has provided mixed results (summarized in Table 1.4), indicating
that there is not a consistent association between disease incidence and the type of housing for calves (Costa et al., 2016).

Individual housing has been shown to be beneficial for calf health due to the reduced direct contact with other animals (McGuirk, 2008). For example, in observational cohort studies carried out on commercial dairy farms in the Netherlands (Perez et al., 1990) and Sweden (Svensson et al., 2003), the risk of diarrhea and respiratory disease, respectively, was found to be significantly higher for group-housed calves compared with individually-housed calves. Specifically, Perez et al. (1990) found that the risk of diarrhea in calves followed during the first 4 months of life was 2.1 times greater for group-housed calves compared to individually-housed, but this was not the case for BRD. The authors did not provide information on group size. Regarding respiratory disease, Svensson et al. (2003) found that the risk in ≤ 90 day-old calves was 2.2 times greater when housed in larger groups (i.e., between 6 and 30 calves per group) compared with individually-housed calves; this effect was not observed when calves were housed in smaller groups (i.e., 3 to 8 calves per group). It is important to note that 64% and 50% of the farms in Perez et al. (1990) and Svensson et al. (2003), respectively, fed restricted milk diets (≤ 5 L/d of milk), which could have an impact on calf health, especially in group-housing systems, where more stressors surround calves.

Similarly, an observational study in the United States reported group size to be a key determinant of calf health (Losinger and Heinrichs, 1997). Losinger and Heinrichs (1997) found that the risk for a farm to be classified in the high mortality category (i.e., > 10%) was 0.5 times (95% confidence interval [CI]: 0.3 to 0.7) and 0.6 times (95% CI: 0.4 to 0.8) lower when calves were housed in small groups (i.e., 2 to 6 calves per group) or were individually-housed, respectively, compared with calves housed in larger groups (i.e., ≥ 7 calves per group). Complementary to these observational studies, Warnick et al. (1977), through a trial aiming to determine effects of types of housing (group vs. individual vs. isolated) on body weight and social development of calves up to 4 months of age, observed that individually-housed calves required fewer treatments for disease compared to isolated or group housed calves; but this observation was not tested for significance.
When group housing is used, not only is the size of the group an important determinant for calf health, but the way calves are moved into the groups is key. The available data suggest that if dynamic flow is used (i.e., calves continuously being added to the group), weight gains and health are negatively affected compared to calves raised in stable groups (i.e., “all-in/all-out”) (Pedersen et al., 2009). In a field trial, Pedersen et al. (2009) found that the prevalence of diarrhea and respiratory disease was 2.5 and 2.2 times higher in dynamic groups (diarrhea: 46%; respiratory disease: 44%) compared to stable groups (diarrhea: 18%; respiratory disease: 20%). Additionally, ADG was significantly lower for calves in dynamic groups compared to those raised in stable groups (0.81 vs. 0.87 kg/d).

Similarly, Cobb et al. (2014a), in a controlled trial, showed that group-housed calves (i.e., outdoor hutches of 3 calves per pen) had greater neutrophil responses during the pre-weaning period compared with individually-housed calves (i.e., outdoor individual hutch). The authors suggested that this might be related to an increased immunologic stimulation due to an increased pathogen exposure as a result of the group-housing system.

In contrast, other studies have shown that group housing can be beneficial for calf health. Svensson et al. (2003), in the Swedish observational study mentioned previously, found that the risk of calf diarrhea tended to be 1.7 and 1.9 times higher for individually-housed calves and calves housed in small groups, respectively, compared to calves housed in large groups. However, the authors also found that cases of diarrhea were significantly more severe in calves housed in large groups compared to calves housed individually, and tended to be more severe when compared to small-group housed calves. In addition, Kung et al. (1997) observed that calves raised in individual hutches were medicated for more days (19 days) than calves raised in groups (11 days). However, this difference might have been related to the easier access care givers have to calves raised in hutches compared to calves raised in groups, making identification and treatment of sick calves less difficult. It is important to highlight that the two experiments in Kung et al. (1997) only had 23 and 30 calves, respectively, and although one of their objectives was to compare health between those two systems, they lacked power to be able to find significant differences in calf health.
On the other hand, there are studies that might provide misleading results about benefits of group housing on calf health. For example, a trial in Finland (Hänninen et al., 2003) aiming to compare health and performance of male calves up to 7 weeks of age either housed individually (indoors, inside cow barn) or in groups of four calves (groups indoors: inside cow barn, and outdoors: with or without heated shelter), stated that there were differences in the mean incidence of calf diarrhea days (i.e., sum of calf diarrhea days / sum of all experiment days) between housing treatments. The mean incidence of calf diarrhea days was lower in calves housed in indoor groups (1.2%) compared with individually-housed calves (6.3%) and calves housed in outdoor groups without heated shelter (6.9%). There was no difference in the incidence of calf diarrhea days between group-housed calves indoors or outdoors with heated shelter (4.3%). However, these results were likely confounded by differences in bedding/floor type. While group housing systems were identical in structure, and calves had access to a 3 x 4 m straw-bedded area and a 2 x 10 m bark-bedded area, individually-housed calves were housed in a 1 x 1.2 m slatted floor area. Slatted floors are associated with higher ammonia concentration (7.2 vs. 4.2 ppm), higher air temperature (15 vs. 12 °C) and relative humidity (77 vs. 72%) compared to litter pens (Svensson et al., 2006). Further, Gulliksen et al. (2009) found that housing calves in slatted floors was also associated with higher risk of diarrhea and shedding Cryptosporidium oocysts.

Research providing neutral results regarding individual and group housing also exists. In an observational study done in Canada, Waltner-Toews et al. (1986) showed no significant difference in the risk of a farm to have either above-median treatment days per calf (for all diagnoses) or to have experienced at least one episode of scours, concluding that there was no significant difference in health outcomes between farms raising calves in groups or in individual pens. Similarly, in a controlled trial, Bernal-Rigoli et al. (2015) did not find differences in health scores between individually- and group-housed calves. However, the authors did not acknowledge that the lack of difference could have been a result of a lack of power due to small sample sizes (individually-housed calves: n = 10; and group housing: 10 pens of 3 to 4 calves per pen).

Considering calf growth outcomes, findings from research supports group housing. Some researchers did not find advantages of group housing for calf growth, e.g., Hänninen et al.
22

(2003) found no significant differences in weight gain between individually- (0.75 kg/d) and group-housed calves (0.85 kg/d, respectively). However, the majority of research in this area (described below) shows benefits of group housing for calf growth, especially when high milk allowances are fed.

Bernal-Rigoli et al. (2015), in a trial comparing type of housing (individual vs. groups of 4 calves) and milk feeding method (bucket vs. bottle), found that group-housed calves had significantly higher dry matter intake (DMI; 1.2 vs. 1.1 kg) and ADG (0.5 vs. 0.4 kg/d) compared with individually-housed calves, even though all calves were fed only 4 L/d of milk. The effects of group housing on calf growth have been also seen when calves are fed higher milk allowances. For example, Jensen et al. (2015) found that pair-housed calves consumed more starter (840 g/d vs. 540 g/d) than individually-housed calves (both groups receiving 9 L/d of milk for the first 4 weeks of life), which resulted in higher ADG (0.99 vs. 0.85 kg/d). Jensen et al. (2015) concluded that pair housing can buffer the negative effect of high milk allowances on solid feed intake, by promoting higher intakes. In addition, Costa et al. (2015) found an effect of age at grouping. Early pair-housed calves (i.e., paired at 6 days old) consumed significantly more starter and had higher DMI compared with individually- and late pair-housed calves (i.e., at 6 weeks of age), and the authors also found that this effect remained once calves were weaned. Differences in starter intake between the three groups were seen at 6 (0.18, 0.07, and 0.05 kg/d for early-paired, individually-housed, and late-paired calves, respectively) and 10 weeks of age (2.2, 1.1, and 1.3 for early-paired, individually-housed, and late-paired calves, respectively). As a consequence, ADG was higher for early-paired calves during the weaning period (6 to 10 weeks of age). Similarly, de Paula Vieira et al. (2010) found that at mixing after weaning, paired-housed calves (i.e., paired at 4 days of age) had better ADG (0.9 kg/d) than calves reared individually during the pre-weaning period (0.8 kg/d). Costa et al. (2015) concluded that there are advantages to providing early social housing to calves because it somehow encourages calves to consume more solid feed and improves weight gains, which positively impact calves’ development; thus, the authors recommended to introduce calves to a group within 3 weeks of life.
1.4.2 Impacts on Affective States and Natural Living

Cattle are one of the domesticated species that are highly social (Phillips, 2002). Calves like to be close to their dam for the first days of life but as calves grow, their preferred neighbor is often another calf of similar age (Ylipekkala and Woivalin, 1991). Holm et al. (2002) measured calves’ motivation for social contact and found that calves had a stronger motivation to have full social contact with another calf than just head contact (i.e., through bars), evidencing that social contact is an important resource to which calves should have access. Additionally, Færevik et al. (2006) and Duve and Jensen (2011) showed that calves have a preference for their companion calf compared with an unfamiliar calf, and this effect was stronger when pair-housing was implemented right after birth (Duve and Jensen, 2011), meaning that calves develop social bonds at an early age. Specifically, Færevik et al. (2006) found that calves subjected to separation from their group in the company of a familiar calf did not vocalize, while calves separated from their dam alone or with an unfamiliar calf had a mean number of vocalizations of 4.5 and 1.7, respectively. The authors concluded that this effect might be because calves felt safer in the presence of a familiar companion.

Research on housing systems for raising calves also looked at effects on calves’ reactivity, especially to novel situations (Table 1.5). On dairy farms, examples of novel situations for an animal could be isolation from the herd due to illness, mixing with other cattle, or introduction to a new environment. Veissier et al. (1994) reported on one of the earliest studies to show that individually-housed calves were significantly more reactive and started more agonistic (i.e., associated with conflict) encounters when mixed with other calves at 14 weeks of age compared to calves reared in groups (mean frequency of agonistic encounters: head butts: 6.7 vs. 1.7; flight: 3.1 vs. 0.7; fight: 4.2 vs. 1.7). Similarly, Jensen et al. (1997) showed that calves raised individually expressed more fear (i.e., were more reluctant to enter a new environment and approach an unfamiliar calf, and had a higher heart rate) when introduced into a new environment with an unfamiliar calf compared with calves raised in groups of four. De Paula Vieira et al. (2012) showed that individually-housed calves defecated 2 times more, and were more active (i.e., more time running: 83 vs. 57 seconds/test) than pair-housed calves when introduced in a novel environment. Individually-housed calves could be more reactive to novel situations due to the fact that they were raised in isolation in a more predictable environment, so
when exposed to a new situation, calves might experience anxiety and fear, and thus, be more reactive to new stimuli.

Weaning off milk, which for dairy calves usually comes with a change in environment, is a stressful period, but calves’ performance can be improved when weaned with a companion rather than individually (Weary et al., 2008) (Table 1.5). For example, De Paula Vieira et al. (2010) found that calves raised individually vocalized 3 times more than paired-housed calves (paired at 5 days old), concluding that stress during weaning can be buffered by raising calves in pairs. In addition, after mixing calves once weaned, De Paula Vieira et al. (2010) also found that paired-housed calves had a significantly shorter latency to approach the starter feeder (9 vs. 49 hours), spent more time at the feeder (88 vs. 65 min/d), and consumed more starter (3.5 vs. 2.3 kg/d) compared to calves raised individually before mixing. They attributed the higher starter intakes among paired-housed calves to social facilitation and that paired-housed calves already learned how to cope with other calves, while individually-housed calves had to do it all at once.

Even though it has been shown that calves with access to high milk allowances are able to experience positive emotions and perform positive behaviour such as play (Krachun et al., 2010; Duve et al., 2012), especially locomotor play (e.g., gallop, leap, jump, buck, buck-kick, turn, and head-shake) (described previously in section 1.2.2), it seems that group housing does not appear to have an effect as strong as milk allowance (Jensen et al., 2015) (Table 1.5). Duve et al. (2012) found no differences in the duration of all play behaviours together between individually-housed calves on high milk allowances (9 L/d of milk), group-housed calves fed 9L/d of milk, and group-housed calves on restricted milk diet (5 L/d of milk), but these three groups differed from individually-housed calves on restricted diets, suggesting that the combination of individual housing and restricted diets impairs the expression of play behaviour.

Individual housing might not directly suppress play behaviour in calves, but researchers have recently found that cognitive performance might be impaired when housing calves in individual pens (Table 1.5). Gaillard et al. (2014) and Meagher et al. (2015) found that individually- and pair-housed calves performed similarly when learning a discrimination task (i.e., the learning criterion was reached after a median of 10 to 15 vs. 9 to 12 training sessions, respectively) and when re-learning after the task was reversed. However, as training sessions of
the reversed task continued, individually-housed calves performed more poorly than pair-housed calves (19 vs. 13 training sessions). Gaillard et al. (2014) attributed the deficit in reversal learning (indicative of behavioural inflexibility; Meagher et al., 2015) in individually-housed calves to the lack of variability in their environment and less unpredictable situations. Although this area of research is new and the implications of behavioural inflexibility in calves are unknown, it is desirable to have animals that are able to cope well and adapt appropriately to changing environments to avoid detrimental effects on biological functioning and welfare.

If not managed appropriately, group housing can increase stress on calves through competition for resources. For example, von Keyserlingk et al. (2004) found that when group-housed calves were provided with fewer teats (teat-to-calf ratio of 1:3) they drank 25% less milk and performed twice as many displacements compared to calves that had access to more teats (teat-to-calf ratio of 4:3). Similar results were observed by Miller-Cushon et al. (2014) comparing a teat-to-calf ratio of 2:2 to 1:2. von Keyserlingk et al. (2004) attributed the decrease in milk intake to the higher number of displacements when there were fewer teats available. As discussed in the section 1.2.2, aggression can be a sign of frustration, which could be what calves experience when competition for the food source is higher. Moreover, Miller-Cushon et al. (2014) found that displacements at the feed bunk persisted after weaning for calves raised under a competitive environment (teat-to-calf ratio of 1:2).

1.5 MANAGEMENT AND PERFORMANCE OF GROUP-HOUSED AUTOMATICALLY-FED CALVES

Little research about management practices and performance of dairy calves raised in groups, and specifically fed milk with AMF in commercial dairy farms, is available in English (other published information is available in other languages such as Swedish, Finish, Norwegian, and German, cited in Hepola, 2003). Only one observational study in Sweden assessed factors associated with the incidence of calf diseases on farms housing calves in groups with AMF compared to individual housing and feeding, or farms using group housing but feeding milk manually. There are observational and experimental studies that looked at specific aspects of
management, providing some insight into group housing and automated milk feeding systems, as discussed below.

1.5.1 Calf Health and Performance on Commercial Dairy Farms using Automated Milk Feeders

In a longitudinal observational study of 122 dairy farms in Sweden, calves were followed from birth to 90 days of age to evaluate calf- (Lundborg et al., 2003; Svensson et al., 2003) and herd-level factors (Lundborg et al., 2005) associated with morbidity and performance of dairy calves. In all three reports, housing for calves was categorized as individual housing (manually-fed calves), small group (3 to 8 manually fed-calves), and large group (6 to 30 automatically-fed calves per group). Lundborg et al. (2003) focused on the effects of dam-related and management factors on calf growth and health, whereas Svensson et al. (2003) looked at the effects of colostrum type, season, and housing, among other calf-level factors on calf health. Lundborg et al. (2003) found that large group-housed automatically-fed calves tended to have a lower growth rate (based on hearth girth measures) than individually-housed calves (0.02 cm/day less) and had a significantly lower growth rate compared to small group-housed manually-fed calves (0.04 cm/ day less). The biological impact of these growth differences (2 to 3 cm by weaning – median of 72 days) can be arguable, and the authors do not provide information on growth variations within housing systems to be able to see which system allowed for a more homogeneous growth among calves. On the other hand, the authors suggested that differences in growth could have been due to the fact that being housed in a group would allow calves to experience social facilitation, thus calves would eat together, whereas calves in larger groups could have grown less due to higher levels of activity from having more space to move around.

When looking at the effects of housing on respiratory disease, housing calves in large groups with AMF was associated with a higher incidence risk of respiratory disease compared to single housing (Lundlorg et al., 2003: 3.7 times higher; Svensson et al., 2003: 2.2 times higher (7.4 vs. 3.5%); Lundlorg et al., 2005: 2.3 times higher) or to small groups of manually-fed calves (Lundlorg et al., 2005: 2.4 times higher). These studies did not find an effect of housing on the incidence of diarrhea, although Svensson et al. (2003) found that the incidence risk of diarrhea
among large group-housed automatically-fed calves (4.4%) tended to be 0.5 times lower than in the other two housing systems (individual: 7.4%; small group: 8.1%).

The issue with these three studies is that they all share the same data and there are no other replicating studies with different populations to compare with their findings. Additionally, the fact that the classification of group sizes (small vs. large) confounded the relationship between milk feeding methods (manual vs. automated) and outcomes (growth and incidence of disease), does not allow for specific conclusions about the ideal size or the ideal feeding system.

In North America, an observational study across 38 farms raising calves in group housing systems with an AMF in the Midwest United States is the only available published research investigating associations of management practices and the risk of higher (worse) individual calf health scores (e.g., attitude, temperature, hind-end dirtiness score; adapted from the health scoring method developed by McGuirk, University of Wisconsin-Madison) (Jorgensen et al., 2017). In this research, the authors found that management factors related to cleanliness of the AMF, milk feeding plan, stocking density, and ventilation were key determinants of calf health (n = 10,179 calves). Specifically, the authors found that the median total bacteria count (TBC) from milk samples collected at the mixing jar of the AMF was 166,916 cfu/mL, and that TBC above 100,000 cfu/mL (limit for bacteria contamination of milk fed to calves based on recommendations given by McGuirk and Collins, 2004) was associated with an increase in the odds of a calf having a higher attitude score (5-point scale, where 0 = active and 4 = dead) or ear score (5-point scale, where 0 = no ear droop and 4 = head tilt) (by 21 and 32%, respectively), or of having fever (rectal temperature > 39.4 ºC) by 81%. The authors stated that the milk replacer container, the mixing jar, the hoses, and the teats are potential reservoirs of bacteria in these feeding systems, which can contaminate the milk fed to calves if not sanitized adequately. In addition, it was hypothesized that the heated rooms where the AMF are usually installed could also increase the proliferation of bacteria in the milk.

Regarding the milk feeding plan among farms visited by Jorgensen et al. (2017), the mean start daily milk allowance once calves were introduced to the AMF was 5.4 L (range: 3 to 15 L), the mean peak daily milk allowance was 8.3 L (range: 5 to 15 L), and the latency to reach this peak was 18 days (range: 0 to 44 days). Interestingly, the authors found that the peak milk
allowance was negatively associated with the odds of a calf being classified as having a higher hind-end dirtiness score (a 12% decrease for each additional litre of milk), and that the latency to reach the peak was positively associated with the odds of a calf having a higher score for: attitude (1.3% increase for each additional day), ear (2.2% increase), eye discharge (2.2% increase), and hind-end dirtiness (1.9% increase), and of a calf having fever (2.5% increase). Based on these findings, the authors concluded that increasing the daily milk allowance faster once calves are introduced to the AMF might benefit calf health.

When looking at the effects of group management, this observational study (Jorgensen et al., 2017) found that group size (mean of 18 calves/pen; range: 6 to 60 calves/pen) also impacted calf health scores. For each additional calf in the group pen, the odds of a calf having a higher nasal score increased by 1.1%, and the odds of a calf having a higher hind-end dirtiness scored decreased by 1.3%. However, the authors concluded that the odds ratio (OR) were very small (OR; 95% CI, nasal score: 1.01; 1 to 1.02; dirtiness score: 0.99; 0.97 to 1), thus, the biological consequences were meaningless. In addition, the authors found that independently of group size, for each additional square meter of space allowed per calf, there was a decrease in the odds of a calf having a higher score for ears or eyes (10.4 and 7.7% decrease, respectively).

Finally, Jorgensen et al. (2017) found that the odds of a calf (group-housed and automatically-fed) having fever increased 81% when the barn did not have a positive pressure ventilation systems. There is no other published studies on farms using AMF systems that evaluate ventilation systems available for comparison. However, data from an observational study on naturally-ventilated farms housing calves individually (in the United States) have shown that reduced airborne bacteria counts in the pens were associated with a reduced prevalence of respiratory disease (Lago et al., 2006). These authors also found that airborne bacteria counts were higher in pens with smaller area per calf, with higher air temperature, and with solid sides. Similarly, Cobb et al. (2014b) found that under poor indoor ventilation and drainage conditions, the incidence risk of BRD tended to be higher for group-housed calves compared to individually-housed calves (34 vs. 10%). The findings from Lago et al. (2006) and Cobb et al. (2014b) show how some features of housing facilities can affect the air hygiene and the mixing of the air within the barn and the pens for calf health, and how the risk of BRD is higher for group-housed calves when air quality is affected.
1.5.2 Management Aspects of Group Housing with Automated Milk Feeders from Experimental Trials

Experimental research trials have focused primarily on the age of introduction to the group pen, on the adaptation of calves to learn and use the AMF, and ideal group sizes. These will be described below.

1.5.2.1 Age of introduction to the group pen

Typically on farms using AMF systems, a newborn calf will be housed alone in an individual pen or hutch for several days. The time spent in this individual housing before introduction to the group pen with an AMF varies from farm to farm, from a few hours after birth to more than one month of age. Data from dairy farms in the Midwest United States showed a median age of introduction of 5.4 days, with a range from 0 to 14 days (Endres, 2016), whereas in Sweden the median age of introduction was 12 days and ranged from 2 to 35 days (Svensson and Liberg, 2006). Therefore, producers using AMF are introducing calves to a group at an earlier age than on conventional dairy farms, where calves are normally introduced to a group either at the beginning of the weaning period or after being weaned (between 5 and 8 weeks of age approximately; USDA, 1994; Svensson et al., 2003).

On the other hand, research on the best time to introduce calves to a group pen with an AMF is scarce and lacks integration. Aspects such as labour (Jensen, 2007), calf health and performance (Svensson and Liberg, 2006), and the calf’s social integration into a large, dynamic group (Rasmussen et al., 2006) have been looked at only separately.

A randomized controlled trial comparing calves introduced to a large group pen (mean group size = 16 calves; range: 8 to 25 calves) with an AMF at 6 vs. 14 days old (Rasmussen et al., 2006) showed that younger calves were significantly more restless (changed posture more often) during the first 24 hours after introduction compared to older calves (18 vs. 15 times per 8 h of observation). In addition, the authors found that younger calves performed less sniffing and licking compared to older calves after introduction (26 vs. 33 bouts per 8 h of observation, respectively), but no difference in locomotor play behaviour was found (11 vs. 13 bouts per 8 h, respectively). Rasmussen et al. (2006) proposed two explanations for these differences in social
behaviour. First, differences could be due explicitly to age rather than to the treatments, because social behaviour tends to increase as calves get older. Second, early introduction to a group could causetimidity in those calves. Rasmussen et al. (2006) suggested that the experience of timidity was supported by their lower frequency of performing licking and sniffing and their tendency for having less standing time, which authors explained was a result of younger calves attempting to hide by lying down. Based on these findings, Rasmussen et al. (2006) concluded that calves introduced to a large group at 14 days old were able to integrate better than calves introduced at 6 days of age.

Considering labour as a main outcome in a randomized controlled trial in which calves were assigned to introduction to a group pen with an AMF at 6 or 14 days old (with a median group size of 18 calves), Jensen (2007) found that during the first week in the group pen, the odds of requiring guidance to drink from the AMF were 2.3 times higher for calves introduced at 6 days old compared to calves introduced at 14 days old. Additionally, these authors stated that calves introduced at 6 days old were less able to compete for access to the AMF because younger calves spent less time at the feeder and ingested less milk during the first 12 days after introduction compared to calves introduced at 14 days old. However, comparing milk consumption between calves of different ages (6 to 18 days of age vs. 14 to 26 days of age) is not a fair comparison as it is known that milk intake increases with calf’s age.

Svensson and Liberg (2006) conducted a randomized controlled trial on nine Swedish farms using AMF, where the main objective was to compare the effects of group size (6 to 9 calves vs. 12 to 18 calves per pen) on calf health and growth. They found a negative association between the incidence risks of clinical respiratory disease and increased respiratory sounds and the age of introduction to the group pen. Specifically, they found that the risk of having increased respiratory sounds was approximately 1.5 and 1.6 times higher among calves introduced before 8 days of age or calves introduced between 8 and 12 days of age, respectively, compared to calves introduced after 19 days of age. The risk of increased respiratory sounds did not differ between calves introduced between 12 and 19 days and calves introduced after 19 days. Jensen (2007) and Svensson and Liberg (2006) both recommended delaying introduction to the group pen to reduce labour for guiding calves to the feeder and to preserve calf health. They also argued that
because disease incidence is higher during the second week of life, introduction should not occur at that age, but rather later.

It is important to mention that in the Rasmussen et al. (2006) and Jensen (2007) studies, calves were under a low milk allowance diet: 6.4 L/d for breeds such as Holsteins, and 5.2 L/d and 4.8 L/d for Jerseys. Svensson and Liberg (2006) did not report daily milk allowance in each of the farms. The milk allowance in these studies could have had an impact on the results, especially for behavioural and health outcomes. In the case of behavioural outcomes, restricted milk diets have an impact on restless behaviour and usage of the AMF (as reviewed in section 1.2.2), thus newly-introduced calves in Rasmussen et al. (2006) and Jensen (2007) could have been less curious and spent less time at the feeder as a result of the competitive behaviour and displacements from older calves that were motivated to find food. In the case of health outcomes, low milk allowance has been found to be associated with an increased incidence of relapses of BRD (Bach et al., 2013). Thus, it is as important as to know the age of introduction to the group pen, to have knowledge on daily milk volumes prior introduction to the AMF and during the pre-weaning period, and control for it during analysis.

1.5.2.2 Adaptation to the automated milk feeder

Once a calf is introduced to the feeder, the next step in the process is to teach the calf to use the AMF and recognize it as the milk source (Fujiwara et al., 2014). Little research has been done on this topic. Jensen (2007), as previously described, found that younger calves (6 days old) needed more guidance from the farmer to go to the feeder, suggesting that the adaptation of these young calves to the feeder was more difficult than for older calves (14 days old), based on the frequency of guided visits to the feeder during the first week in the group pen.

Using the latency to calves’ first feeder visit (unassisted) with voluntary milk intake after introduction to the group as a measure of adaptation and learning to use the feeder, Fujiwara et al. (2014) evaluated factors affecting calves learning to use an AMF through two experiments. The first focused on the effects of standing time, health, daily milk consumption, and BW prior to introduction (at 6 days old) to the group pen with the AMF on adaptation to the feeder. There was large variability between calves in when they first voluntarily drank milk from the AMF, with a median of 45.3 hours after introduction (interquartile range: 23 to 74 hours).
The majority of calves (69%) consumed milk during their first voluntary visit to the feeder, although 9% of calves took almost 2 days to voluntarily drink after their first unassisted visit to the feeder. This suggests that at least 75% of the calves would voluntarily visit the AMF and drink milk within 3 days after introduction. These findings are congruent with Jensen (2007) findings, where a 6 days old-calf needed 1 to 4 days after introduction to learn how to drink milk from the feeder. However, Fujiwara et al. (2014) found that the number of guided (i.e., assisted by the farmer) visits to the feeder between introduction and calf’s first voluntarily visit with milk intake ranged from 0 to 25 (median = 5). Not surprisingly, latency to the first feeder visit with voluntary milk intake was positively correlated with the number of guided visits ($r_s = 0.81$). This could be interpreted as: 1) the more guidance is provided by the farmer, the longer it will take for a calf to adapt and voluntarily drink milk from the feeder for the first time (i.e., assistance causes delay in learning), or 2) the longer a calf takes to adapt to the feeder, more labour will be needed (assistance is neutral or beneficial to learning). The mean daily duration of standing time prior to introduction (days 2, 3, and 4 of life) and BW at introduction day were also associated with calf adaptation to the feeder, although the correlations were weak. The heavier the calf was on the day of introduction to the group pen (which happened at the same age: 6 days), the shorter the latency to first voluntary drink from the feeder ($r_s = -0.25$); and the more active the calf was prior to introduction (5 or more hours standing), the shorter the latency ($r_s = -0.30$). Fujiwara et al. concluded that although the majority of calves adapted to the feeder relatively quickly, there was a proportion of calves that would require more assistance, which may represent a challenge for the farmer and those calves that are slow to adapt. This slow adaptation might be a challenge for calves in terms of experiencing negative affective states such as hunger and stress (as shown by Fujiwara et al., 2014 where these calves consumed less milk than calves that adapted sooner), which would be relieved when the farmer comes and guides them to the feeder.

In a second experiment, Fujiwara et al. (2014) tested whether pair vs. individual housing prior to introduction had any effect on calf adaptation to the feeder, and found no difference between housing systems. Nevertheless, the study design was not the ideal to test this hypothesis because pairs were not introduced together to the group pen, which could have caused an additional stress due to their separation, thus possibly affecting the outcomes. Combining data from both experiments, researchers also tested whether age at introduction (ranging from 6 to 13 days old) had any effect on the adaptation of calves to the feeder. They found that as age at
introduction increased, the latency to first voluntary milk intake decreased significantly ($r_s = -0.23$). Nonetheless, the authors suggested that introduction to the group pen with the AMF should not be done based on a fixed age but based on the “readiness” of the calf (i.e., based on vigor after birth, and standing time prior introduction), because many young calves in the trial did adapt quickly to the feeder.

The way calves are trained to drink from the AMF might have an impact on calves’ adaptation to the AMF and on the advantages feeders offer in terms of labour savings. However, there is no published research on methods of introducing calves to the group pens with an AMF. Despite the lack of research on this topic, producers have to do the training using the technique that most suits their routine based on their own knowledge and perceptions of what works better. For example, an article in the lay press (Guthrie, 2015) described how a dairy producer from Ontario, Canada, trains his calves to drink from the AMF. The producer housed calves individually for 2 to 3 days after birth, where calves were fed 6 L/d of whole milk. Once calves were drinking appropriately they were introduced to what the producer called “a training pen” with space for 5 to 6 calves, intended to allow calves to learn to drink from the feeder and get “well-started”. After that, calves were transferred to a bigger pen, where they were housed in groups of 20 and allowed 12 L/d of whole milk through an AMF. Beyond these, there is no guideline available for producers, or research investigating the possible effects of training procedures on calf’s adaptation and learning to use the feeder.

1.5.2.3 Group sizes

Automated feeding systems have been reported to facilitate the management of group-housed calves and reduce producers’ workload (Kung et al., 1997). However, group size could be one of the weaknesses of AMF systems. Svensson and Liberg (2006) carried out a controlled field trial on 9 farms to evaluate the effects of group size (small: 6 to 8 calves/pen vs. large: 12 to 18 calves/pen) on calf health and performance. Group size did not have an effect on the incidence of diarrhea (mean incidence of diarrhea in small-sized groups: 15.4%; large-sized groups: 18.1%), but calves housed in large groups had 1.4 times greater odds of having respiratory disease compared to calves housed in small groups (21.8 vs. 28.3%). In addition, growth rate was significantly lower in calves housed in large groups (40 g/day less). The authors
did not provide information on milk allowances, only milk type (whole milk was fed in 4 farms, milk replacer in one farm, and a combination in the rest of farms).

Larger group sizes can also impact calf feeding behaviour via competition when trying to access a single food source as is typically the case for group-housed calves fed through AMF systems. Jensen (2004) found that calves were housed in groups of 24 vs. 12 spent significantly more time waiting to access the feeder (21 vs. 6 min/day) and performed more displacements at the feeder (2.4 vs. 1.4 displacements/day), causing calves to drink their milk meals faster (18 vs. 23 min/day). These behavioural changes, especially the increase in drinking rate, have been hypothesized by Nielsen (1999) as adaptations to a social and competitive environment.

1.6 ADOPTION OF TECHNOLOGY ON FARMS

Farmer behaviour is dependent on personal factors and external farm factors (Willock et al., 1999). The former relate to factors such as personality, age, and level of education (Bewley, 2010), and are influenced by a farmer’s goals and attitudes towards farming (Willock et al., 1999). Specifically, decision-making for a dairy producer is likely influenced by an interest in maximizing efficiency and productivity of their farm, but external factors such as food safety concerns, consumer preferences, and the increased attention on the care of animals also play a key role (Bewley, 2010, 2013; Endres, 2013). Economic return is a crucial factor that influences technology adoption, but the use of technology by other farmers and peers’ experiences with it also have an impact on adoption (Bewley, 2010, 2013; Russell and Bewley, 2013).

Research on reasons for adopting new technologies among dairy farmers has mainly focused on automatic milking systems (AMS) and, in general, precision farming technologies (PFT). Reasons for adopting AMS and other precision dairy technologies, and producers’ perceptions of these technologies can help to understand the motives behind the adoption of AMF and group housing for raising calves.
1.6.1 Adoption of Automatic Milking Systems

In Canada, the adoption of AMS has increased approximately 20% per year since 2013, with 7.5% of Canadian dairy farms, on milk recording, using robotic milking systems in 2016 (CDIC, 2017). In North America (de Jong et al., 2003) and the UK (Butler et al., 2012), farmers who adopted AMS indicated that the main reasons were a desire for a lifestyle change, time flexibility, decreased labour, increased interest in farming for younger generations, and increased productivity. Butler et al. (2012) found that producers found that the AMS changed their lifestyle and they did not feel tied to the “traditional dairy farming style”. However, these producers perceived that labour did not decrease but rather it changed, meaning that they perceived they had more time available to perform other work at the farm, which seemed to have a positive impact on productivity and profitability. Interestingly, another reason for adoption, especially for tenant farmers, was that AMS could be disassembled and moved if needed, or eventually be sold (Butler et al., 2012).

There is no information available indicating that concerns regarding cow welfare were a main reason for adopting AMS. Therefore, it could be inferred that the adoption of AMS has been mainly driven by human factors, such as the need for a change in lifestyle and reduced workload. Nonetheless, after adoption, producers perceived that cows were more relaxed, calm and quiet compared to when using a conventional parlour (Butler et al., 2012). In a Canadian study, Tse (2016) found that, after adoption, 80% of producers perceived that disease detection was easier with the AMS. However, those producers, in the same study, that perceived disease detection to be more difficult stated that it was a result of less direct contact with the cow. Russell and Bewley (2013) stated that producers measure part of their success by knowing their animals have a good welfare. Therefore, producers might not directly take into account cow welfare when deciding to adopt an AMS, but they do when expressing their satisfaction with their system.

On the other hand, one of the main reasons for slow adoption of AMS is the required financial investment (Butler et al., 2012; Bergman and Rabinowicz, 2013). In a survey of 217 Canadian producers who adopted an AMS, Tse et al. (2017) found that 55% of those producers built new barns in order to accommodate the milking robots, and 71% of these changed housing
system (mainly from tie- to free-stall), which exemplifies the extent of the investment needed to implement a technology on farm.

1.6.2 Adoption of Precision Technologies

Bewley (2010) defined PFT as “… technologies that measure physiological, behavioural, and production indicators on animals to improve management and farm performance” such as estrus detection monitors and milk component monitoring systems.

When producers are thinking of adopting PFT, the perceived economic return (i.e., benefit to cost ratio) has been shown to be a highly influential consideration (Russell and Bewley, 2013) along with the total investment required (affordability) and the simplicity of the technology (Borchers and Bewley, 2015). Additionally, producers seem to seek proof of the performance of the technology by independent research (which should demonstrate that the technology will definitely help them to accomplish specific goals) and the availability of local support when debating whether to adopt certain PDF (Borchers and Bewley, 2015). Moreover, Daberkow and McBride (2003) identified that larger, full-time, and computer-oriented producers in the USA were more likely to adopt PFT.

Taking advantage of all the features provided by a technology takes time to achieve. Data from Australian dairy producers who adopted PFT (Eastwood et al., 2012) showed that it takes a year to develop and consolidate knowledge on basic functions of the technology, while using the technology to the maximum (advanced learning) can only be achieved by proactive management and engagement of all staff with the technology, and by interacting and exchanging experiences with other current users. However, it is known that lack of simplicity and ease of use, and the time involved in using the technology can slow down adoption of PFT (Borchers and Bewley, 2015).

Other factors associated with non-adoption of PFT are farm size (Jackson-Smith and Barham, 2000), feeling overwhelmed by information recorded by devices (without a clear idea of what to do with it), poor technical support, better manual alternatives, perceiving that the technology needs improvements before they can adopt it, and lack of familiarity with PFT and fear of technologies (Russell and Bewley, 2013). Daberkow and McBride (2003) found that
producers who were not aware of existing PFT were older, less educated, less familiar with computers, and had smaller farms.

All these factors reflect the importance of coordinated efforts among researchers, whose findings should evidence the benefits and disadvantages of the technology available, extension agents and dairy advisors, who should transfer knowledge to producers about technologies that match their needs (Eastwood et al., 2012), and manufacturers, who should provide applicable evidence of benefits and good technical support to generate trust in producers, for a technology to be successfully used on farms (Russell and Bewley, 2013; Borchers and Bewley, 2015).

1.7 CONCLUSIONS AND RESEARCH OBJECTIVES

Researchers have shown that calves can benefit from higher milk allowances and from sucking milk from a teat. The Canadian Dairy Code of Practice (NFACC, 2009) recommends feeding calves at least 20% of their BW in milk during the first 28 days of life; however, implementation of this recommendation is still slow (Vasseur et al., 2010; USDA, 2016). Limitations for implementing this practice are multifactorial, but are mainly because of rooted traditions and beliefs, labour, and rearing costs. Individual housing is still the predominant system used to rear calves in North America, despite the benefits shown on growth, starter intake, development, and calf health achieved when calves are raised in small groups at an early age. Finding feasible ways of implementing higher milk allowances and group housing for unweaned calves without increasing physical labour on farms can be challenging. On the other hand, the development and adoption of technologies to improve efficiency and facilitate farm management is a reality, and raising calves need not be any exception. Automated milk feeders have been developed to facilitate the increase of daily milk allowance and management of group-housed calves. However, there is scarce knowledge about producers’ motivations around decisions related to calf feeding methods and adoption of AMF systems.

In any calf raising system, good management practices are required; however, this is essential when using group housing with AMF systems because calves could be more exposed to pathogens and stressors than when housed and fed individually, and there is potential for
intensive group housing to have detrimental effects on calf health and welfare if not managed properly. Research has addressed group size and age of introduction to the group, concluding that small groups of calves and introducing calves to the group pen after at least 2 weeks of age would be ideal practices. Nevertheless, more research on best management and feeding practices on farms raising calves in groups with AMF is needed. To be able to draw comparisons and establish goals, it is necessary first to determine current practices on Canadian dairy farms, as the latest study on this was done in 2008 and only in the province of Quebec (Vasseur et al., 2010). In addition, to be able to support current users and future adopters of AMF, it is necessary to estimate the frequency and determinants of calf health problems under AMF systems.

Therefore, the overall purpose of my thesis was to build knowledge on the use and management of AMF for raising group-housed dairy calves, and to investigate potential determinants of calf health on commercial Canadian dairy farms using this system. The specific objectives of my thesis were to:

1) Determine the prevalence of various milk-fed calf management and feeding practices in Canada and compare these practices between dairy farms using manual milk feeding systems (MMF) and AMF systems.

2) Determine factors that influenced producers to continue using MMF systems or to switch to AMF and gather information about advantages and disadvantages perceived by producers regarding both feeding systems.

3) Estimate the prevalence of calf diarrhea and bovine respiratory disease and identify factors associated with prevalence of these diseases at the pen level on dairy farms feeding milk to group-housed calves with AMF in southern Ontario, Canada.

4) Evaluate the effects of introducing young calves (within 24 hours after birth) to the group pen with AMF on calf growth and learning to use the feeder, and required labour.
1.8 REFERENCES


<table>
<thead>
<tr>
<th>Parameter</th>
<th>USDA – NAHMS studies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cow-calf separation¹</td>
<td>90</td>
</tr>
<tr>
<td>Individual housing²</td>
<td>83</td>
</tr>
<tr>
<td>Feeding</td>
<td></td>
</tr>
<tr>
<td>Daily milk allowances</td>
<td></td>
</tr>
<tr>
<td>≤3.6 L</td>
<td>19²</td>
</tr>
<tr>
<td>&gt; 3.6 &lt; 7.4 L</td>
<td>76²</td>
</tr>
<tr>
<td>3.7 to 4.7 L</td>
<td>---</td>
</tr>
<tr>
<td>5.6 to 6.6 L</td>
<td>---</td>
</tr>
<tr>
<td>7.5 to 8.5 L</td>
<td>---</td>
</tr>
<tr>
<td>Two milk feedings per day</td>
<td>---</td>
</tr>
<tr>
<td>Weaning age, weeks</td>
<td>8</td>
</tr>
<tr>
<td>Incidence risk of mortality³, %</td>
<td>8</td>
</tr>
<tr>
<td>Causes of death</td>
<td></td>
</tr>
<tr>
<td>Diarrhea⁴</td>
<td>50</td>
</tr>
<tr>
<td>Respiratory disease⁵</td>
<td>18²</td>
</tr>
<tr>
<td>Age at grouping, weeks</td>
<td>7 to 8</td>
</tr>
</tbody>
</table>

¹Before 24 hours after birth
²Either hutch, tie stall, or individual pen
³Percentage of calves born alive that died prior to weaning
⁴Percentage of deaths caused by digestive problems
⁵Percentage of deaths caused by respiratory disease
⁶From birth to 3 weeks of age
--- Information not available
Table 1.2. Published research addressing the effects of higher milk allowances on growth and disease of dairy calves

<table>
<thead>
<tr>
<th>Type of study</th>
<th>Calf housing</th>
<th>Variable</th>
<th>Effect(^3) on</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Controlled trial</td>
<td>Individual</td>
<td>Restricted (14% of BW(^6)) vs. High (20% of BW(^5) and ad libitum)</td>
<td>+</td>
<td>Woodward, 1923</td>
</tr>
<tr>
<td>Controlled trial</td>
<td>Individual</td>
<td>Restricted (10% of BW(^6)) vs. Ad libitum</td>
<td>+</td>
<td>Appleby et al., 2001</td>
</tr>
<tr>
<td>Controlled trial</td>
<td>Individual</td>
<td>Restricted (10% of BW(^6)) vs. Ad libitum</td>
<td>+</td>
<td>Jasper and Weary, 2002</td>
</tr>
<tr>
<td>Controlled trial</td>
<td>Individual</td>
<td>Restricted (10% of BW(^6)) vs. Ad libitum</td>
<td>+</td>
<td>Miller-Cushon et al., 2013</td>
</tr>
<tr>
<td>Controlled trial</td>
<td>Individual</td>
<td>Restricted (4 L/d) vs. 6 to 7 L/d</td>
<td>+</td>
<td>Terre et al., 2009</td>
</tr>
<tr>
<td>Controlled trial</td>
<td>Individual</td>
<td>6 L/d vs. 8 L/d</td>
<td>=</td>
<td>Bach et al., 2013(^7)</td>
</tr>
<tr>
<td>Controlled trial</td>
<td>Individual</td>
<td>1.2% vs. 2.1% of BW (in a DM basis)</td>
<td>=</td>
<td>Davis Rincker et al., 2011</td>
</tr>
<tr>
<td>Controlled trial</td>
<td>Group</td>
<td>Restricted (4 L/d) vs. High (12 L/d and ad libitum)</td>
<td>+</td>
<td>Borderas et al., 2009a</td>
</tr>
<tr>
<td>Controlled trial</td>
<td>Group</td>
<td>6 L/d vs. 12 L/d</td>
<td>+</td>
<td>Rosenberger et al., 2017</td>
</tr>
<tr>
<td>Observational study</td>
<td>Group</td>
<td>Peak daily milk allowance, L</td>
<td>–</td>
<td>Jorgensen et al., 2017(^8)</td>
</tr>
</tbody>
</table>

\(^1\)Presented in chronological order.
\(^2\)Categorical variable (milk allowance treatment) for controlled trials; continuous variable for observational studies.
\(^3\)Direction (decrease, –; increase, +; no difference, =) of the reported effect of feeding higher milk allowances.
\(^4\)Average daily gain.
\(^5\)Incidence of diarrhea, respiratory disease, or relapses.
\(^6\)Body weight in milk.
\(^7\)Differences in disease: lower incidence of relapses of pneumonia.
\(^8\)Differences in disease: lower risk of having a dirty hind-end (diarrhea presence was estimated based on hind-end dirtiness score).
Table 1. Published controlled trials addressing the effects of higher milk allowances on behaviours indicative of negative and positive affective states in dairy calves

<table>
<thead>
<tr>
<th>Behaviour</th>
<th>Calf housing</th>
<th>Treatment</th>
<th>Effect$^2$</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Indicative of negative affective states</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frequency of vocal calls</td>
<td>Individual</td>
<td>Restricted (10% of BW$^3$) vs. 8 L/d</td>
<td>–</td>
<td>Thomas et al., 2001</td>
</tr>
<tr>
<td>Displacements</td>
<td>Group</td>
<td>4.8 L/d vs. 8 L/d</td>
<td>–</td>
<td>Jensen and Holm, 2003</td>
</tr>
<tr>
<td>Hyperphagia$^4$</td>
<td>Group</td>
<td>Restricted (10% of BW$^3$) vs. ad libitum</td>
<td>–</td>
<td>De Paula Vieira et al., 2008</td>
</tr>
<tr>
<td>Frequency of un-rewarded visits$^5$</td>
<td>Group</td>
<td>Restricted (10% of BW$^3$) vs. ad libitum</td>
<td>–</td>
<td>De Paula Vieira et al., 2008</td>
</tr>
<tr>
<td>Displacements</td>
<td>Group</td>
<td>Restricted (10% of BW$^3$) vs. ad libitum</td>
<td>–</td>
<td>De Paula Vieira et al., 2008</td>
</tr>
<tr>
<td>Duration of non-nutritive sucking</td>
<td>Group</td>
<td>Restricted (4 L/d) vs. High (12 L/d and ad libitum)</td>
<td>–</td>
<td>Borderas et al., 2009a</td>
</tr>
<tr>
<td>Duration of non-nutritive sucking</td>
<td>Group</td>
<td>Increased vs. reduced hunger level$^6$</td>
<td>–</td>
<td>Herskin et al., 2010</td>
</tr>
<tr>
<td>Butting</td>
<td>Group</td>
<td>Increased vs. reduced hunger level$^6$</td>
<td>–</td>
<td>Herskin et al., 2010</td>
</tr>
<tr>
<td>Duration of non-nutritive sucking</td>
<td>Individual</td>
<td>Restricted (10% of BW$^3$) vs. Ad libitum</td>
<td>–</td>
<td>Miller-Cushon et al., 2013</td>
</tr>
<tr>
<td>Hyperphagia$^4$</td>
<td>Individual</td>
<td>Restricted (10% of BW$^3$) vs. Ad libitum</td>
<td>–</td>
<td>Miller-Cushon et al., 2013</td>
</tr>
<tr>
<td><strong>Indicative of positive affective states</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Duration of play running</td>
<td>Group</td>
<td>6 L/d vs. 12 L/d</td>
<td>+</td>
<td>Krachun et al., 2010</td>
</tr>
<tr>
<td>Duration of play running</td>
<td>Individual</td>
<td>5 L/d vs. 9 L/d</td>
<td>+</td>
<td>Duve et al., 2012</td>
</tr>
<tr>
<td>vs. group</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$^1$Presented in chronological order.
$^2$Body weight in milk.
$^3$Direction (decrease, –; increase, +; no difference, =) of the reported effect of feeding higher milk allowances.
$^4$Abnormal great desire for food or excessive eating (Oxford Dictionary, 2018).
$^5$Visits to the automated milk feeder without milk ingestion.
$^6$The level of hunger was manipulated by either feeding the normal ration the night before (3 L) plus feeding an extra of 1.5 L prior morning feeding (reduced hunger level), and feeding half ration the night before without feeding the extra milk prior morning feeding (increased hunger level).
Table 1. 4. Published research\(^1\) addressing the effects\(^2\) of group housing on growth and disease of dairy calves in dairy calves

<table>
<thead>
<tr>
<th>Type of study</th>
<th>Group size, calves/pen</th>
<th>Risk of CD(^3)</th>
<th>Risk of BRD(^4)</th>
<th>Risk of high mortality(^4)</th>
<th>Treatment days for disease</th>
<th>ADG</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Controlled trial</td>
<td>5 to 6</td>
<td></td>
<td></td>
<td>+</td>
<td></td>
<td></td>
<td>Warnick et al., 1977</td>
</tr>
<tr>
<td>Observational study</td>
<td>Not reported</td>
<td>=</td>
<td></td>
<td>=</td>
<td></td>
<td></td>
<td>Waltner-Toews et al., 1986</td>
</tr>
<tr>
<td>Observational study</td>
<td>Not reported</td>
<td>+</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Perez et al., 1990</td>
</tr>
<tr>
<td>Observational study</td>
<td>≥ 7</td>
<td></td>
<td></td>
<td>+</td>
<td></td>
<td></td>
<td>Losinger and Heinrich, 1997</td>
</tr>
<tr>
<td>Controlled trial</td>
<td>15</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>−</td>
<td>Kung et al., 1997</td>
</tr>
<tr>
<td>Observational study</td>
<td>6 to 30</td>
<td>=+</td>
<td></td>
<td>+</td>
<td></td>
<td></td>
<td>Svensson et al., 2003(^6)</td>
</tr>
<tr>
<td>Controlled trial</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td>=</td>
<td></td>
<td>Hänninen et al., 2003</td>
</tr>
<tr>
<td>Controlled trial</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td>+</td>
<td></td>
<td>De Paula Vieira et al., 2010</td>
</tr>
<tr>
<td>Controlled trial</td>
<td>3 to 4</td>
<td>=</td>
<td></td>
<td>=</td>
<td></td>
<td></td>
<td>Bernal-Rigoli et al., 2015</td>
</tr>
<tr>
<td>Controlled trial</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td>+</td>
<td></td>
<td>Costa et al., 2015</td>
</tr>
<tr>
<td>Controlled trial</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td>+</td>
<td></td>
<td>Jensen et al., 2015</td>
</tr>
</tbody>
</table>

\(^1\)Presented in chronological order.
\(^2\)Direction (decrease, −; increase, +; no difference, =) of the reported effect of group housing.
\(^3\)Calf diarrhea.
\(^4\)Bovine respiratory disease.
\(^5\)Risk of a farm being classified in the high mortality category (>10%).
\(^6\)Differences: higher risk of severe diarrhea.
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Group size, calves/pen</th>
<th>Effect(^2)</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agonistic encounters when mixed</td>
<td>4</td>
<td>–</td>
<td>Veissier et al., 1994</td>
</tr>
<tr>
<td>Fear when introduced to new environment</td>
<td>4</td>
<td>–</td>
<td>Jensen et al., 1997</td>
</tr>
<tr>
<td>Vocalization during weaning</td>
<td>2</td>
<td>–</td>
<td>De Paula Vieira et al., 2010</td>
</tr>
<tr>
<td>Latency to approach feeder at mixing after weaning</td>
<td>2</td>
<td>–</td>
<td>De Paula Vieira et al., 2010</td>
</tr>
<tr>
<td>Consumption of starter after weaning</td>
<td>2</td>
<td>+</td>
<td>De Paula Vieira et al., 2010</td>
</tr>
<tr>
<td>Defecation when introduced to new environment</td>
<td>2</td>
<td>–</td>
<td>De Paula Vieira et al., 2012</td>
</tr>
<tr>
<td>Duration of play behaviour</td>
<td>2</td>
<td>=</td>
<td>Duve et al., 2012</td>
</tr>
<tr>
<td>Performance at learning reversed task</td>
<td>2</td>
<td>+</td>
<td>Gaillard et al., 2014</td>
</tr>
<tr>
<td>Duration of all types of play behaviour</td>
<td>2</td>
<td>=</td>
<td>Jensen et al., 2015</td>
</tr>
<tr>
<td>Performance at learning reversed task</td>
<td>2</td>
<td>+</td>
<td>Meagher et al., 2015</td>
</tr>
</tbody>
</table>

\(^1\)Presented in chronological order.

\(^2\)Direction (decrease, –; increase, +; no difference, =) of the reported effect of group housing.
CHAPTER 2

As previously published

A SURVEY OF DAIRY CALF MANAGEMENT PRACTICES AMONG FARMS USING MANUAL AND AUTOMATED MILK FEEDING SYSTEMS IN CANADA

2.1 ABSTRACT

Dairy calves in North America traditionally are housed individually and fed by manual milk feeding (MMF) systems with buckets or bottles. Automated milk feeders (AMF) allow for more natural milk feeding frequencies and volumes, and calves are usually housed in groups. The objectives of this study were to: (1) determine the prevalence of various milk-fed calf management and feeding practices, and (2) compare these practices between dairy farms using MMF and AMF systems. A national online survey was performed from January to May 2015 to quantify management practices for the care of milk-fed dairy calves in Canada. A total of 670 responses were received (6% of all dairy farms in Canada). Among respondents, 16% used AMF and 84% used MMF. Seventy percent of the farms using AMF had free-stall barns compared with only 48% of those using MMF. A greater proportion of AMF farms (30%) also had automatic milking systems (AMS) compared with MMF farms (8%). Among tie-stall farms, a herd size of >80 milking cows was associated with having an AMF [odds ratio (OR) = 3.8; 95% confidence interval (CI): 1.6 to 11.4]. For free-stall or bedded-pack farms, a herd size of >80 milking cows (OR = 3.5; 95% CI: 1.8 to 6.6), having an AMS (OR = 3.1; 95% CI: 1.6 to 5.7), and use of cow brushes (OR = 3.1; 95% CI: 1.3 to 6.9) were associated with having an AMF. Calves fed with an AMF typically were housed in groups of 10 to 15, whereas almost 76% of the farms with MMF housed calves individually. Although both AMF and MMF farms fed similar amounts of milk in the first week of life (median = 6 L/d), the cumulative volume fed in the first 4 weeks differed significantly, with a median of 231 vs. 182 L for AMF and MMF, respectively. Median peak milk allowance was higher for AMF than for MMF (10 vs. 8 L/d, respectively). In summary, farms using AMF were larger, provided more milk to calves, and used more automation in general (i.e., in other areas of their operation). These data provide insights into calf-rearing practices across Canada and into how the use of AMF is affecting calf feeding and management on dairy farms.
2.2 INTRODUCTION

Under conventional dairy systems in North America, most calves are individually housed and fed by MMF systems through open buckets or bottles (Vasseur et al., 2010; USDA, 2016). In addition, dairy farms traditionally use restricted milk feeding plans, providing calves 10% of their body weight (BW) in milk per day (Khan et al., 2011). These practices may allow for early weaning of calves by promoting early solid feed intake and reduction of rearing costs. The latter often is achieved by feeding restricted volumes of milk with restricted frequency (i.e., 2 meals per day; Khan et al., 2011). In the United States, the USDA’s National Animal Health Monitoring System (USDA, 2016) found that 85% of dairies housed calves individually, 72% fed milk through open buckets, and 56% offered 4.7 L of milk/day or less to calves. Similarly, in Canada, 88% of farms in Quebec housed calves individually and 92% used open buckets, and the median amount of milk offered to calves was 5.5 L/d (Vasseur et al., 2010).

Research from Canada, Denmark, and the United Kingdom has shown that restricted milk feeding and the lack of socialization associated with individual housing constrain the welfare of calves by limiting their expression of natural behaviours such as sucking for milk and social play (de Passillé et al., 1993; Jensen et al., 2015), subjecting calves to hunger and frustration (Thomas et al., 2001; Borderas et al., 2009; Rosenberger et al., 2017) and impairing calf health (Appleby et al., 2001; McCorquodale et al., 2013). These common practices also do not realize calf growth potential (Miller-Cushon et al., 2013; Rosenberger et al., 2017), and although other factors such as genetics play a role (Davis Rincker et al., 2011), these practices may also reduce future milk production performance (Soberon et al., 2012; Soberon and Van Amburgh, 2013; Gelsinger et al., 2016). Automated milk feeders are an alternative to MMF systems. They involve the use of computer-controlled systems and typically are associated with housing calves in groups while providing individualized feeding of milk (Jensen and Weary, 2013). They provide for more natural and efficient rearing of calves than MMF systems by allowing larger amounts of milk to be fed several times a day, resulting in improved calf welfare (Käck and Ziemerink, 2010; Jensen and Weary, 2013). Nonetheless, good management practices are required when using AMF because there is some potential for intensive group housing to have detrimental effects on calf health and welfare if not managed
properly (Svensson and Liberg, 2006). For example, when calves are housed in large groups, risk of respiratory disease and mortality rate increase (Svensson et al., 2003, 2006; Svensson and Liberg, 2006) and feeding patterns of newly introduced calves are altered (Jensen, 2003).

Information on current calf management practices is necessary to assess changes in practices and the effect of potential on-farm interventions and adoption of technology to improve calf welfare and performance on dairy farms. Therefore, the objectives of this study were to (1) determine the prevalence of various milk-fed calf management and feeding practices and (2) compare these practices between dairy farms using MMF and AMF systems.

2.3 MATERIALS AND METHODS

A cross-sectional online survey of dairy farmers across Canada was conducted from January 2015 to the end of May 2015. The survey was administered via a web-based survey platform (FluidSurveys; SurveyMonkey, San Mateo, CA). An email with an introductory letter and the hyperlink to the survey was sent by the 2 dairy herd management centres in Canada (CanWest DHI, Guelph, Ontario; Valacta, Sainte-Anne-de-Bellevue, Quebec) to dairy producers registered in their databases (implied sampling frame = ~80% of dairy producers in Canada). Additionally, the survey was advertised in the Dairy Farmers of Canada (Ottawa, Ontario) internal newsletter, the Dairy Research Cluster blog (https://dairyresearchblog.ca), and 2 dairy cattle magazines distributed across Canada (Milk Producer and Le Producteur de Lait Québécois) and on social media (e.g., Facebook). This study was reviewed and approved by the University of Guelph Research Ethics Board (REB no. 14JN025).

2.3.1 Sample Size Estimation

The WINPEPI statistical program (version 11.62; Abramson, 2011) was used to estimate the number of farms required to describe population attributes (n = 11,962) such as mean daily milk allowance and proportion of farms housing calves in groups. Using an assumed standard deviation of 2.5 L/day and an acceptable error of 0.2 L/d for daily milk allowance, the required sample size was 574 farms for a confidence level of 95%. Using an assumed proportion of farms housing calves in groups of 0.3 and an acceptable error of 0.035, the required sample size was 685 farms.
2.3.2 Collection and Description of Data

The survey was designed in consultation with a panel of experts (11 dairy specialists from academia, industry, and government) and was pretested by 8 dairy producers, an equal number of which used MMF or AMF systems. The final version of the survey (available in English and French) consisted of 2 questionnaires with closed- (i.e., multiple choice, ranking, and 5-point Likert scales) and open-ended questions; 1 questionnaire was for producers using MMF systems (i.e., milk offered via open bucket or teat-bottle, bucket, or milk bar), and 1 questionnaire was for producers using AMF (i.e., computer-controlled systems).

Both questionnaires started and ended with 2 identical sections: generalities of the farm (e.g., location, breed of cattle, type of housing) and demographics of the personnel responsible for calves (e.g., age and education level). At the end of the first section, producers were asked what type of automated devices they had on their farm, and based on their answer for AMF (i.e., yes/no question) they were directed to the corresponding questionnaire. We collected data on management and calf care during calves’ first days of life (i.e., cow–calf separation, colostrum management) and management and care during the entire milk feeding period. Both questionnaires gathered the same type of information (thus allowing comparisons), but questions were worded differently to be consistent with the milk feeding system being used. In addition, a set of questions was tailored to capture information that was unique to AMF (e.g., the feeder setup and the process of introducing calves to the AMF). See full-length questionnaires (total number of questions: MMF = 70, AMF = 86) in Appendix 2.1.

No survey question was required to be answered; therefore, the total number of responses varied by question, as noted later. Although the survey could be answered in a median time of 30 minutes (based on the completion times of the pretesting), the web-based platform allowed producers to save and return to their answers any time before submitting their survey.
2.3.3 Data Management and Analysis

Data were exported from the web-based survey platform into Microsoft Excel (Microsoft Corp., Redmond, WA) for data cleaning and screening. A total of 837 producers clicked the survey link and consented to complete the questionnaire. After screening the data, 167 producers were removed for the following reasons: no answers were provided to any of the questions \( n = 121 \); it was not clear whether the farms were Canadian \( n = 9 \); homemade AMF were used and it was not clear whether these were computer-controlled systems \( n = 9 \); herd size was very small \( 2 \) and \( 5 \) milking cows, \( n = 2 \); producers had just sold their milk quota); and farm was located in the United States \( n = 1 \). In addition, 25 producers participated twice; the response with the highest number of questions answered was kept.

All data were analyzed with SAS version 9.3 (SAS Institute Inc., Cary, NC). Descriptive statistics calculated included percentages, 95% confidence intervals (CI), medians, and 25th and 75th percentiles. The Anderson-Darling test was used to test normality of continuous variables. Chi-squared (or Fisher’s exact) and Wilcoxon two-sample (with Hodges–Lehmann estimation of the median of the differences with 95% CI) tests were used to evaluate differences in categorical and continuous variables, respectively, between farms with AMF and MMF systems. When no differences between farms with AMF and MMF were found, the overall percentages or medians are presented.

For the variable cow barn type (housing for milking cows), bedded-pack and free-stall barns were grouped into a single category due to a low number of observations in the bedded-pack category, leaving cow barn type as a dichotomous variable (tie-stall vs. loose housing). A variable for geographical region was created by grouping provinces into 3 categories - western region (provinces of British Columbia, Alberta, Saskatchewan, and Manitoba), Ontario region, and Quebec and Atlantic region (provinces of Quebec, New Brunswick, Prince Edward Island, Nova Scotia, and Newfoundland and Labrador) - based on geographic location or dairy herd management centre to have a balanced number of observations in each region. The association of having an AMF with farm size, producer age, producer gender, number of personnel looking after calves, and use of other technology devices (e.g., cow activity monitors, automated feed pushers, and automated milking systems;
AMS) was evaluated using logistic regression (PROC LOGISTIC in SAS) with geographic region included as a fixed effect to adjust for the effect of region. Two separate models were fit - one for tie-stall farms and another for loose housing barns—to help control for confounding caused by inherent differences in milking systems and the use of other technologies between both housing types (e.g., few ties-tall barns had activity monitors; AMS was present exclusively in loose housing barns). Explanatory variables with an association (\( P < 0.20 \)) with the outcome in univariable models were offered to the multivariable model. The linearity assumption for the variable farm size could not be fulfilled; therefore, it was dichotomized based on the average milking herd size for Canada (80 milking cows; Cyprien Awono, Agriculture and Agri-Food Canada, Ottawa, Ontario, Canada; personal communication). Correlation between predictors was assessed using Spearman correlation coefficients (\( r_s > 0.8 \)). A variable was considered a confounder if its removal caused > 20% change in the coefficient (on the logarithmic odds scale) of another variable in the model. Any non-significant variables (\( P > 0.05 \)) were checked for confounding by removing them from the full model using backward elimination, starting with the variable with the largest \( P \)-value. All 2-way interactions were tested between variables that remained in the model. The Pearson goodness-of-fit test was used to evaluate whether the models fit the data.

Differences between AMF and MMF farms in the volume of milk (L/d per calf) offered to calves by week of life were evaluated using linear regression (PROC MIXED in SAS) with geographic region as a fixed effect and accounting for repeated measures within farm. Specifically, the model included the fixed effects of week, milk feeding system (AMF vs. MMF), and week by milk feeding system interaction. The unstructured variance-covariance matrix structure was used for the random effect of farm on the basis of best fit according to Akaike information criterion (Dohoo et al., 2009). Daily milk allowance was compared only during the first 4 weeks of life; after this point, the length of the milk feeding period varied between farms, making comparisons difficult.
2.4 RESULTS

2.4.1 General Description of Producers and Farms

A total of 670 dairy producers across Canada were included in the analysis (6% of all dairy farms in Canada; CDIC, 2015). Of the respondents, 16% (95% CI: 13 to 19; n = 105) used AMF to raise calves, and 84% (95% CI: 81 to 87; n = 565) used MMF systems. The majority of respondents were from Ontario (48%), followed by Quebec and Atlantic Provinces (29%). More than three-quarters of the respondents (79%) completed the survey in English. Approximately 72% of respondents were male, and the age category most common among all participants was 45 to 54 years old. Table 2.1 shows demographics by type of farm based on milk feeding system.

Overall, the average reported herd size was 90 milking cows (range: 17 to 2,800). Farms with AMF had a significantly larger herd size compared with farms with MMF systems (median of the difference = 35 milking cows; 95% CI: 25 to 45; \( P < 0.001 \); Table 2.2). Holstein was the most common breed among all farms (96% and 93% of farms with AMF and MMF, respectively). The proportion of free-stall barns for housing milking cows was significantly higher among farms using AMF compared with farms using MMF (Table 2.3). A higher proportion of farms with AMF had adopted AMS and other types of technology compared with farms using MMF (Table 2.3).

2.4.2 Factors Associated with Having an Automated Milk Feeder

Farms with more than 80 milking cows in either tie-stall or loose housing were more likely to have an AMF (Table 2.4). Additionally, loose housing farms using an AMS and using cow brushes were also more likely to have an AMF for calves. Age of the producer was a factor associated with having an AMF only in tie-stall farms, where producers aged 55 years or above had lower odds of using an AMF (Table 2.4).

2.4.3 Newborn Calf and Colostrum Management

Overall, 59% of farms reported disinfecting the newborn’s navel (95% CI: 55 to 63; n = 640); there was no difference between farms with AMF and MMF (\( P = 0.26 \)). The majority of farms with AMF and MMF separated the calf from the dam within 24 hours after birth (97% of
farms; 95% CI: 96 to 99; n = 630; P = 0.15); however, a smaller proportion of farms with MMF (86%; 95% CI: 83 to 89) reported separation within 12 hours compared to farms with AMF (98%; 95% CI: 93 to 100) (P < 0.001). Similarly, the proportion of farms separating the calf from the dam within 2 hours after birth was lower for farms with MMF (51%; 95% CI: 47 to 55) than AMF (63%; 95% CI: 53 to 73) (P = 0.03).

No differences were found in the timing of first colostrum feeding after birth between farms with AMF and MMF (P = 0.87); most farms reported giving the first meal of colostrum within the first 6 hours after birth (87%; 95% CI: 84 to 89; n = 639). There was no difference (P = 0.08) in the proportion of farms feeding colostrum through a teat (either teat bottle or teat bucket) between farms with AMF and farms with MMF (82%; 95% CI: 79 to 85; n = 659). The proportion of farms feeding colostrum exclusively through an open bucket differed between farms (AMF: 1%; 95% CI: 0 to 6; MMF: 8%; 95% CI: 6 to 11; P < 0.01). The proportion of farms feeding colostrum strictly through an esophageal tube did not differ between farms with AMF and MMF (8%; 95% CI: 6 to 10; n = 659; P = 0.29).

There was no significant difference (P > 0.1) between farms with AMF and MMF regarding the amount of colostrum fed to calves in the first 12 hours of life. Half of the farms reported giving calves 4 to 5 L of colostrum in the first 12 hours of life (51%; 95% CI: 47 to 55; n = 649); 30% gave 6 L or more (95% CI: 26 to 33; n = 649), whereas 14% reported giving 3 L or less (95% CI: 11 to 16; n = 649). Ad libitum colostrum was given on 2% of farms (95% CI: 1 to 3; n = 649). The evaluation of colostrum quality did not differ between AMF and MMF farms; only 23% of all farms reported always evaluating the quality of colostrum (95% CI: 20 to 26; n = 642). Nevertheless, the evaluation of colostrum quality was done subjectively by looking at color and consistency on 44% of all farms, whereas the use of a colostrometer or a refractometer was reported by 30% and 18% of all farms, respectively. Newborn calf and colostrum management practices are summarized in Appendix 2.2.

2.4.4 Housing of Calves During the Milk-fed Period

Housing practices during the milk fed period differed between farms with AMF and farms with MMF. The proportion of farms housing calves in groups was higher among farms with AMF (P < 0.001). Milk-fed calves on all AMF farms (n = 105) were all group-housed (no
farm exclusively used an AMF for individual housed-calves during the whole milk-fed period - i.e., calf rail). In contrast, 76% of farms using MMF systems housed milk-fed calves individually (95% CI: 72 to 80; n = 526). The median age of introduction to a group (and to the AMF for AMF farms) differed (P < 0.001) between farms with MMF systems (median: 60 days of age; 25th - 75th percentile: 28 to 74 d, n = 475) and farms with AMF (median: 5 days of age; 25th - 75th percentile: 3 to 7 d; n = 93), with an estimated median of the differences of 54 days (95% CI: 51 to 56).

For farms using group housing, group size and maximum age difference between calves was greater on farms with AMF compared with farms with MMF (P < 0.001). Among farms with AMF (n = 86), 58% (95% CI: 47 to 69) housed calves in groups of a maximum of 10 to 15 calves, 25% (95% CI: 16 to 35) housed calves in groups of no more than 9 calves, 14% (95% CI: 7 to 23) housed a maximum of 16 to 20 calves, and 3% (95% CI: 1 to 10) housed a maximum of 21 to 40 calves per group. Among farms with MMF and group housing (n = 125), 26% (95% CI: 18 to 34) of the farms housed calves in pairs, 64% (95% CI: 55 to 72) housed calves in groups of a 3 to 9 calves, 8% (95% CI: 4 to 14) housed a maximum of 10 to 15 calves per group, and 2% (95% CI: 0.2 to 6) housed a maximum of 16 to 20 calves.

Maximum age difference between calves housed in groups was higher among farms with AMF compared with farms with MMF systems (P < 0.001). The most commonly reported age difference for AMF farms (n = 88) was 3 to 4 weeks (48% of the farms; 95% CI: 37 to 59) followed by 7 weeks or more (25%; 95% CI: 16 to 35). For MMF farms (n = 122), the most common age difference was 2 weeks or less (54%; 95% CI: 45 to 63) followed by 3 to 4 weeks (32% of the farms; 95% CI: 24 to 41).

Indoor housing was the most common type of housing used among the farms surveyed. A higher proportion (P < 0.001) of indoor housing was used on farms using AMF (98%; 95% CI: 92 to 100) compared with farms using MMF systems (70%; 95% CI: 66 to 74). There was no difference in the type of bedding material used in winter or summer between farms with AMF and farms with MMF systems; straw was the most commonly used material (winter: 82%; 95% CI: 80 to 85; summer: 73%; 95% CI: 70 to 77). Other materials used for bedding were sawdust (winter: 16%; summer: 24%), peat moss (winter: 16%; summer: 24%), sand (winter: 0.2%;
summer: 2%), and dried manure (winter and summer: 0.3%). Housing practices are summarized in Appendix 2.3. Among farms using AMF, 50% (95% CI: 39 to 60; n = 95) renovated the existing calf barn, 41% built a new calf barn (95% CI: 31 to 52), and 9% (95% CI: 4 to 17) neither renovated nor built a new barn to accommodate calves in groups and install the AMF.

2.4.5 Calf Feeding During the Milk-fed Period

2.4.5.1 Type of milk fed

There were differences ($P < 0.001$) in the main type of milk fed to calves between farms with AMF ($n = 93$) and MMF systems ($n = 525$). Milk replacer was the main type of milk used among AMF farms (89%; 95% CI: 81 to 95), whereas only 40% of MMF farms gave milk replacer to calves (95% CI: 36 to 44). Among MMF farms, 36% (95% CI: 32 to 41) used saleable milk and 20% (95% CI: 17 to 24) used waste milk (i.e., non-saleable milk from sick or antibiotic-treated cows). In comparison, among AMF farms, 5% (95% CI: 2 to 12) used saleable milk and 4% (95% CI: 1 to 11) used waste milk. Only 2% (95% CI: 0 to 6) and 4% (95% CI: 2 to 5) of AMF and MMF farms, respectively, reported using a combination of salable and waste milk.

Among farms mainly using whole or waste milk, pasteurization of milk was implemented in a higher ($P = 0.002$) proportion of AMF farms (44%; 95% CI: 14 to 79) compared with MMF farms (7%; 95% CI: 4 to 10). Acidification did not differ between AMF and MMF farms ($P = 0.32$); only 3% of farms in total ($n = 617$) acidified milk or milk replacer (95% CI: 2 to 5). Practices regarding milk type fed to calves on AMF and MMF farms is summarized in Appendix 2.4.

2.4.5.2 Daily milk allowance

Figure 2.1 shows the distribution of the daily milk volumes fed by week and type of milk feeding system. Overall, the cumulative volume of milk fed to calves during their first 4 weeks of life differed ($P < 0.001$) between farms with AMF (median: 231 L; 25th–75th percentiles: 203 to 287; $n = 79$) and farms with MMF (median: 182 L; 25th–75th percentiles: 154 to 224; $n = 523$), with an estimated median of the differences of 56 L (95% CI: 42 to 70). In multivariable analysis, daily milk allowance per calf by week was higher (week 1: $P <
0.01; week 2 to 4: \( P < 0.001 \) on AMF farms compared with MMF farms and peaked higher on AMF farms \( P < 0.001 \).

2.4.5.3 Method of feeding milk

The majority of farms using AMF had 1 feeder (86%; 95% CI: 78 to 92; \( n = 95 \)); 11% (95% CI: 5 to 19) had 2 feeders, 2% (95% CI: 0.3 to 7) had 3 feeders, and 1% (95% CI: 0 to 6) had 6 feeders. Two feeding stations (each placed in a separated pen) per feeder was the most common setup among the surveyed farms (65% of the farms; 95% CI: 55 to 75; \( n = 92 \)). One feeding station per feeder was the setup for 31% of the farms (95% CI: 21 to 41), whereas 2% (95% CI: 0.3 to 8) had 3 feeding stations per feeder and 1% (95% CI: 0 to 6) had 4 feeding stations per feeder. For those farms with 1 feeder supplying 2 or more feeding stations in separate pens, only 19% (95% CI: 10 to 31) had simultaneous feeding (i.e., 2 calves drinking at the same time from 2 different feeding stations), and 47% (95% CI: 34 to 60) did not have a simultaneous feeding but had activated the priority mode, which was set mainly based on calf age (i.e., younger calves had priority over older calves to drink first), pen (i.e., a specific feeding station had priority over the others), or level of milk consumption (i.e., calves with a low consumption had priority to drink first). Among all farms using AMF (\( n = 97 \)), 67% (95% CI: 57 to 76) had a feeder from Förster Technik (Engen, Germany) for group-housed calves, 24% (95% CI: 16 to 33) used an Urban feeder (Rombouts, Salford, Ontario, Canada), 6% (95% CI: 2 to 13) used a Holm and Laue feeder (Holm and Laue GmbH and Co. KG, Westerröndorf, Germany), and 3% (95% CI: 1 to 9) used an Uddermatic milk feeding system (Uddermatic, Alma, Ontario, Canada). Only 1 farm reported having a Förster Technik feeder for individually housed calves (calf rail feeding system), which was used during the first days of life before introducing calves to the group pen with an AMF. The earliest year of implementation of AMF among the surveyed farms was 2003; the greatest number of respondents implemented AMF in 2011.

Within farms feeding milk manually, 53% (95% CI: 48 to 57; \( n = 531 \)) used teats (bottles, teat buckets, or milk bars) to feed calves for at least the first 2 months of life, whereas 36% (95% CI: 32 to 40) fed milk through open buckets and 11% (95% CI: 8 to 14) implemented a mix of teats and open buckets to feed milk. Among the latter, 60% of farms
(95% CI: 45 to 74) reported feeding milk through a teat only for the first 2 weeks of life, 24% (95% CI: 13 to 38) used teats for the first 3 weeks of life, 10% (95% CI: 3 to 22) used teats only for the first month of life, and 6% (95% CI: 1 to 17) used teats only for the first 5 to 6 weeks of life. Most MMF farms (86%; 95% CI: 82 to 89; n = 526) fed calves 2 times/day. Only 10% (95% CI: 8 to 13) fed calves 3 times/day, whereas 1% fed calves 4 times/day (95% CI: 0.2 to 2); 3% (95% CI: 2 to 5) reported feeding calves ad libitum, although their maximum milk allowance ranged from 6 to 12 L/day. Methods of feeding milk on AMF and MMF farms are summarized in Appendix 2.4.

2.4.5.4 Solid feed and water

There were no differences between AMF and MMF farms (n = 610; P > 0.1) in the proportion of farms that reported allowing milk-fed calves to access starter grain (97%; 95% CI: 95 to 98), hay (67%; 95% CI: 63 to 70), TMR (8%; 95% CI: 6 to 11), or water (91%; 95% CI: 88 to 93). Age at access to different solid feeds and water is described in Table 2.5. The proportion of farms allowing ad libitum access to starter was higher (P < 0.01) among AMF farms (86%; 95% CI: 76 to 92; n = 84) compared with MMF farms (70%; 95% CI: 66 to 74; n = 484). Similarly, ad libitum access to hay was more common (P < 0.001) for AMF farms (93%; 95% CI: 83 to 98; n = 56) than for MMF farms (66%; 95% CI: 61 to 71; n = 336), as was ad libitum access to water (AMF: 99%; 95% CI: 93 to 100; n = 81; MMF: 81%; 95% CI: 77 to 85; n = 437; P < 0.001). The proportion of farms allowing ad libitum access to TMR did not differ between AMF and MMF farms (58%; 95% CI: 47 to 72).

2.4.5.5 Weaning

Age was the main criterion for starting weaning calves off milk in both AMF farms (n = 88) and MMF farms (n = 521), although its use was greater among AMF farms (94%; 95% CI: 87 to 98) compared with MMF farms (84%; 95% CI: 80 to 87; P = 0.01). The use of starter intake as a criterion for weaning was more common within MMF farms (50%; 95% CI: 46 to 55) than within AMF farms (16%; 95% CI: 9 to 25). Differences in the age at weaning and the length of the weaning period between AMF and MMF farms are shown in Table 2.5.
There was a difference \((P < 0.001)\) in the method of weaning between AMF and MMF farms. Gradual weaning was used on all AMF farms and on 85\% of MMF farms (95\% CI: 82 to 88), indicating that 15\% of MMF farms used abrupt weaning. Gradual weaning was mainly done by progressively reducing the volume of milk offered to calves (instead of diluting it with water) on all AMF farms and on 75\% of MMF farms (95\% CI: 71 to 80).

### 2.4.6 Personnel in Charge of Calves Care

The proportion of farms that reported having 1 person designated for the care of milk-fed calves tended to be larger \((P = 0.07)\) among AMF farms (28\%; 95\% CI: 19 to 39; \(n = 86\)) compared with MMF farms (18\%; 95\% CI: 15 to 22; \(n = 503\)). On the contrary, the proportion of farms reporting to have 3 or more personnel tended to be smaller among AMF farms (27\%; 95\% CI: 18 to 37) compared with MMF farms (36\%; 95\% CI: 32 to 40). The most common number of personnel in charge of the care of calves for both AMF and MMF farms was 2 (46\% of farms; 95\% CI: 42 to 50). A family member was in charge of looking after the calves in both AMF (\(n = 85\)) and MMF (\(n = 487\)) farms (99\%; 95\% CI: 98 to 100). In a given year, personnel looking after the calves generally did not change (98\%; 95\% CI: 97 to 99).

Gender and age of the personnel looking after calves differed between AMF (farms: \(n = 86\); personnel: \(n = 177\)) and MMF (farms: \(n = 58\); personnel: \(n = 164\)) farms. A higher proportion \((P = 0.04)\) of personnel were female on MMF farms (45\%; 95\% CI: 37 to 53) compared with AMF farms (33\%; 95\% CI: 27 to 41). The proportion of personnel under 25 years of age was higher \((P = 0.01)\) among MMF farms (37\%; 95\% CI: 29 to 44) compared with AMF farms (24\%; 95\% CI: 18 to 31), as was the proportion of personnel over 64 years of age (AMF: 1\%; 95\% CI: 0 to 3; MMF: 4\%; 95\% CI: 2–9; \(P = 0.03\)). In contrast, the proportion of personnel between 25 and 44 years of age was higher \((P < 0.001)\) among AMF farms (47\%; 95\% CI: 40 to 55) compared with MMF farms (30\%; 95\% CI: 24 to 38). There were no differences in the level of education between AMF and MMF farms \((P = 0.63)\); the higher proportion of personnel had a college degree or higher (59\%; 95\% CI: 50 to 61), followed by a high school diploma (37\%; 95\% CI: 32 to 42).
2.5 DISCUSSION

This study is the first to provide insights into calf rearing practices on a sample of farms across Canada by comparing the prevalence of procedures and routines between farms based on their calf milk feeding system. Overall, we found that 16% of participant farms in this survey used AMF. The use of AMF has increased in Canada in recent years. For example, in a survey conducted in the province of Quebec (Vasseur et al., 2010) between 2005 and 2007, no farms had adopted these devices. Another survey conducted in the province of Ontario in 2012 showed that only 3% of 890 farms used AMF (Ken Leslie, University of Guelph, Guelph, ON, Canada; personal communication). However, it is important to take into account that in the present study there was a higher proportion of farms from Ontario and western provinces compared with the target population of Canadian farms (Ontario: 48 vs. 33%; western provinces: 23 vs. 12%; Table 2.1) and a higher proportion of free-stall barns compared with the target population (50 vs. 22%; Table 2.3), which could have caused an overestimation of the proportion of farms using AMF.

We found that the use of AMF was more common among farms with larger herd size and farms that were already using other types of technology (i.e., AMS and automated cow brushes). In a survey in France, farms that had adopted AMS were larger compared with the national average (77 vs. 36 dairy cows, respectively; Veysset et al., 2001), similar to what we found for AMF in Canada. However, census data of Canadian dairy farms (CDIC, 2015) and studies in the Netherlands (Steeneveld et al., 2012) looking at AMS did not show a difference in farm size compared with farms with a conventional milking system. It is also known that producers who have adopted AMS did so mainly driven by factors that were not related to profits, such as improving working environment, getting more time for family and for other business, and making a change in lifestyle (de Jong et al., 2003; Butler et al., 2012; Bergman and Rabinowicz, 2013). Although we did not gather information to show that the adoption of AMS preceded the adoption of AMF among participant farms, we speculate that producers who had already adopted AMS (and AMS had met their expectations after installation) wanted to reduce some of the workload and lack of flexibility involved in the chore of feeding milk to calves, which led them to adopt an AMF, or vice versa. In addition, we found that participants 55 years or older were less likely to use an AMF;
however, this association was present only among tie-stall farms. Younger people are more likely to adopt agriculture technologies (Warren, 2004), possibly, as suggested by Pierpaoli et al. (2013), because they have a “larger working horizon.” It has been suggested that older producers are harder to reach and more resistant to change (Warren, 2004); thus, we could say that this might be the case for older participants from tie-stall farms in the present study. However, the effect of age on the adoption of technology has been described inconsistently in the literature. Other researchers have found age to be positively correlated with the use of technology; this correlation has been attributed to older farmers’ greater experience and capability of recognizing the efficiency of new technology compared with younger farmers (Torbett et al., 2007; Pierpaoli et al., 2013).

We found that newborn calves were managed similarly in farms with AMF and MMF. Nonetheless, rearing practices did differ once calves were separated from the dam. Generally, calves on respondents’ farms were separated from the cow before 24 hours after birth and were fed colostrum through a teat bottle or teat bucket within 6 hours; at least 4 L of colostrum was fed in the first 12 hours.

Raising calves in individual pens during the milk feeding period is a standard practice in the dairy industry (Costa et al., 2016). Our study supports this finding; more than three-fourths of farms that fed milk manually, housed calves individually during the milk feeding period. Similarly, Vasseur et al. (2010), Staněk et al. (2014), and Love et al. (2016) found that 87.9%, 96.7%, and 92.8% of farms in Quebec (Canada), Czech Republic, and California (USA), respectively, housed calves individually. However, this was not the case for farms surveyed in our study feeding milk through AMF, where all calves were housed in groups from early in life (median = 5 days of age). These results are similar to those reported by Endres (2016), where calves were introduced to the feeder group at 5.4 days of age. In contrast, we found that calves raised on MMF farms were grouped at a median age of 8 weeks. Recent research has shown that when calves are group housed after 6 weeks (Costa et al., 2015) or 8 weeks (De Paula Vieira et al., 2010) of age they consume less solid feed and have lower weight gain and reduced performance when mixed with other calves compared with calves grouped at an early age (i.e., pair housing in the first week of life).
Group housing has been associated with a higher risk of enteric and respiratory diseases in dairy calves (Svensson et al., 2003). The size of the group, among other factors, is one of the main contributors to health issues rather than group housing per se. Keeping the size of the group small (3 to 8 calves) reduces the risk of illness and mortality (Svensson et al., 2003, 2006) as well as the level of competition among calves (12 vs. 24 calves; Jensen, 2004). We found that the most common group size for AMF farms was 10 to 15 calves, although 18% of farms were housing more than 16 calves per group. On the other hand, the majority of MMF farms housing calves in groups used a maximum group size of 9; only 2% of farms housed more than 16 calves in a group. Svensson et al. (2003) found no difference in the incidence risk of diarrhea and respiratory disease between farms housing calves individually and farms housing calves in small groups (i.e., 3 to 8 calves; both farms feeding milk manually). On the other hand, when comparing individually housed and manually fed calves with calves raised in large groups (i.e., 6 to 30 calves) and fed through an AMF, Svensson et al. (2003) found an increase in the risk of respiratory disease and the severity of diarrhea cases. In addition, Svensson and Liberg (2006) concluded that housing calves in groups of 10 or less was preferred in terms of having lower risk of respiratory disease compared with bigger groups. Based on this, the group size used in the majority of AMF farms in our study is slightly above the recommended size and could potentially affect the health and performance of calves on these farms; conversely, this may be offset by feeding greater volumes of milk.

Looking at the first month of life, which is known to be the period when calves rely mainly on nutrients from milk for maintenance of vital functions and growth (Khan et al., 2011), we found that farms using AMF fed more milk to calves than farms using MMF systems. Automated feeders allow producers to offer larger amounts of milk to each calf by providing small meals several times a day, independent of labour availability and time (Käck and Ziemerink, 2010). Producers reported a greater daily amount of milk fed to calves from week 1 of life to the last week before weaning (AMF farms: 6 to 10 L; MMF farms: 6 to 8 L) compared with what was reported by Vasseur et al. (2010), where calves were fed 4 to 5.5 L of milk or milk replacer on farms in the province of Quebec, and compared with milk levels reported by Staněk et al. (2014) and Love et al. (2016). It is important to note that although we found a general increase in the levels of milk fed to calves across Canada, 25% of
producers still provided restricted milk diets (i.e., ≤ 6 L/d) during the entire first month of life, which does not fulfil the recommendation in the Canadian Code of Practice for the Care and Handling of Dairy Cattle, which recommends a daily allowance of 20% of calves’ BW in milk (NFACC, 2009).

Feeding saleable milk to calves is expensive (Godden et al., 2005), but some Canadian producers give it to calves when milk is produced over their available production quota (Vasseur et al., 2010). Non-saleable milk is often used as an alternative (Duse et al., 2013; Love et al., 2016); however, this practice is associated with an increased risk of transmitting pathogens such as Mycoplasma spp. to calves (Butler et al., 2000). Pasteurization of nonsaleable milk is known as an effective method for destroying pathogens in milk associated with diseases during calfhood (Godden et al., 2005). Milk replacer is another alternative that has other benefits such as easy storage and the control of disease transmission (Godden et al., 2005). We found that 89% of AMF farms and 40% of MMF farms fed milk replacer to calves. Similarly, Endres (2016) found that 68% of AMF farms in Minnesota fed calves milk replacer. The use of non-saleable milk as the main type of milk fed to calves was more common among MMF farms than AMF farms (20 vs. 4%); however, pasteurization was not a common practice among MMF farms feeding non-saleable milk (7%). In contrast, in a recent study in California, 48% of participating farms did pasteurize non-saleable milk (Love et al., 2016).

Farms using AMF fed milk through an artificial teat, whereas 53% of MMF farms used an artificial teat. Similarly, Staněk et al. (2014) and Love et al. (2016) found that 57% of Czech and 71% of Californian dairy farms used teats to feed milk to calves. Our findings showed a lower use of open buckets compared with producers in Quebec, where only 8% used teat-based systems (Vasseur et al., 2010). Teat feeding is favorable for calves because they adopt a more natural position when drinking, which may aid digestion and health (Stewart, 1976; de Passillé et al., 1993; Appleby et al., 2001). In addition, teat feeding allows calves to perform sucking behaviour, which they are highly motivated to do (de Passillé et al., 1993).

Weaning calves off milk at a fixed age is the most common method of weaning used
across dairy farms (6 to 8 weeks of age, Vasseur et al., 2010; 9 to 10 weeks old, Staněk et al., 2014; 9 weeks old, Love et al., 2016), and this was true for the surveyed farms (7 to 8 weeks). There is a large variation in the age at which calves start consuming measurable amounts of starter (de Passillé and Rushen, 2012). For instance, calves under a high milk allowance diet (12 L/d) consumed 200 and 1,400 g/d of starter at 55 days (range: 23 to 82) and 75 days (range: 58 to 94) of age, respectively (de Passillé and Rushen, 2016). Similarly, calves allowed to drink 6 L of milk/d consumed 2,000 g/d at 76 days of age (range: 45 to 98; Roth et al., 2009). Therefore, weaning at a fixed age might impair the welfare of calves that might not be ready to be weaned. Weaning based on starter intake is an alternative and is one of the advantages of using an automated grain feeder in combination with an AMF (de Passillé and Rushen, 2016); however, it is still not widely used.

Reduction in labour has been identified as one of the reasons for adopting AMF in the United States (Endres, 2016). However, we found that the most common number of personnel looking after calves in both MMF and AMF farms was 2 people, and the proportion of farms with 3 or more people working in the calf barn tended to be higher among MMF farms. As such, the use of AMF could potentially imply a reduction in labour force, as has been the case for AMS (Jacobs and Siegford, 2012).

2.6 CONCLUSIONS

The present study described the main differences between AMF and MMF farms regarding feeding and management practices for raising dairy calves. Farms with AMF were larger and used more automation. The AMF farms provided more milk to calves and housed them in groups from early in life, whereas the majority of MMF farms housed calves individually. The adoption of AMF potentially allows for improved animal welfare through social housing of calves and increased access to more milk. Nevertheless, the risks of increased incidence of disease in calves when large groups are used cannot be ignored. Data on housing and milk feeding management practices in this study might help guide the focus of future research and knowledge and technology transfer outreach to bridge the gap between understanding and adopting science-based recommendations on calf care by dairy producers.
2.7 ACKNOWLEDGEMENTS

This research was funded by Dairy Farmers of Canada (Ottawa, ON, Canada) as part of the Dairy Research Cluster 2 program. The first author thanks the Administrative Department of Science, Technology and Innovation–Colciencias (Bogota, Cundinamarca, Colombia) for the PhD scholarship granted. The authors also thank the following individuals who helped create the survey questionnaire: research experts Jan Ziemerink (Förster-Technik North America, Cambridge, ON, Canada), Ken Leslie (University of Guelph, Guelph, ON, Canada), Ann Godkin and Neil Anderson (Ontario Ministry of Agriculture, Food and Rural Affairs, Elora, ON, Canada), Elsa Vasseur (McGill University, Saint- Anne-de-Bellevue, QC, Canada), and Nelson Dinn (University of British Columbia, Agassiz, BC, Canada); students Hana Brown, Craig LeRoy, and Jessie Hubbs (University of Guelph, Guelph, ON, Canada); and dairy producers Evan Eckert (Eckerlea Acres, Seaforth, Ontario, Canada), Tim May (Mayhaven Farms, Rockwood, Ontario, Canada), Todd Nixon (Alexerin Dairy Inc., Manotick, Ontario, Canada), Rob Vanden Hengel (Vinselaar Holsteins Inc., Seaforth, Ontario, Canada), and Philip Armstrong (Armstrong Manor Farm, Caledon, Ontario, Canada). Special thanks to Richard Cantin (CanWest DHI, Guelph, ON, Canada), Daniel Lefebvre and Steve Adam (Valacta, Sainte-Anne-de- Bellevue, QC, Canada), Shelley Crabtree (Dairy Research Cluster, Ottawa, ON, Canada), Sharon Laidlaw (Milk Producer Magazine, Mississauga, ON, Canada), and the Ontario Veterinary College marketing communications team for collaborating with the distribution of the survey; to William Sears for his guidance with SAS; and to the dairy producers who participated in the survey and made this study possible.
2.8 REFERENCES


Table 2. Percentage (95% CI) of participant farms using automated milk feeders (AMF, n= 105) and manual milking feeding (MMF, n = 565) systems for raising dairy calves from an online questionnaire completed by 670 dairy producers in Canada.

<table>
<thead>
<tr>
<th>Demographics</th>
<th>AMF</th>
<th>MMF</th>
<th>P-value</th>
<th>All participant farms</th>
<th>Canadian statistics(^1), %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Language</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>English (vs. French)</td>
<td>77 (68 - 85)</td>
<td>80 (76 - 83)</td>
<td>0.59</td>
<td>79 (76 - 82)</td>
<td></td>
</tr>
<tr>
<td>Gender</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male (vs. female)</td>
<td>70 (61 - 79)</td>
<td>72 (68 - 75)</td>
<td>0.81</td>
<td>72 (68 - 75)</td>
<td></td>
</tr>
<tr>
<td>Participant age, years</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;25</td>
<td>8 (3 - 15)</td>
<td>8 (6 - 10)</td>
<td>0.42</td>
<td>8 (6 - 10)</td>
<td>15</td>
</tr>
<tr>
<td>25-34</td>
<td>24 (16 - 33)</td>
<td>27 (23 - 31)</td>
<td></td>
<td>27 (23 - 30)</td>
<td>20</td>
</tr>
<tr>
<td>35-44</td>
<td>30 (22 - 40)</td>
<td>20 (17 - 24)</td>
<td></td>
<td>22 (19 - 25)</td>
<td>37</td>
</tr>
<tr>
<td>45-54</td>
<td>26 (18 - 35)</td>
<td>30 (26 - 34)</td>
<td></td>
<td>29 (26 - 33)</td>
<td>28</td>
</tr>
<tr>
<td>&gt;54</td>
<td>12 (7 - 20)</td>
<td>15 (12 - 18)</td>
<td></td>
<td>14 (12 - 17)</td>
<td></td>
</tr>
<tr>
<td>Geographic region</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Western(^2)</td>
<td>21 (14 - 30)</td>
<td>23 (20 - 27)</td>
<td>0.29</td>
<td>23 (20 - 26)</td>
<td>12</td>
</tr>
<tr>
<td>Ontario</td>
<td>49 (39 - 59)</td>
<td>48 (44 - 52)</td>
<td></td>
<td>48 (44 - 52)</td>
<td>33</td>
</tr>
<tr>
<td>Quebec and AP(^3)</td>
<td>30 (22 - 40)</td>
<td>29 (25 - 33)</td>
<td></td>
<td>29 (26 - 33)</td>
<td>55</td>
</tr>
</tbody>
</table>

\(^1\)Source for age distribution: Canadian Dairy Information Centre-Census 2011 (dairy farm operators; n=22,055); for province distribution: Canadian Dairy Information Centre, 2015 (dairy farms; n = 11,683).

\(^2\)British Colombia, Alberta, Saskatchewan, and Manitoba.

\(^3\)AP = Atlantic Provinces (New Brunswick, Prince Edward Island, Nova Scotia, and Newfoundland and Labrador).
Table 2. Number of milking cows on farms using automated milk feeders (AMF) and manual milking feeding (MMF) systems for raising dairy calves from an online questionnaire completed by 670 dairy producers in Canada.

<table>
<thead>
<tr>
<th>Farm size¹</th>
<th>AMF</th>
<th>MMF</th>
<th>P-value</th>
<th>All participant farms</th>
<th>Canadian statistics²</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>Median (Q1-Q3)</td>
<td>n</td>
<td>Median (Q1-Q3)</td>
<td>n</td>
</tr>
<tr>
<td>Overall</td>
<td>103</td>
<td>110 (66-150)</td>
<td>561</td>
<td>60 (45-100)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>≤80 milking cows³</td>
<td>39</td>
<td>60 (50-70)</td>
<td>389</td>
<td>50 (40-60)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>&gt;80 milking cows³</td>
<td>64</td>
<td>140 (112-175)</td>
<td>172</td>
<td>120 (100-155)</td>
<td>&lt;0.01</td>
</tr>
</tbody>
</table>

¹ Dichotomization of farm size based on the average farm size of Canadian dairy farms.
² Source: Cyprien Awono, Agriculture and Agri-Food Canada, Ottawa, Ontario, Canada; personal communication.
³ Q1 = 25th percentile, Q3 = 75th percentile.
Table 2. Percentage (95% CI) of farms using automated milk feeders (AMF, n = 105) and manual milking feeding (MMF, n = 565) systems for raising dairy calves from an online questionnaire completed by 670 dairy producers in Canada.

<table>
<thead>
<tr>
<th>Farm descriptor</th>
<th>AMF(^1)</th>
<th>MMF(^2)</th>
<th>P-value</th>
<th>All participant farms</th>
<th>Canadian statistics(^3), %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cow-barn type</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bedded-pack</td>
<td>6 (3 - 6)</td>
<td>4 (2 - 6)</td>
<td>&lt;0.001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Free-stall</td>
<td>69 (60 - 78)</td>
<td>46 (42 - 50)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tie-stall</td>
<td>25 (17 - 34)</td>
<td>50 (46 - 54)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Access to pasture allowed</td>
<td>14 (8 - 23)</td>
<td>26 (23 - 30)</td>
<td>0.012</td>
<td></td>
<td>24 (21 - 28)</td>
</tr>
<tr>
<td>Milking system type</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Automatic milking system</td>
<td>30 (21 - 40)</td>
<td>8 (6 - 10)</td>
<td>&lt;0.001</td>
<td></td>
<td>11 (9 - 14)</td>
</tr>
<tr>
<td>Conventional parlor</td>
<td>46 (37 - 56)</td>
<td>42 (38 - 46)</td>
<td></td>
<td></td>
<td>43 (39 - 46)</td>
</tr>
<tr>
<td>Pipeline</td>
<td>24 (16 - 33)</td>
<td>50 (46 - 55)</td>
<td></td>
<td></td>
<td>46 (43 - 50)</td>
</tr>
<tr>
<td>Devices at the farm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Activity monitors</td>
<td>63 (53 - 72)</td>
<td>32 (29 - 36)</td>
<td>&lt;0.001</td>
<td>37 (33 - 41)</td>
<td></td>
</tr>
<tr>
<td>Automated manure scrapers</td>
<td>69 (60 - 78)</td>
<td>39 (35 - 44)</td>
<td>&lt;0.001</td>
<td>44 (40 - 48)</td>
<td></td>
</tr>
<tr>
<td>Automated feed pushers</td>
<td>17 (2 - 26)</td>
<td>7 (5 - 10)</td>
<td>&lt;0.001</td>
<td>9 (7 - 11)</td>
<td></td>
</tr>
<tr>
<td>Cow brushes</td>
<td>70 (61 - 79)</td>
<td>36 (32 - 40)</td>
<td>&lt;0.001</td>
<td>42 (38 - 45)</td>
<td></td>
</tr>
<tr>
<td>Automated grain feeder for cows</td>
<td>22 (15 - 31)</td>
<td>24 (21 - 28)</td>
<td>0.621</td>
<td>24 (21 - 28)</td>
<td></td>
</tr>
<tr>
<td>Automated grain feeder for calves</td>
<td>9 (5 - 17)</td>
<td>0.2 (0 - 1)</td>
<td>&lt;0.001</td>
<td>2 (1 - 3)</td>
<td></td>
</tr>
<tr>
<td>Switched back(^4)</td>
<td>2 (1 - 3)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\(^1\)Except for milking system type, where n=104.
\(^2\)Except for milking system type, where n=564.
\(^3\)n = 8,389; CDIC (2015).
\(^4\)Producers who had used AMF in the past but switched back to MMF systems.
Table 2.4. Final logistic regression models evaluating factors associated with having an automated milk feeder for raising milk-fed dairy calves with geographic region as fixed effects to adjust for region effects\(^1\).

<table>
<thead>
<tr>
<th>Model and variable</th>
<th>Coefficient</th>
<th>SE</th>
<th>OR(^2)</th>
<th>95% CI(^3)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>LCL</td>
<td>UCL</td>
</tr>
<tr>
<td>Model 1: Tie-stall farms(^4)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intercept</td>
<td>-3.77</td>
<td>1.34</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Farm size</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(\leq 80) milking cows</td>
<td>Referent</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(&gt; 80) milking cows</td>
<td>1.34</td>
<td>0.56</td>
<td>3.81</td>
<td>1.26</td>
<td>11.48</td>
</tr>
<tr>
<td>Age of producer, years</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(&gt; 54)</td>
<td>Referent</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(&lt; 25)</td>
<td>1.68</td>
<td>1.22</td>
<td>5.38</td>
<td>0.49</td>
<td>59.11</td>
</tr>
<tr>
<td>(25) to (34)</td>
<td>1.82</td>
<td>1.10</td>
<td>6.18</td>
<td>0.71</td>
<td>53.98</td>
</tr>
<tr>
<td>(35) to (44)</td>
<td>2.18</td>
<td>1.09</td>
<td>8.91</td>
<td>1.04</td>
<td>76.25</td>
</tr>
<tr>
<td>(45) to (54)</td>
<td>0.04</td>
<td>1.25</td>
<td>1.04</td>
<td>0.12</td>
<td>12.09</td>
</tr>
<tr>
<td>Geographic region</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Western(^5)</td>
<td>Referent</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quebec and Atlantic(^6)</td>
<td>-0.43</td>
<td>0.86</td>
<td>0.65</td>
<td>0.12</td>
<td>3.52</td>
</tr>
<tr>
<td>Ontario</td>
<td>-0.03</td>
<td>0.88</td>
<td>0.97</td>
<td>0.17</td>
<td>5.49</td>
</tr>
<tr>
<td>Model 2: Loose-housing farms(^7)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intercept</td>
<td>-3.82</td>
<td>0.51</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Farm size</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(\leq 80) milking cows</td>
<td>Referent</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(&gt; 80) milking cows</td>
<td>1.24</td>
<td>0.32</td>
<td>3.47</td>
<td>1.82</td>
<td>6.62</td>
</tr>
<tr>
<td>Automatic milking system</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No</td>
<td>Referent</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>1.12</td>
<td>0.31</td>
<td>3.07</td>
<td>1.65</td>
<td>5.72</td>
</tr>
<tr>
<td>Cow brushes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No</td>
<td>Referent</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>1.13</td>
<td>0.41</td>
<td>3.08</td>
<td>1.37</td>
<td>6.93</td>
</tr>
<tr>
<td>Geographic region</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Western(^5)</td>
<td>Referent</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quebec and Atlantic(^6)</td>
<td>1.29</td>
<td>0.42</td>
<td>3.65</td>
<td>1.58</td>
<td>8.42</td>
</tr>
<tr>
<td>Ontario</td>
<td>0.58</td>
<td>0.32</td>
<td>1.79</td>
<td>0.94</td>
<td>3.39</td>
</tr>
</tbody>
</table>

\(^1\) Separate models constructed for tie-stall farms (n = 308) and loose housing farms (n = 354).
\(^2\) Odds ratio for having an automated milk feeder.
\(^3\) Confidence interval for the odds ratio, lower confidence limit (LCL), and upper confidence limit (UCL).
\(^4\) Pearson goodness-of-fit test \(\chi^2 = 20.4, P = 0.25\).
\(^5\) British Colombia, Alberta, Saskatchewan, and Manitoba.
\(^6\) New Brunswick, Prince Edward Island, Nova Scotia, and Newfoundland and Labrador.
\(^7\) Pearson goodness-of-fit test \(\chi^2 = 20.2, P = 0.12\).
Table 2.5. Age at access to solid feed and water, age at weaning, and length of weaning period reported by farms using automated milk feeders (AMF) and manual milk feeding (MMF) systems from an online questionnaire completed by 670 dairy producers in Canada.

<table>
<thead>
<tr>
<th>Survey answer</th>
<th>AMF</th>
<th></th>
<th></th>
<th>MMF</th>
<th></th>
<th></th>
<th></th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>Q1(^1)</td>
<td>Median</td>
<td>Q3(^1)</td>
<td>n</td>
<td>Q1</td>
<td>Median</td>
<td>Q3</td>
</tr>
<tr>
<td>Solid feed and water</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age at starter access, days</td>
<td>84</td>
<td>1</td>
<td>3.5</td>
<td>7</td>
<td>483</td>
<td>3</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>Age at hay access, days</td>
<td>53</td>
<td>5</td>
<td>7</td>
<td>20</td>
<td>324</td>
<td>7</td>
<td>15</td>
<td>30</td>
</tr>
<tr>
<td>Age at TMR(^2) access, days</td>
<td>6</td>
<td>15</td>
<td>18</td>
<td>30</td>
<td>36</td>
<td>30</td>
<td>47</td>
<td>60</td>
</tr>
<tr>
<td>Age at water access, days</td>
<td>77</td>
<td>1</td>
<td>3</td>
<td>7</td>
<td>436</td>
<td>1</td>
<td>7</td>
<td>15</td>
</tr>
<tr>
<td>Weaning process</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age at weaning(^3), weeks</td>
<td>85</td>
<td>6</td>
<td>7</td>
<td>8</td>
<td>524</td>
<td>6</td>
<td>8</td>
<td>10</td>
</tr>
<tr>
<td>Length of weaning period, days</td>
<td>66</td>
<td>9</td>
<td>13</td>
<td>17</td>
<td>524</td>
<td>4</td>
<td>7</td>
<td>14</td>
</tr>
</tbody>
</table>

\(^1\)Q1 = 25\(^{th}\) percentile, Q3 = 75\(^{th}\) percentile.

\(^2\)Total mixed ration.

\(^3\)The beginning of the weaning period was defined as the day when the peak of milk offered to calves started to be decreased.
Figure 2. Distribution of daily amount of milk offered to calves by week of age during the first 4 weeks of life and the peak amount offered before starting weaning for farms with automated milk feeders (AMF) or with manual milk feeding (MMF) systems. Median = line within the box; 25th and 75th percentiles = box part of the plot; and 10th and 90th percentiles = end of the whiskers.
CHAPTER 3

As previously published

3.1 ABSTRACT

As part of a cross-sectional survey, Canadian dairy producers were asked a set of questions to: (1) determine factors that influenced them to continue using manual milk feeding (MMF) systems or to switch to automated milk feeding (AMF), and (2) investigate producers’ perceived advantages and disadvantages regarding both feeding systems. A total of 670 responses were received. Among respondents, 16% used AMF and 84% used MMF. The four most frequent factors that producers reported as important in motivating them to switch to AMF were to raise better calves, offer more milk to calves, reduce labour, and improve working conditions. For MMF farms, investment in equipment and group housing facilities, as well as farm size, were the primary reasons reported for their continued use of MMF systems. The principal perceived advantages of having AMF systems were that calves are able to express natural behaviours and drink more milk without increased labour input. For MMF systems, the main perceived advantage was related to easier identification of sick calves. Results provide insights into factors affecting the choice of calf feeding methods by dairy producers, and improve understanding of producers’ needs and expectations regarding calf management and adoption of technology.

3.2 INTRODUCTION

There are different management approaches to feed milk to dairy calves, which can be categorized as manual milk feeding (MMF) and automated milk feeding (AMF) systems. The former is the most common milk feeding system in North America (Vasseur et al. 2010; USDA 2016), where calves are mainly fed through buckets (i.e., open buckets) or artificial teats (e.g., teat buckets, teat bottles or multiple teat milk bars). In the United States (USDA 2016) and in the province of Quebec, Canada (Vasseur et al. 2010), 72% and 92% of producers, respectively, reported feeding milk using buckets. Calves fed through MMF systems are typically housed
individually and traditionally fed restricted volumes of milk (10% of their BW in milk per day on average; Khan et al. 2011). On the other hand, automated milk feeders are computer-controlled systems that can facilitate the increase of daily milk allowance and group housing of calves, while also retaining the benefits of feeding calves individually (de Passillé et al. 2004; Käck and Ziemerink 2010; Jensen and Weary 2013). Automated feeders have the potential to be used to predict illness before the onset of clinical signs, by closely monitoring calf feeding behaviour (Svensson and Jensen 2007; Borderas et al. 2009; Knauer et al. 2017).

Decision-making for a dairy producer is influenced by efficiency, food safety, consumer choices, and the care of the animals (Bewley 2013; Endres 2013). Economic return is a crucial factor that influences technology adoption, among other factors such as the producer’s age, farm size, and other producers’ experiences (Bewley 2013). To date, research on reasons for adopting new technologies has mainly focused on automatic milking systems (AMS). In North America, the top two reasons for adopting AMS were allowance for a more flexible labour schedule and savings in the cost of hired labour (de Jong et al. 2003). Nevertheless, the investment required has reportedly been one of main reasons for non-adoption of AMS (Butler et al. 2012; Bergman and Rabinowicz 2013). Interest in AMF is growing among producers in North America (Endres, 2015), but research on the adoption and the use of AMF is limited (Barkema et al. 2015).

A better understanding of producers’ motivations around decisions related to calf feeding systems, and the perceived barriers to adoption of new technologies in the dairy industry is needed. Therefore, the objectives of this study were to determine factors that influenced producers to continue using MMF systems or to switch to AMF, and to gather information about advantages and disadvantages perceived by producers regarding both feeding systems.

3.3 MATERIALS AND METHODS

The present study was part of a cross-sectional online survey of dairy calf management practices among farms using MMF and AMF systems in Canada that was conducted from January through May 2015. This survey was administered via a web-based survey platform.
(FluidSurveys, SurveyMonkey product, Ottawa ON, Canada), and it was reviewed and approved by the University of Guelph Research Ethics Board (REB No. 14JN025).

Dairy producers registered in the two dairy milk recording services in Canada (CanWest DHI, Guelph, Ontario; Valacta, Sainte-Anne-de-Bellevue, Quebec; implied sampling frame ~80% of dairy producers in Canada) received an introductory letter and the hyperlink to the survey. Additionally, the survey was advertised in dairy cattle magazines and on social media. Detailed description of the survey development, administration and data handling are presented in Chapter 2. Briefly, the survey consisted of 2 questionnaires with closed- and open-ended questions; one questionnaire was for producers using MMF systems (i.e., milk offered via open bucket or teat - bottle, bucket, milk bar), and one questionnaire was for producers using AMF (i.e., computer-controlled systems). Both questionnaires collected the same type of information, but questions were phrased differently to be consistent with the milk feeding system being used. Questionnaires started with an identical section: generalities of the farm (e.g., location, breed of cattle, type of housing). At the end of this first section, producers were asked what type of automated devices they had on their farm, and based on their answer for automated milk feeder (i.e., yes/no question), they were directed to the corresponding questionnaire.

To address the objectives of this study we used the survey questions related to factors influencing decision-making and perceptions (i.e., advantages and disadvantages) of respondents’ current calf milk feeding system. Specifically, using symmetrical 5-point Likert scales, respondents rated a series of statements regarding possible influential factors for adopting AMF or continuing to use MMF systems (1 = important to 5 = not important), and perceived advantages and disadvantages of the systems (1 = agree to 5 = strongly disagree). Optional open text boxes were provided to allow producers to complement the ordinal response and to expand on their answers. Full-length questionnaires are available as supplementary data in Appendix 2.1.

Descriptive statistics (proportions) were calculated, and Chi Squared and Wilcoxon Two-sample tests were used to evaluate differences in categorical and continuous variables, respectively, between farms with AMF and MMF systems, using SAS version 9.3 (SAS Institute Inc., Cary, NC, USA). Complementary responses added by respondents in the open fields were
open-coded and themes identified. Themes were used as categories for analysis, where each given response was classified based on common patterns of information (Boyatzis 1998).

3.4 RESULTS

3.4.1 General Description of Producers and Farms

A total of 670 dairy producers across Canada were included in the analysis, representing 6% of all dairy farms in Canada (CDIC 2015). Of the respondents, 16% (n = 105) used AMF systems to raise calves, and 84% (n = 565) used MMF systems. The respondents were from all 10 Canadian provinces (Figure 3.1). Language, gender, and age of respondents did not differ between AMF and MMF farms (P > 0.4). The majority of respondents completed the survey in English (79%; n = 532), and most respondents (72%; n = 473) were male. Ages of respondents were: < 25 years (8%; n = 51), 25 to 34 years (27%; n = 177), 35 to 44 years (22%; n = 147), 45 to 54 years (29%; n = 195), and ≥ 55 years (14%; n = 96).

Overall, the average reported herd size was 90 milking cows (range: 17 to 2800). Farms with AMF systems were significantly (P < 0.001) larger (median [25th - 75th percentiles]: 110 milking cows [66 - 150]) compared to farms with MMF systems (median [25th - 75th percentiles]: 60 milking cows [45 - 100]). For more details on farm demographics see Chapter 2.

The majority of farms using AMF had one feeder (86%); 11%, 2%, and 1% of the farms had 2, 3, or 6 feeders, respectively. Within farms using MMF, 53% used teats (bottles, teat buckets and/or milk bars) to feed calves for at least the first 2 months of life, while 36% of farms fed milk through open buckets, and 11% used a mix of teat and open bucket to feed milk. Most MMF farms (86%) fed calves 2 times/day. Only 10% fed calves 3 times/day, while 1% fed 4 times/day, and 3% reported feeding calves ad libitum.

3.4.2 Factors Influencing Decision-making Regarding Milk Feeding System for Calves

From a list of potential factors that might have motivated producers to switch from MMF to AMF systems, the 4 most frequent factors reported as being important by producers (n = 105) from AMF farms were to: raise better calves, offer more milk to calves, reduce labour,
and improve working conditions (Figure 3.2). Sixteen of these producers (15%) provided additional information in an open-ended response regarding what factors influenced them to switch to AMF; 6 of them gave more than one additional factor. These responses included: consistency of feeding (e.g., constant quantity, temperature; 31%), allow calves to be fed multiple times a day (31%), reduce stress on calves at weaning (19%), seeking time flexibility (13%), better data management (6%), easy way of combining whole milk and milk replacer (6%), continuous calf access to warm milk (6%), and desire to switch to group housing (6%). Figure 3.3 describes these factors and how they relate to each other.

Among producers using MMF, the most frequent factors reported as influencing their decision to continue using this feeding system were the economic investment involved in changing to automated systems, and small farm size (Figure 3.4). A total of 150 producers (26%; total n = 565) provided more information in the open-ended response regarding what have influenced them to continue feeding calves manually or have them housed individually; 55 of those producers gave more than one reason. Thirty-nine percent of the 150 producers said that they preferred individual manual feeding and housing because of the direct contact with each calf at milk feeding time, which allowed them to observe calves and identify any change in feeding behaviour and health, while 16% of producers preferred the direct contact with calves because it allowed them to raise calmer calves that are easier to handle (“… tame from birth and very easy to work with throughout their life”). Twenty-three percent of producers believed that reduced disease transmission and healthier calves were easier to achieve when calves were kept in individual housing. Another 11% of producers indicated that they felt satisfied with how they were managing calves, and thus they were not interested in changing something that was already working well. Other influential factors included: concerns about cross-suckling between group-housed calves (4%), family roles (i.e., children or a member of the family were in charge of feeding calves and that manual feeding was “giving them a sense of responsibility” or “something to do”; 3%), concerns about the cleanliness of AMF systems (3%), lack of concerns about labour (i.e., having enough personnel to feed calves manually; 2%), not having reliable personnel to handle automated feeding technology (1%), and, being close to retirement (1%). Four producers (3%) reported having previously used automated feeders but switched back to manual feeding due to health and cross-suckling problems. Figure 3.5 describes these factors and how they relate to each other.
3.4.3 Perceived Advantages and Disadvantages of Automated and Manual Milk Feeding Systems

3.4.3.1 Advantages of automated milk feeding systems

The advantages to using AMF systems perceived by producers are presented in Figure 3.6. The top four advantages of having AMF (perceived by more than 90% of producers from farms using this technology) were that these devices allowed calves to express natural behaviours, that producers could increase calf milk allowance without increasing labour, that farm working conditions were improved by automated milk feeders, and that workers spent less time cleaning feeding equipment. In addition, 82% of producers agreed or strongly agreed that having an AMF facilitated management of group-housed calves, and 68% also agreed that detection of illness could be done earlier. Eleven producers (10%) provided additional factors in the open-ended response about the perceived advantages that brought to their farm (one producer listed more than one advantage). Of these, 36% indicated that AMF systems have allowed them to wean calves very gradually and the process seemed less stressful on the calves. Consistency of feeding in terms of quantity of milk powder, volume, and temperature were also reported as an advantage (39%). Other advantages reported by producers were that calves begin water and solid feed consumption faster compared to calves in hutches (9%); feeding through an automated milk feeder was actually cheaper than the “old way” (9%); and that calves were less stressed when moved to larger group pens (because of group housing) (9%).

3.4.3.2 Advantages of manual milk feeding systems

The advantages to using MMF perceived by producers are presented in Figure 3.7. The majority of producers from farms using MMF systems perceived that the direct contact that they had with calves at feeding time facilitated the identification of sick animals, facilitated handling, and decreased risk of disease transmission. Sixty-one producers (11%) provided additional advantages in the open-ended field. Of these, 41% remarked on the advantage of being able to monitor health and feeding more easily when calves were fed manually and housed individually, and thus being able to intervene faster when necessary. Individualized feeding and, thus, no competition between calves, was an advantage reported by 15% of the 61 producers, while 12% highlighted the low capital cost of feeding milk by hand. Fresh air, available to calves in
individual hutches, was perceived as another advantage by 7%. Other advantages noted were: cleaning of buckets was fast and easy (5%), producers were able to know each calf’s personality (3%), measuring weight of calves housed individually was more practical than group-housed calves (2%), and feeding milk manually was an activity that the producer actually enjoyed (2%).

3.4.3.3 Disadvantages of automated milk feeding systems

The disadvantages to using AMF perceived by producers are presented in Figure 3.6. Less direct contact with calves was identified as the top disadvantage (40% of producers) of using AMF systems among producers using these feeders. Twenty-two producers using AMF (21%) provided additional detail about the disadvantages they perceived from automated milk feeders in open-ended responses. Of these, 23% indicated that they had concerns about sanitation of the feeding system; 36% reported having cross-sucking issues; and 14% perceived that disease transmission increased. Other disadvantages listed by producers were related to increased calf training they had to do (i.e., first train calves to bottle feed and then train them again to the teat at the AMF station; 4%), and the need for appropriately trained staff to be in charge of the feeder (4%).

3.4.3.4 Disadvantages of manual milk feeding systems

The disadvantages to using MMF perceived by producers are presented in Figure 3.7. The majority (56%) of producers strongly agreed that a disadvantage of manual feeding is that it makes it more difficult to increase milk feeding frequency per day. Furthermore, among those using outdoor housing for calves, it was agreed that having to feed calves in winter is not pleasant. Thirty-three producers using MMF systems (6%) provided detail in open-ended responses about the disadvantages they perceived about MMF systems, and when applicable, the implementation of individual housing. Fifty-six percent of the 33 producers expressed the concern of not having consistency in feeding when multiple people were feeding the calves, and also regarding temperature of the milk. The extra physical labour needed when feeding calves manually was another disadvantage expressed by 15% of producers. Nine percent of producers stated that the lack of socialization and the restriction of movement was the biggest disadvantage of their system. Among other disadvantages listed on the open-ended section were: competition among calves when milk-bars are used (3%); the weaning process is not as “smooth” as it can be
with AMF (3%), not able to record data on feeding vigor (3%), and the challenge they face teaching calves to drink from a bucket (6%).

3.5 DISCUSSION

This research is the first study that provides insights into Canadian dairy producers’ decision-making and perceptions towards manual and automated milk feeding systems for raising calves.

3.5.1 Farms with Automated Milk Feeders

Research previously done on precision dairy farming has shown that the main drivers for investing in new technologies, such as AMS and sensor systems, were a desire to change lifestyle, increased flexibility in time, reduced labour, increased productivity and profitability, as well as perceived economic returns (Bergman and Rabinowicz 2013; Bewley 2013; Steeneveld and Hogeveen 2015). Extrinsic factors, such as increased concern about animal care and welfare, and other producers’ experiences with the technology, also influenced the decisions made by a producer (Bewley 2013). When deciding to invest in an AMF, producers surveyed in this study expressed the desire to be able to raise better calves and increase milk allowance, while reducing labour and improving conditions at work; hence, producers were interested in reducing labour and costs, and were also interested in improving the quality of life of both calves and workers. Similarly, Endres (2016) found that dairy producers in the state of Minnesota purchased AMF systems mainly looking to decrease time spent on menial tasks, improve calf growth and records on calf feeding, as well as allow for more natural feeding for calves, and improve labour conditions. In the present study, we also found that more than half of producers reported that knowledge about other producers’ experiences with AMF was an important factor influencing their decision to invest in this technology. Likewise, in a study conducted in Sweden, the most important information source for the adoption of AMS reported by producers was “other milk producers”, demonstrating that producers place importance in information and guidance obtained from other producers (Bergman and Rabinowicz 2013).
Calves expressing natural behaviours, being able to give more milk to calves without increasing labour, and improved working conditions were the main advantages perceived by the majority of producers using AMF. Comparing these perceived advantages with the previously mentioned factors that influenced the adoption decision, it can be inferred that automated milk feeders fulfilled the expectations that producers had when deciding to switch to automation. These results are similar to the findings of Bergman and Rabinowicz (2013) regarding adoption and outcomes associated with installing an AMS. In addition, almost 70% of producers using AMF surveyed in our study perceived that earlier detection of sick calves was an advantage of this system. Although there are concerns regarding detection of illness in group housing systems, especially when large group sizes are used (Svensson and Jensen, 2007), research has shown that daily monitoring of behavioural data provided by AMF can help to detect sickness before the onset of clinical signs (Borderas et al., 2009a; Knauer et al., 2017).

Producers surveyed in our study also reported that it was easier to manage group-housed calves and to wean them gradually through the use of an automated milk feeder (vs. MMF systems) and that calves started consuming water and solid feed earlier than they did when fed individually. These perceived benefits of AMF systems result from an interaction between the feeding system (automated) and the housing system (group housing) under appropriate management, the latter being essential for limiting competition and cross-suckling, especially during the weaning period (Steele et al. 2015). Researchers have found that one of the disadvantages of feeding more milk to calves (which is one of the advantages of AMF systems) is that solid feed consumption is lower during the milk-fed period (Borderas et al. 2009b); but when group housing is implemented, starter intake is stimulated (Jensen et al. 2015). Therefore, what producers see as an advantage of AMF is, in fact, an advantage of the whole system.

On the other hand, the main disadvantages reported by producers using AMF systems was the decrease in time spent directly in contact calves, which 16% of producers (Figure 4) perceived might lead to more fearful or aggressive calves. Similarly, Bergman and Rabinowicz (2013) found that producers who did not want to install an AMS were concerned about having less contact with the cows. Although there has not yet been research investigating the temperament of group-housed calves specifically raised with AMF systems, findings from research done comparing handling and fearfulness between individual- and group-housed calves
are conflicting. Lensink et al. (2001) found that pair-housed calves took longer to approach an unfamiliar person and spent less time interacting with the person, and they were less easy to handle than individually housed calves. Similarly, Veissier et al. (1998) found that calves reared in groups were more stressed during handling than calves raised in individual housing. However, Lensink et al. (2001) also found that, irrespective of housing conditions, if additional contact (e.g., petting after milk feeding) was provided, calves’ motivation to interact with an unfamiliar person increased and calves were easier to handle. In contrast to these studies, recent research has shown that calves reared in groups were less fearful and food-neophobic than individually-housed calves (Costa et al. 2014). Producers surveyed here who felt they were having little direct contact with calves could increase the frequency of interactions (ensuring they are positive) to potentially reduce the level of fear calves experience during handling.

3.5.2 Farms Feeding Milk Manually

Large investment has been one of the top reasons for the non-adoption of precision dairy technologies (Butler et al. 2012; Bergman and Rabinowicz 2013). In addition, intrinsic factors related to the producer and the farm influence decision-making (Bewley 2013). The main reasons identified by the majority of MMF producers were the cost of equipment and the cost of renovating facilities to fit the new equipment. Similarly, Bergman and Rabinowicz (2013) found that the top two reasons for producers to decide not to install an AMS were the expense of buying the milking robot and large investments for reconstruction in the barn. Moreover, producers from our study also indicated that their farm size was too small to justify the purchase and the use of an automated milk feeder. This result is parallel to what we found regarding features of surveyed farms, where larger farms were more likely to have AMF compared to small farms (Medrano-Galarza et al., 2017). Manufacturers promote that an AMF can supply a group of approximately 25 calves per feeding station (Käck and Ziemerink 2010). Therefore, producers with a small number of calves per year might not see benefit in switching to automation when feeding manually is working reasonably well.

What MMF producers in this study liked the most about their feeding system was the direct contact with calves during feeding time, which they indicated allowed them to identify sick calves by looking at changes in behaviour, as well as reduced disease transmission achieved
through individual housing and feeding. It has been suggested that individual housing until weaning reduces the risk of pathogen transmission and facilitates surveillance of calves’ health status by the producer (Kung et al. 1997; Marcé et al. 2010). Research on group housing is relatively new (Costa et al. 2016); therefore, data related to this housing system are limited.

On the other hand, we found that one of the biggest perceived disadvantages of manually feeding calves was the limitation in the frequency of feedings per day. Feeding higher milk amounts (i.e., 20% of BW in milk) is recommended in the Canadian Code of Practice (NFACC 2009); however, research regarding optimal meal sizes when feeding a high plane of nutrition is still in development and is conflicting. Yunta et al. (2015) found that receiving higher amounts of milk in only 2 daily feedings can have a negative effect on glucose metabolism, emphasizing the need for increasing feeding frequency, while MacPherson et al. (2016) found that it has a minimal effect and did not decrease insulin sensitivity.

In addition, if raised with their dams, calves normally suck milk about 5 to 8 times a day (Phillips 2002); thus, only feeding 2 meals per day is unlike the natural feeding pattern of a calf. Research on feeding labour in conventional systems (i.e., manually feeding milk twice a day) has shown that to feed a single calf through a bucket takes approximately 10 min/d (Kung et al. 1997). Therefore, feeding more frequently would require an increase in labour, which producers might be reluctant or unable to undertake. This is supported by research on adoption of technologies or implementation of new practices mainly driven by the desire of reducing labour and saving time (Bewley 2013; Hötzel et al. 2014).

3.6 CONCLUSIONS

The key motivators indicated by dairy producers for adoption of automated milk feeders included: to raise better calves, give more milk to calves, reduce labour, and improve working conditions; the key barriers were mainly costs related to investment in the equipment and group housing facilities. The main perceived advantages of an automated milk feeder were to allow calves to express more natural feeding behaviour and drink more milk without increasing labour, indicating that producers experienced the expectations that motivated them to adopt this
technology. In contrast, easier disease detection and handling of calves were the positive aspects perceived by producers feeding milk manually to their calves.

3.7 ACKNOWLEDGEMENTS

This research was funded by Dairy Farmers of Canada (Ottawa, ON, Canada) as part of the Dairy Research Cluster program. The first author also thanks the Administrative Department of Science, Technology and Innovation – Colciencias (Bogota, Cundinamarca, Colombia) for the Ph.D. scholarship granted. The authors also thank those research experts, students, and dairy producers who helped to create the survey questionnaire: Jan Ziemerink (Förster-Technik North America, Cambridge, ON, Canada), Ken Leslie (University of Guelph, Guelph, ON, Canada), Ann Godkin and Neil Anderson (OMAFRA, Elora, ON, Canada), Elsa Vasseur (McGill University, Ste. Anne de Bellevue, QC, Canada), Nelson Dinn (University of British Columbia, Agassiz, BC, Canada), students Hana Brown, Craig LeRoy, and Jessie Hubbs (University of Guelph, Guelph, ON, Canada), and dairy producers Evan Eckert (Eckerlea Acres), Tim May (Mayhaven Farms) Todd Nixon (Alexerin Dairy Inc.), Rob Vanden Hengel (Vinselaar Holsteins Inc.), and Philip Armstrong (Armstrong Manor Farm). Special thanks to Richard Cantin (CanWest DHI, Guelph, ON, Canada), Daniel Lefebvre and Steve Adam (Valacta, Sainte-Anne-de-Bellevue, QC, Canada), Shelley Crabtree (Dairy Research Cluster, Ottawa, ON, Canada), Sharon Laidlaw (Milk Producer Magazine, Mississauga, ON, Canada), and the OVC Marketing Communications Team for collaborating with the distribution of the survey, and to the dairy producers who participated in the survey and made this study possible.
3.8 REFERENCES


Figure 3.1. Distribution of respondents (with 95% CI) from an online questionnaire completed by 670 dairy producers (Jan-15 to May-15) by region (Western provinces = British Colombia, Alberta, Saskatchewan, and Manitoba [n = 153]; Ontario [n = 322]; and Quebec and Atlantic provinces = New Brunswick, Prince Edward Island, Nova Scotia, and Newfoundland and Labrador [n = 195]) compared with National industry data (n = 11,683; CDIC, 2015).
Figure 3.2. Level of importance reported by 105 producers with automated calf milk feeders for a list of potential factors influencing their decision to switch from manual milk feeding systems to automated milk feeders to raise calves (responses from an online questionnaire; Canada, January 2015 to May 2015).
Figure 3. Factors influencing producers’ decision to switch from manual milk feeding systems to automated milk feeders to raise calves, and how these factors relate to each other (arrows). Factors of influence (thinner circles) are grouped into main themes (represented by thicker circles). The themes are derived from the responses to closed-ended questions (Likert scales) regarding decision-making statements and the analysis of the 16 responses to open text comment boxes in an online survey with 105 respondents using automated calf milk feeders.
Figure 3.4. Level of importance reported by 558 producers for a list of potential factors influencing their decision to continue using manual milk feeding systems to raise calves (responses from an online questionnaire; Canada, January 2015 to May 2015). AMF, automated milk feeding systems.
Figure 3.5. Factors influencing producers’ decision to continue using manual milk feeding systems to raise calves, and how these factors relate to each other (arrows). Factors of influence (thinner circles) are grouped into main themes (represented by thicker circles). The themes are derived from the responses to closed-ended questions (Likert scales) regarding decision-making statements and the analysis of the 150 responses to open text comment boxes in an online survey with 565 respondents using manual milk feeding systems. AMF, automated milk feeder.
Figure 3.6. Level of agreement reported by 97 producers using automated milk feeders with a list of statements regarding potential advantages and disadvantages that automated feeders brought to their farms (responses from an online questionnaire; Canada, January 2015 to May 2015).
Figure 3.7. Level of agreement reported by 548 producers using manual milk feeding systems (MMF) with a list of statements regarding potential advantages and disadvantages that MMF brought to their farms (responses from an online questionnaire; Canada, January 2015 to May 2015). MR, milk replacer.
As previously published

ASSOCIATIONS BETWEEN MANAGEMENT PRACTICES AND WITHIN-PEN PREVALENCE OF CALF DIARRHEA AND RESPIRATORY DISEASE ON DAIRY FARMS USING AUTOMATED MILK FEEDERS

4.1 ABSTRACT

Data on management practices used with automated milk feeders (AMF) are needed to identify factors associated with calf health in these systems. The objectives of this observational, longitudinal, cross-sectional study were to estimate the prevalence of calf diarrhea (CD) and bovine respiratory disease (BRD), and to identify factors associated with prevalence of these diseases at the pen level on dairy farms feeding milk to group-housed calves with AMF. Seventeen dairy farms with AMF in Ontario, Canada, were visited 4 times, seasonally, over 1 year. The clinical health of all calves (n = 1,488) in pens (n = 35) with AMF was scored to identify the number of calves with CD and BRD. Data on calf, feeder, and pen management practices were analyzed using generalized linear mixed regression models for each disease. Overall calf-level prevalence of CD and BRD were 23 and 17%, respectively. Median (interquartile range, IQR) within-pen prevalence of CD and BRD were 17% (7 to 37%) and 11% (0 to 28%), respectively. Median age (IQR) for diarrheic calves was 25 days (16 to 42 days), and for calves with BRD was 43 days (29 to 60 days). Factors associated with lower within-pen prevalence of CD were the administration of vitamin E and selenium at birth [odds ratio (OR) = 0.56; 95% confidence interval (CI): 0.32 to 0.99], feeding of probiotics (OR = 0.44, 95% CI: 0.22 to 0.93), and adding fresh bedding every 2 to 3 days (OR = 0.43; 95% CI: 0.24 to 0.76) compared with every 7 or more days. In contrast, sharing air with older cattle (>9 months old) was associated with increased within-pen prevalence of CD (OR = 4.54, 95% CI: 1.88 to 10.52). Additionally, total bacteria counts ≥100,000 colony forming units/mL in milk samples taken from the AMF mixing jar were associated with increased within-pen prevalence of CD during the summer visit (OR = 3.34; 95% CI: 1.31 to 8.54). Increased total solids in milk or milk replacer (OR = 0.48, 95% CI: 0.27 to 0.85) and feeding whole milk versus milk replacer (OR = 0.29, 95% CI: 0.11 to 0.75) were associated with lower within-pen prevalence of BRD. Factors associated with greater within-pen prevalence of BRD were sharing air with weaned cattle up to 8
months old (OR = 3.21, 95% CI: 1.26 to 8.16), and greater depth of the wet bedding pack. The use of maternity pens for reasons other than just calving was associated with increased prevalence of both CD and BRD (OR = 1.85, 95% CI: 1.03 to 3.33; OR = 2.61, 95% CI: 1.21 to 5.58, respectively). These results suggest that isolation from older animals and frequent cleaning of the feeder and pen may help to reduce disease prevalence in group-housed calves fed with an AMF.

4.2 INTRODUCTION

In North America, a growing proportion of calves is group-housed and fed with automated milk feeders (AMF) during the milk-feeding period (USDA, 2016). Medrano-Galarza et al. (2017a) reported that 36% of 670 dairy farms that participated in a survey on calf rearing practices across Canada housed calves in groups and 16% fed milk through AMF machines. The adoption of AMF is increasing steadily among producers (Medrano-Galarza et al., 2017a) as a way to improve working conditions and reduce physical labour while facilitating feeding high volumes of milk in multiple portions throughout the day to group-housed calves (Medrano-Galarza et al., 2017b). Nevertheless, some producers attribute difficulties with AMF (i.e., perceived high morbidity and mortality) to the feeders themselves and the type of housing (Endres, 2013), with some producers switching back to individual housing and feeding (Medrano-Galarza et al., 2017a). Producers perceive individual housing and individual feeding as a way to reduce disease transmission (Medrano-Galarza et al., 2017b) by limiting direct contact between calves, which has also been recommended by veterinarians (Callan and Garry, 2002; Stull and Reynolds, 2008). Observational studies in Sweden have shown the risk of bovine respiratory disease (BRD) to be significantly higher for AMF-fed calves housed in groups of 6 to 30 calves/pen compared with manually fed calves housed individually (Lundborg et al., 2003, 2005; Svensson et al., 2003) or in groups of 3 to 8 calves/pen (Lundborg et al., 2005). The severity of calf diarrhea (CD) cases was significantly higher in AMF-fed calves in large groups than in individually housed calves (Svensson et al., 2003).

For Swedish farms feeding calves with an AMF, overall calf-level incidence risk of
CD and BRD, up to 90 days of age, were 9 and 14%, respectively (Svensson et al., 2003). Additionally, Svensson and Liberg (2006) controlled group size in pens with AMF (6 to 9 calves vs. 12 to 18 calves) and found that within-pen incidence risk of CD and BRD ranged from 1 to 42%, and from 0 to 54%, respectively (median incidence in small groups: CD = 13% and BRD = 18%, and in large groups: CD = 20% and BRD = 31%). However, only the risk of respiratory disease was significantly higher for calves housed in large groups compared with those housed in small groups.

Research focused on the health impacts of raising calves with AMF systems and management practices other than group size is scarce. In North America, an observational study across farms in the Midwest United States is the only available published research on this topic (Jorgensen et al., 2017). In that study, researchers found associations between individual calf health scores (e.g., attitude, temperature, hind-end dirtiness score) and management practices regarding milk feeding plan, cleanliness of the AMF, and ventilation. To be able to support farmers by helping users of AMF improve their management practices and by providing information to guide decision-making of future adopters of AMF systems, it is essential to estimate disease frequency and determinants of calf health under AMF systems. Hence, the objectives of the present study were to estimate prevalence of CD and BRD, and to identify factors associated with prevalence of these diseases at the pen level on dairy farms feeding milk to group-housed calves with AMF in southern Ontario, Canada.

4.3 MATERIALS AND METHODS

This observational, longitudinal, cross-sectional study was reviewed and approved by the University of Guelph Animal Care Committee (Animal Use Protocol #3212).

4.3.1 Sample Size Estimation

During planning stages, and based on research done on farms with AMF in Sweden (Svensson and Liberg, 2006; the only research available at the time), we made the assumption that the mean within-pen prevalences of CD and BRD were 10 and 20%, respectively (SD of 10%), in small (as defined above) groups and 20 and 30%, respectively
(SD of 15%), in large groups. Using these assumptions, we estimated a total sample size of 52 pens for a power of 80% and a confidence level of 95% to be able to detect a difference of 10% (WINPEPI statistical program, version 11.62; Abramson, 2011). The estimated sample size was adjusted for clustering by farm (with an estimated average cluster size of 2 pens per farm) and an assumed intra-class correlation of 0.2. This gave an estimated sample size of 64 pens (~32 farms) when analyzing the effect of one exposure variable.

4.3.2 Enrollment of Farms and Farm Visits

A convenience sample of commercial dairy farms was obtained from a list of volunteer farms that expressed interest in participating in this study after completing an online survey on calf management practices (Medrano-Galarza et al., 2017a). Farms were initially selected based on location (no more than 2.5 h drive from the University of Guelph, Ontario, Canada) and willingness to complete a short questionnaire on calving, newborn calf, group-pen, and AMF management practices. Farms fulfilling the location criterion were contacted by telephone to confirm their willingness to participate and to schedule the first farm visit. Of the farms with AMF that completed the online survey, 73 indicated that they were interested in participating in the present study and provided their contact information. Of these, 32 farms were located in the province of Ontario, Canada. Only 18 farms fulfilled the location criterion, 17 of which agreed to participate and were enrolled.

Each farm was visited 4 times, once per season, over 1 year, starting in the fall of 2015 and ending in the summer of 2016. Fall farm visits were carried out between November 2 and December 1, 2015; winter visits occurred between February 3 and March 16, 2016; spring visits between April 19 and May 30, 2016; and summer visits between August 3 and September 6, 2016. All group pens with AMF that were being used (i.e., housing calves) on the day of the visit were included in the study. A total of 34, 35, 33, and 35 group pens with AMF were evaluated during each seasonal visit, respectively. Before each visit, producers were contacted by telephone, text, or email to set the visit date. All measurements were performed by the same person (first author), with the help of at least 1 volunteer per visit.

4.3.3 Measurements at the Calf Level

The health of all calves (heifers and bulls) housed in group pens with AMF was
scored during each of the 4 seasonal visits to each farm, using the fecal and calf respiratory scoring charts developed by McGuirk (2008) and the University of Wisconsin-Madison (2013a). Because calves were moved to other pens after being weaned in between visits, only one health assessment was done for each calf.

Table 4.1 summarizes the health scoring charts used in this study. The fecal scoring chart consisted of a 4-point scale that, ultimately, was dichotomized such that a score of 0 or 1 indicated absence of CD, and a score of 2 or 3 indicated the presence of CD. The respiratory scoring chart consisted of a conjunct evaluation of rectal temperature, nasal discharge, ocular discharge, ear position, and cough parameters. Each parameter was graded using a 4-point scale where 0 was considered normal and 3 severely abnormal. Scores for each parameter were added, and calves with a total respiratory score >4 were considered to have BRD (McGuirk and Peek, 2014).

In addition, body condition, navel, and attitude were evaluated (Table 4.1). Body condition was evaluated using 2-point scoring (modified from Wilson et al., 2000), where 0 was considered a satisfactory condition, and 1 was considered poor condition (very thin calf). Navel (modified from Wilson et al., 2000) and attitude were evaluated using a 4-point scale, where a score of 0 was considered normal, and a score of 3 was considered severely abnormal.

The age of each calf during each visit was obtained using farm birth records, and the age of introduction to the pen with the AMF was calculated using the birth date of each calf and the individual start date in the AMF. The latter was directly obtained from the AMF handheld terminal or screen, which records and stores information on each calf (e.g., start date on the feeder, number of days on the feeder to date, milk feeding plan assigned).

4.3.4 Measurements at the Pen Level

4.3.4.1 Stocking density and range in calf age

The width and length of the lying surface (surface with bedding) were measured during each farm visit using a measuring tape. These measurements were the same per pen across visits except for 3 farms. Lying area per calf (in m²) was calculated by dividing the total area by the total number of calves housed in the pen during each visit. Maximum age difference (in
days) among calves for each pen during each visit was calculated by subtracting the age of the youngest calf from the age of the oldest calf. In addition, we recorded whether the pen was located against an outer wall.

4.3.4.2 Nesting score

Each pen was assigned an overall nesting score. A 3-point scale was used based on the ability of calves to nestle into the bedding, as described by Lago et al. (2006). At least 75% of calves in each pen were observed while lying down (ideally at the beginning of the visit) and assigned an individual nesting score. A score of 1 indicated that the calf was lying on top of the bedding with legs exposed; a score of 2 indicated that the calf was slightly able to nestle into the bedding, but legs were partially exposed above the bedding; and a score of 3 indicated that a calf was nestling deeply into the bedding with legs not visible. Then, the most frequently observed score within a pen (i.e., mode) was the overall score assigned to the pen.

4.3.4.3 Wetness of the bedding

To evaluate the wetness of the bedding, a paper towel scoring system, developed by the Dairy Research Cluster (2011), and dry matter (DM) estimation were used. The former was modified to be able to evaluate a group pen rather than a single stall as described in the Dairy Research Cluster protocol. Eight spots across the entire pen were evaluated for wetness following an imaginary “W” pattern (mimicking methodologies used on estimation of DM of pasture-based systems; e.g., Pennsylvania State University, 2007; Appendix 4.1). A new paper towel folded in 4 (Bounty, Procter & Gamble, Cincinnati, OH) was placed each time on top of the bedding on each of the 8 sampling spots (making sure the towel was not placed on top of calf feces). Three seconds of pressure was applied onto the towel by kneeling down on it, and the wetness score was recorded (dry, wet, or very wet). The percentage of dry spots across the pen was used as an estimate of the percentage of dry bedding surface per pen.

A representative sample of the top bedding for each pen was collected to determine DM. A handful of the top of the bedding material was collected from each of the same 8 sampling spots used for the paper towel scoring system. The bedding from each spot was collected in a re-sealable plastic bag and stored at −20°C until all samples for the season
were collected. Then, bedding samples were defrosted over a 24-h period at 4°C, and samples were weighed, oven-dried at 60°C for 48 h, and reweighed to determine DM.

4.3.4.4 Bedding depth

The depth (cm) of the wet bedding pack (manure-saturated bedding) and of the dry layer of the bedding were measured 8 times across the pen (at the same spots as the paper towel test). A garden spoon was used to dig a hole to the pen floor, and a measuring tape was used to measure depth. The average depths of the wet bedding pack and of the dry layer of the bedding were calculated for each pen using the values obtained for each of the 8 spots evaluated. In addition, the type of bedding material was recorded.

4.3.5 Measurements Related to the Automated Milk Feeder

Information on the milk feeding plan — milk type (whole vs. milk replacer), start milk allowance [volume (L) offered per calf on the first day in the group pen with the AMF], peak milk allowance [maximum volume (L/d) offered per calf during the milk feeding period], latency to peak (number of days to reach the peak milk allowance), length of peak (number of days calves were allowed to drink the maximum volume), the weaning process used [age at weaning, duration (d) of weaning, and age when weaned], and solids (g) per liter of water when milk replacer was used — was obtained at each visit directly from the AMF. Hygienic quality of the milk fed to calves was assessed by bacteriological culture of the milk. Under the most aseptic conditions possible, samples of milk or milk replacer were collected after a portion of milk was automatically prepared in the mixing jar. The first sample was taken directly from the jar using a 50-mL sterile syringe to collect the milk and place it in a 15-mL sterile tube; then, another sample of milk was taken at the end of the hose(s), which was previously detached from the teat, using a 15-mL sterile tube directly to collect the milk coming out of the hose. Milk samples were immediately placed in an insulated container (Coleman Company Inc., Brampton, ON, Canada) and delivered the same day to the Animal Health Laboratory (AHL; University of Guelph, Guelph, ON, Canada) for bacteriological analysis [total bacteria count (TBC) and total coliform count (TCC)]. The samples were processed according to AHL standard operating procedure. Briefly, serial dilutions of each sample were made in PBS. One milliliter of each dilution was plated on Petrifilm (3M Inc.,
St. Paul, MN) and incubated at 35°C under aerobic conditions. The TCC were obtained after 24 h of incubation, followed by TBC after 48 h of incubation.

The TBC and TCC were dichotomized as acceptable or not acceptable based on suggested limits of bacteria counts in milk fed to calves (TBC: <100,000 colony forming units (cfu)/mL; TCC: <10,000 cfu/mL; McGuirk and Collins, 2004). Another sample of milk was collected from the mixing jar to determine the percentage total solids using a Brix Refractometer (Atago PAL-1-3810, ITM Instruments Inc., Newmarket, ON, Canada). Briefly, 2 to 3 drops of vortexed milk was placed on the measurement prism and a reading was obtained after 3 s. The refractometer was calibrated before each use and cleaned between samples. Additionally, when milk replacer was being fed, a sample of the powder was collected to be able to create a standard curve with Brix readings at different concentrations of milk replacer solution and adjust the Brix readings from the samples collected at the farms (University of Wisconsin-Madison, 2013b).

4.3.6 Questionnaires and Measurements at the Farm Level

Farm-level measurements were collected throughout each of the 4 seasonal visits by direct observation and questionnaires. Direct observation was used to collect information on type of ventilation (natural ventilation, positive-pressure ventilation system, or both) used in the facilities where calves were housed. In addition, when a positive-pressure ventilation system was used, the source of the air coming into the calf barn was recorded (e.g., from outdoors, attic, or cow barn). Two questionnaires were used to collect information on calving, colostrum, pen dynamics, bedding, and AMF management practices. The first questionnaire (Appendix 4.2) was handed to each producer on the first visit to the farm and producers were asked to have it completed by the second visit. The second questionnaire (Appendix 4.3), which was focused on pen management practices and calf movements between pens, was completed by face-to-face interview conducted by the first author at the fourth visit. In addition, we asked producers to keep records of treatments for disease and mortality (i.e., calves that died excluding stillbirths) during the study period.

4.3.7 Data Management and Statistical Analysis

Calf-, pen-, and farm-level data were entered into Excel (Microsoft Corp.,
Redmond, WA). All Excel sheets were imported into SAS version 9.3 (SAS Institute Inc., Cary, NC). Calf-level, within-pen, and within-herd prevalence of CD and BRD were calculated using the SUMMARY procedure in SAS 9.3. The within-pen prevalence SAS data set was merged (by season, farm, and pen) with pen- and farm-level data sets.

Generalized linear mixed regression models (PROC GLIMMIX in SAS) with binomial distribution and the “events/trials” syntax were used for analysis (Schabenberger, 2005). The 2 outcomes of interest were the number of diarrhea cases in a pen (events) out of the total number of calves in that pen (trials), and the number of BRD cases in a pen (events) out of the total number of calves in that pen (trials). Therefore, the models assessed the odds of greater prevalence of disease. Farm was included as a random effect to account for clustering (i.e., observations within a farm might not be independent). Pen nested within farm was included as a residual-side random component using the autoregressive variance-covariance structure to adjust for repeated measures within pen. Seasonal visit was included as a fixed effect. Because of the large number of factors being evaluated, independent variables were grouped into 4 logical clusters and separate models constructed (Dohoo et al., 2009) based on management areas: calving and newborn management; milk feeding plan; AMF calibration and cleaning practices; and pen management and barn features (Appendices 4.4 to 4.7, respectively). The association of bacteria counts in milk (Appendix 4.8) and prevalence of CD and BRD was examined separately, because if included in the model for AMF cleaning practices, it would become an intervening variable (Dohoo et al., 2009).

The linearity of continuous predictors was evaluated by examining the quadratic term (Dohoo et al., 2009). If the linearity assumption could not be fulfilled, the variable was categorized based on quartiles. The correlation between continuous and categorical variables was evaluated to assess collinearity using Pearson and Spearman correlation coefficients, respectively. If the correlation was ≥0.8, the least significant variable when tested in the univariable analysis was removed. Management factors with $P < 0.3$ in the univariable analysis were offered to the multivariable model. For each multivariable model, a variable was considered a confounder when the difference between coefficients of the full model (controlling for potential confounder) and reduced model (without the confounder) was >20%
(Dohoo et al., 2009). The model was reduced using backward elimination and variables remained in the model when $P < 0.1$. Plausible interactions between independent variables were tested and remained in the model if significant ($P < 0.05$). Interpretation of interaction terms was done by calculating, comparing, and plotting the least squares means estimates of the prevalence of disease for the conditional effects of interactions using PROC PLM in SAS (SAS, 2017; UCLA, 2017). Least squares means estimates of the prevalence of disease ($x$) were used to calculate adjusted prevalence ($AP$) values using the formula

$$AP = 100 \times \frac{1}{1 + e^{-x}}$$

The assumptions of normality and homoscedasticity of BLUPS (best unbiased predictors) was assessed graphically. Outliers were examined graphically by plotting Pearson residuals with the predicted probability of the outcome. Removal of extreme observations did not affect the models, thus we chose to leave them in the final models.

Using producers’ treatment and mortality records, which only included calves born and kept during the year the study was carried out (September 22, 2015, to September 21, 2016), herd-level incidence risks of being treated for each disease were calculated as the number of calves treated for the first time up to 90 days of age (risk period) divided by the total number of calves at risk (half of withdrawals were subtracted from the denominator; Dohoo et al., 2009). Withdrawals included any calf that was not followed for the entire risk period and was not treated for the disease. Herd-level incidence risks of mortality (i.e., all deaths excluding stillbirths) were calculated similarly.

4.4 RESULTS

4.4.1 Farm Features and Automated Milk Feeder and Group Pen Setup

Median herd size was 115 milking cows (range: 70 to 330 milking cows). Eleven of the 17 farms housed their milking cows in free-stalls and used a conventional milking parlor, 4 farms housed cows in free-stalls with automatic milking systems, 1 farm housed cows in a bedded-pack barn with automatic milking systems, and 1 farm housed cows in tie-stalls
with a portable milking system. Ten farms exclusively raised heifer calves, and 7 farms also raised bulls to be sold as dairy beef or red veal. The majority of the farms (76%) had only Holstein cattle, whereas 4 of the 7 farms raising bulls bred some Holstein cows with beef breeds.

The median year when farms installed AMF was 2010 (range: 2003 to 2015). The ratio of AMF machines to farms was 1:1 for 13 farms, and 2:1 for 4 farms. The most common ratio of pens to AMF was 2:1 (i.e., 1 feeder delivered milk into 2 feeding stations — typically one for calves under 30 days of age and one for calves above 30 days of age and a couple of weeks after being weaned — each located in 2 separate pens), although 1 pen housing all calves per feeder was present too (Appendix 4.9).

Median daily milk allowance during the period between birth and introduction to the group pen with AMF was 6 L/d (range: 4 to 9 L/d). Median peak milk allowance per day once calves were automatically fed was 10 L/d (range: 6 to 15 L/d). Between 82 and 88% of the farms fed milk replacer to calves through the AMF (varied by season), which was offered at a set concentration that ranged from 140 to 170 g/L. When the measured percentage of TS was compared with the expected percentage of TS (based on the set concentration), the median of the difference was −2.3% (95% CI: −2.8 to −1.7; range: −8.4 to 4.8%; P < 0.001).

Only 1 farm (6%) implemented a partial “all-in/all-out” stocking approach, where the producer had 2 rooms (each with 1 AMF and 2 pens) so when 1 room was full, no more calves were added as calves left the room. The rest of farms (16 of 17) used a continuous flow approach. The distribution of independent variables is presented in Appendices 4.4 to 4.8.

4.4.2 Prevalence of Disease and Mortality

4.4.2.1 Prevalence of calf diarrhea and bovine respiratory disease

Of the 1,488 calves assessed at a single point in time, 23% had CD (n = 337) and 17% had BRD (n = 246). Among CD cases, 32% had a BCS of 1 (indicative of emaciated appearance), 5% had an abnormal attitude score of 2 or 3 (indicating depression or a nonresponsive status, respectively), 5% had an abnormal navel score (2 or 3), and 16% had fever (rectal temperature ≥39.5°C). Within BRD cases, 26% of calves had a BCS of 1,
10% had an abnormal attitude score of 2 or 3, 1% had an abnormal navel, and 42% had fever.

The median age of calves with diarrhea was 25 days [range: 3 to 93 days; interquartile range (IQR): 16 to 42 days], while for calves with BRD it was 43 days (range: 6 to 145 days; IQR: 29 to 60 days]). Sixty-six percent of the total calves assessed had neither CD nor BRD, and 5% had both diseases. Effects of seasonal visit were detected for CD (\(P = 0.002\)) but not for BRD (\(P = 0.29\)). Summer visits had the lowest prevalence of CD cases compared with the other visits (Table 4.2). Median within-herd prevalence (n = 17) of CD and BRD were 24% (range: 8 to 46%) and 14% (range: 3 to 31%), respectively. Median within-pen prevalence of CD and BRD were 17% (range: 0 to 100%) and 11% (range: 0 to 60%), respectively. Prevalence values by seasonal visit are shown in Tables 4.2 and 4.3.

The association between within-pen prevalence of BRD and CD was not significant (\(P = 0.13\); Figure 4.1). Within-pen prevalence of CD was positively associated with within-pen prevalence of calves with abnormal navel (coefficient = 0.08; 95% CI: 0.05 to 0.11; \(P < 0.001\)) or with inadequate BCS (coefficient = 0.03; 95% CI: 0.02 to 0.04; \(P < 0.001\)), whereas within-pen prevalence of BRD was positively associated with within-pen prevalence of calves with an abnormal attitude (coefficient = 0.04; 95% CI: 0.02 to 0.07; \(P = 0.002\)).

4.4.2.2 Treatments and mortality

Based on producers’ treatment and mortality records, the median herd-level incidence risk of being treated for CD at least once was 8% (range: 1 to 56%). The median age at first treatment for CD was 12 days (range: 1 to 88 days). The median herd-level incidence risk of being treated for BRD at least once was 37% (range: 2 to 89%). The median age at first treatment for BRD was 27 days (range: 1 to 86 days). The median herd-level mortality risk was 4% (range: 0 to 21%).

4.4.3 Factors Associated with Within-Pen Prevalence of Calf Diarrhea

The final models describing factors associated with CD at the pen level are summarized in Table 4.4. We found significant associations of seasonal visit and pen type with the prevalence of CD (Model 1). Regarding calving and newborn management, use of
calving pens for additional purposes was associated with increased within-pen prevalence of CD. In addition, administration of both vitamin E and selenium to calves at birth was associated with decreased within-pen prevalence of CD (Model 2). Pens in which calves were drinking milk with probiotics added to it had a lower prevalence of CD compared with pens in which calves either drank milk with no additives or drank milk with antibiotics added to it (Model 3). We did not find any significant association between the within-pen prevalence of CD and any factor regarding milk allowance (e.g., start and peak milk allowance, and latency to reach that peak).

There was an interaction \( (P = 0.02) \) between seasonal visits and bacteria counts (TBC) in milk samples taken from the mixing jar (Figure 4.2). Pens in which calves were drinking milk with TBC \( \geq 100,000 \) cfu/mL had significantly higher within-pen prevalence of CD compared with pens in which calves drank milk with TBC \( <100,000 \) cfu/mL, but only during the summer visits [odds ratio (OR) = 3.3; 95% CI: 1.3 to 8.5; \( P = 0.01 \)]. We did not find any association between bacteria counts and AMF cleaning practices, but significant associations between frequency of AMF cleaning and within-pen prevalence of CD were found (Table 4.4, Model 4). Running the automatic cleaning of the AMF 3 times/day was associated with a reduced prevalence of CD compared with only running it once or twice. The frequency of cleaning hoses and replacing teats were detected as confounders, and therefore retained in the final model.

Regarding pen management and calf barn features, as the age of cattle sharing air with the calves in the group pens with the AMF increased, the prevalence of CD also increased. Furthermore, we detected a negative association between the frequency of adding bedding and the prevalence of CD (Table 4.4, Model 5). The frequency of removing all bedding was detected as confounder and therefore retained in the final model.

### 4.4.4 Factors Associated with Within-Pen Prevalence of Bovine Respiratory Disease

The final models describing factors associated with BRD at the pen-level are summarized in Table 4.5. Regarding calving and newborn management (Model 2), we found an association between the use of calving pens for additional purposes and increased within-pen prevalence of BRD (the number of days that calves were fed colostrum confounded this
relationship). Pens where calves had access to whole milk instead of milk replacer and pens where calves were drinking milk with at least 13% TS compared with those <10% TS had a significantly lower prevalence of BRD (Model 3).

Regarding pen management and calf barn features (Table 4.5, Model 4), pens with a mean age of introduction to the group pen < 8 days were associated with a reduced within-pen prevalence of BRD compared with pens with a mean age of introduction between 8 to 13 days, or >13 days. In addition, as the depth of the wet bedding pack increased, so did the prevalence of BRD at the pen level. Similar to the findings for the prevalence of CD, sharing air with older animals had a positive association with within-pen prevalence of BRD. Dry matter of the top layer of bedding was detected as confounder and therefore retained in the final model.

We did not find any association between within-pen prevalence of BRD and any factor regarding milk allowance (e.g., start and peak milk allowance, and latency to reach that peak) or AMF cleaning practices, including bacteria counts in milk.

4.5 DISCUSSION

This study is one of the first to provide information on associations between management practices and calf health at the pen level in a sample of farms using AMF to feed milk to group-housed calves. Multiple factors were found to be associated with either the prevalence of CD or BRD. In particular, quality of bedding and milk fed to calves and air shared with older cattle were found to be key factors because they were observed to be associated with both CD and BRD. These results highlight management practices that could be improved to successfully use group housing for calves using AMF. Our findings can help inform improvements in management practices in these systems, and guide decision-making of future adopters of AMF and group housing systems.

Overall, during the study period, 23 and 17% of the 1,488 calves across the 17 farms had CD and BRD, respectively. Previous research comparing manually fed calves housed individually and AMF-fed calves housed in groups found that group housing with
AMF is detrimental to calf health, especially because of an increased risk of BRD (Svensson et al., 2003). However, calf-level prevalence values found in our study are similar to previously reported incidence risk estimates from dairy farms managing calves in individual pens in southwestern Ontario and Minnesota (CD: 20 and 23%; BRD: 15 and 22%; Waltner-Toews et al., 1986; Windey et al., 2014, respectively). On the other hand, comparing exclusively with research done on farms using AMF, the calf-level prevalence of CD (23%) and BRD (17%) reported in the present study were higher than the calf-level incidence risk of CD and BRD reported by Svensson et al. (2003; 9 and 14%, respectively) on Swedish farms. These differences could be related to dissimilarities in management and populations evaluated, as well as geographical differences; additionally, Svensson et al. (2003) were aware of the low incidences found and noted that this might have been related to low animal density and small farm size in Sweden (36 cows per herd at that time).

When looking at the median within-herd prevalence of CD and BRD (24 and 14%, respectively), we found similar results to the BRD prevalence in a North American study done on farms housing and feeding calves individually (Lago et al., 2006: herd-level prevalence of BRD = 14%). The median within-herd prevalence of CD in the present study was higher than the median within-herd incidence risk of 10% reported by Windey et al. (2014), although the ranges were similar (8 to 46% vs. 0 to 44%), indicating similar variability between farms. Differences from Windey et al. (2014) could be because theirs was an observational study conducted as part of a clinical vaccine trial and farms were a convenience sample; additionally, disease frequency was determined based on producer treatment records, which are known to have low sensitivity (Sivula et al., 1996).

At the pen level, our findings regarding median prevalence of CD (17%) are similar to results reported by Svensson and Liberg (2006) who, in a randomized controlled trial on 9 Swedish farms raising calves in groups with AMF, also found a median within-pen incidence risk of CD of 17%. Our prevalence of BRD at the pen level was lower than the incidence risk found by Svensson and Liberg (2006; 11 vs. 30%, respectively). This difference could be related to the use of small groups, which Svensson and Liberg (2006) found to be protective for BRD. In our study, the median group size was 10 calves (IQR: 8 to 13 calves), whereas in Svensson and Liberg (2006), 50% of their pens held 12 to 18 calves.
Our findings on disease frequency suggest that calf health on farms using group housing with AMF systems is not worse than that on farms housing calves individually. This assertion is also supported by the median within-herd incidence risk of mortality found in the present study (4%), which was similar to mortality risk reported on farms mainly housing calves individually in Ontario and Minnesota (3%; Windeyer et al., 2014) and on farms using group housing with AMF in Minnesota, northwest Iowa, and Wisconsin (4%; Jorgensen and Endres, 2016). Moreover, mortality in the present study (4%) was lower than that of a national United States report in which calves were mainly housed individually (8%; USDA, 2007), and lower than that reported in a recent meta-analysis (5 to 11%; Compton et al., 2017).

Reported disease frequency on farms is affected, among other factors, by the producer’s diagnostic skill and treatment rates. We found that the median herd-level incidence risk of being treated for CD (8%; obtained from producer records) was lower than the median herd-level prevalence of diarrhea (24%) found across the study period, but not for BRD, which was higher in producer records (37 vs. 14%). The difference found for CD could, first, be due to poor sensitivity of producers when identifying sick calves. For example, Sivula et al. (1996) found that the sensitivity of dairy producer diagnosis for enteritis was 58%, meaning that some calves needing attention were not treated. The difference could have also been related to producers only treating calves with severe diarrhea. In the case of BRD, despite the fact that sensitivity of producer diagnosis for BRD could be also low (56%; Sivula et al., 1996), in the present study, some producers tended to treat the whole pen when there were signs of a pneumonia outbreak, which could explain the higher incidence risk of treatment.

### 4.5.1 Common Factors Associated with Within-Pen Prevalence of Calf Diarrhea and Bovine Respiratory Disease

The use of calving pens for additional purposes was associated with increased within-pen prevalence of CD and BRD. Often, dairy farms have limited space to relocate and handle sick animals, leading to cows close to calving being housed with unhealthy cows (Hoe and Ruegg, 2006). Maternity or calving pens are the first place where calves can be infected with enteric and respiratory pathogens after birth (Maunsell and Donovan, 2008). For example,
Fossler et al. (2005) found that the use of maternity pens as a hospital area was associated with 2-times-increased odds of *Salmonella* shedding in calves. Interestingly, Cobbold et al. (2006) found that when a farm exclusively separated the maternity area from the hospital area (as an intervention measure to reduce *Salmonella* in the herd), the prevalence of *Salmonella* isolated from the exclusive maternity pen after intervention decreased from 33 to 4%. As Fossler et al. (2005) stated, implementing this practice could be a feasible change that producers could adopt to help reduce disease prevalence at the pen level where milk- fed calves are housed.

Calf pens located in barns where older cattle were present had a higher prevalence of CD and BRD compared with those that were isolated from older cattle. This increased disease prevalence could be because older animals were a source of infection for the younger calves, which are less able to cope with pathogens in their environment (Radostits et al., 2007). For example, Virtala et al. (1999) found that the probability of developing pneumonia was 2 times higher for calves housed in the presence of adult cows than not, and similarly, Gulliksen et al. (2009) found that sharing a room with cows during the first week of life increased the risk of respiratory infection in calves (vs. calves housed in separate rooms). Another explanation for our findings could be inadequate ventilation and high animal density, which could trigger an increase in pathogens and ambient stressors (i.e., ammonia) in the environment, affecting calf health (Lago et al., 2006). For example, Mohammed et al. (1999) found an association between the lack of a well-ventilated calf barn and increased risk of infection with *Cryptosporidium parvum*. Other negative effects of housing calves with older cattle have been described. For example, Place et al. (1998) found that housing calves in a cow barn had detrimental effects on ADG; housing calves with older cattle could have increased susceptibility to disease, which is known to directly cause a decrease in weight gain (Donovan et al., 1998). Finally, another hypothesis to explain the association between increased disease prevalence and housing calves with older cattle could be the potential risk of transmission of pathogens from adult pens to calf pens by fomites (e.g., feed buckets, dirty boots, coveralls), as has been reported in the case of transmission of *Cryptosporidium* spp. between calves (Nydam and Mohammed, 2005).

Quality of bedding was associated with both CD and BRD prevalence. Within-
prevalence of CD was lower in pens to which fresh bedding was added more frequently (every 2 to 3 days compared with every 7 to >10 days), whereas the depth of the wet bedding pack was positively associated with prevalence of BRD. Manure-saturated bedding is one of the primary sources of pathogens. McGuirk (2008) suggested that at least 7.6 cm (3 inches) of dry bedding should separate the calf from accumulated manure. For example, Mohammed et al. (1999) found that the risk of infection with Cryptosporidium parvum decreased when dirty bedding was removed and fresh bedding was added daily. Our findings suggest that adding fresh bedding on top without cleaning dirty spots would not be useful to reduce disease risk; dirty bedding should be removed frequently to prevent accumulation of waste and potential pneumonia pathogens from the bedding to be aerosolized (McGuirk, 2003).

We did not find any significant association between milk allowance factors and within-pen prevalence of disease. This supports previous research (Appleby et al., 2001; Bach et al., 2013) that evaluated the health of individually housed calves. The lack of significant associations regarding milk allowance and prevalence of disease in the present study might be real or could be because there was not enough difference in management of milk volumes for comparison. In 75% of the pens, peak milk allowance was at least 8 L/d (median: 10 L/d), and only one pen had a peak of 6 L/d, which was the lowest value.

4.5.2 Factors Associated with Within-Pen Prevalence of Calf Diarrhea

Pens on farms that routinely administered both vitamin E and selenium to calves at birth had a significantly lower prevalence of CD. This supports the findings of Waldner and Rosengren (2009), who in an observational study on beef cow-calf farms in Alberta and Saskatchewan, Canada, found that calves born on farms that administered vitamin E and selenium at birth had a significantly lower risk of being treated for any disease (OR = 0.5) or dying (OR = 0.1) compared with calves from herds not implementing this practice. It is known that supplementation with vitamin E (Hughes, 2002) and selenium (McKenzie et al., 2002) is associated with enhanced antibody production and increased resistance to pathogens. Therefore, the administration of vitamin E and selenium at birth could have a truly direct effect in reducing CD; however, it could also be a surrogate measure for other unmeasured variables related to farmers who might pay more attention to detail regarding calf care.
In the present study, the prevalence of CD was 6 percentage points lower when prophylactic antibiotics were added to the milk fed through the AMF than when there were no additives in the milk. The prevalence of CD was 7 percentage points lower when probiotics were added than when antibiotics were added, and was 13 percentage points lower than when there were no additives in the milk. The use of prophylactic antibiotics in milk is mainly to reduce pathogenic flora and has been associated with decreased morbidity in calves (Berge et al., 2005). However, this practice can also increase antibiotic resistance (Pereira et al., 2011). On the other hand, probiotics are known to reduce the incidence and duration of diarrhea in calves (Timmerman et al., 2005). Therefore, probiotics could be implemented to reduce the prevalence of CD in pens with AMF and to decrease the use of prophylactic antibiotics. However, this study assessed whether antibiotics or probiotics were used, without further detail; more research is needed to better understand the issue, including the type of probiotic, timing, dosage, and so on.

Feeding equipment is another important source of enteric pathogens. If not cleaned properly, equipment can contaminate the milk fed to calves (McGuirk, 2008). In the present study, we found that programming the automatic cleaning of the feeder to run 3 times/day was associated with lower prevalence of CD at the pen level compared with less frequent cleaning. Similarly, James et al. (2017) recommended scheduling the automatic cleaning 4 times/day and before the times that calves most frequently suckle (Odde et al., 1985) or go to the feeder (Borderas et al., 2009) (at sunrise: 0500 to 0600 h, from 1000 to 1300 h, and at sunset: 1700 to 2100 h) to lower bacteria counts in milk. However, little work is published regarding cleaning of AMF systems, and guidelines are needed for producers using or considering adopting this technology. We found that milk with a high content of bacteria was significantly associated with an increased prevalence of CD, but only during the summer visit. Jorgensen et al. (2017) found that calves drinking milk with TBC >100,000 cfu/mL had a higher risk of receiving an abnormal score for attitude, ear position, and eye secretion, and a higher risk of having fever; however, they did not find a seasonal visit interaction with bacterial counts in milk. We do not have a clear explanation for the seasonal visit effect found in the present study; however, we speculate that during summer, calves might have experienced heat stress, causing immune suppression and, thus, increased susceptibility to pathogens and lower performance. For example, Place et al. (1998) found that calves born in summer tended to have lower ADG.
4.5.3 Factors Associated with Within-Pen Prevalence of Bovine Respiratory Disease

We found that feeding whole milk instead of milk replacer was associated with a lower within-pen prevalence of BRD. This is similar to the findings of Godden et al. (2005), where calves fed pasteurized whole milk had 0.3 times lower risk of pneumonia compared with calves fed milk replacer. Godden et al. (2005) attributed the advantage of feeding whole milk to the higher nutrient and immune factor content compared with milk replacer. We found that a low TS percentage (< 10%) in milk (either whole milk or milk replacer) was associated with an increased within-pen prevalence of BRD compared with ≥ 13%. The percentage of TS in milk averages 12.5 to 13% (CDIC, 2017). Milk or milk replacer fed to calves should have similar content of solids; McGuirk (2015) specifically implied that nutritional concern increases when TS percentage is < 10%, and our findings support this.

Another finding of the present study was that a mean age of introduction to the group pen with the AMF (mean for the pen) < 8 days was associated with a reduced prevalence of BRD compared with a mean age >13 days old. In contrast, based on their findings, Svensson and Liberg (2006) recommended that age at introduction be at least 2 weeks to reduce the risk of BRD. Our hypothesis for this finding is that it might still be confounded by the daily milk allowance offered to calves during the period from birth to the day of introduction to the group with AMF, even though daily milk allowance before introduction was not a significant factor in the model. The majority of farms in this study fed restricted milk volumes before introduction to the AMF (median: 6 L/d), and the lack of variation in this variable (IQR: 5 to 8 L/d) might explain the lack of significance in the model. Following the stated hypothesis, we assumed that the longer it took for calves to be introduced to the group with AMF (which allowed calves to drink higher milk volumes), the longer calves would have been under a restricted milk diet, which is associated with persistent hunger, reduced nutrient intake, lower ADG (Thomas et al., 2001; Khan et al., 2011; Rosenberger et al., 2017), and higher risk for BRD relapse in individually housed calves (Bach et al., 2013). Therefore, we suggest that if introduction to the group is going to be delayed, calves should have access to high milk allowances immediately after colostrum feeding.
4.6 CONCLUSIONS

Identification of factors associated with within-pen prevalence of health problems of group-housed calves fed through AMF is an essential step toward improving management practices and calf performance in farms currently using AMF and in guiding decision-making of future adopters. Prevalence of CD and BRD on farms using group housing with AMF systems was similar to previously reported disease frequency on farms using individual housing and feeding to raise calves. Thus, calf health is more dependent on management than on a type of system per se. Having exclusive calving pens and isolating calves from older cattle (exclusive calf nurseries) were key factors associated with reduced prevalence of CD and BRD. Poor quality of milk fed to calves, in terms of low percentage of TS and high bacterial counts, was also found to be associated with increased prevalence of BRD and CD, respectively. Other management factors, such as the use of vitamin E and selenium and probiotics, maintaining clean and dry bedding, and daily cleaning of the feeder, as part of routine calf management practice were observed to be protective.

4.7 ACKNOWLEDGMENTS

This research was funded by Dairy Farmers of Canada (Ottawa, ON, Canada) as part of the Dairy Research Cluster 2 program. The first author also thanks the Administrative Department of Science, Technology and Innovation–Colciencias (Bogota, Cundinamarca, Colombia) for the PhD scholarship granted. The authors also thank the students who volunteered during data collection stages: Heidi Eccles, Mohamed Ibrahim, Amanda Armstrong, Allison Moorman, Sophia Marin, Danielle Fawcett, Melissa Speirs, Tanya Wilson (University of Guelph, Guelph, ON, Canada); Jose A. Bran (Universidade Federal de Santa Catarina, Florianópolis, Brazil); Ramiro Rearte (Universidad de La Plata, La Plata, Argentina); Rolnei R. Daros (University of British Columbia, Vancouver, BC, Canada); and Pauline Denis (Agro Campus Ouest, Rennes, France). Special thanks go to William Sears (statistical consultant, University of Guelph, Guelph, ON, Canada) for his patience and guidance with SAS; and to Matt Jorgensen (University of Minnesota, St. Paul, MN) for sharing his knowledge and experience with farms with automated milk feeders in the United States.
Midwest, and to the participating dairy producers, their families, and their staff for allowing us to go into their farms and for all their involvement, help, and time during the year the study lasted.
4.8 REFERENCES


Table 4.1. Calf health scoring system used to classify health status in calves housed in group pens and fed through automated milk feeders in 17 dairy farms in southern Ontario.

<table>
<thead>
<tr>
<th>Factors</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fecal score&lt;sup&gt;1&lt;/sup&gt;</td>
<td>Normal</td>
<td>Semi-formed, pasty</td>
<td>Loose but stay on top of bedding</td>
<td>Watery, sifts through bedding</td>
</tr>
<tr>
<td>Rectal temperature&lt;sup&gt;1&lt;/sup&gt;</td>
<td>37.5 to 38.2 °C</td>
<td>38.3 to 38.8 °C</td>
<td>38.9 to 39.4 °C</td>
<td>39.5 °C or above</td>
</tr>
<tr>
<td>Nasal discharge&lt;sup&gt;1&lt;/sup&gt;</td>
<td>Normal serous discharge</td>
<td>Small amount of unilateral cloudy discharge</td>
<td>Bilateral, cloudy or excessive mucus discharge</td>
<td>Copious bilateral mucopurulent discharge</td>
</tr>
<tr>
<td>Ocular discharge or ear position&lt;sup&gt;1&lt;/sup&gt;</td>
<td>No ocular discharge and normal (alert) ear position</td>
<td>Small amount of ocular discharge or ear flick/head shake</td>
<td>Moderate amount of bilateral discharge or slight unilateral ear drop</td>
<td>Heavy ocular discharge, severe head tilt, or bilateral ear drop</td>
</tr>
<tr>
<td>Cough&lt;sup&gt;1&lt;/sup&gt;</td>
<td>None</td>
<td>Induced – single cough</td>
<td>Induced and repeated, or occasional spontaneous coughs</td>
<td>Repeated spontaneous coughs</td>
</tr>
<tr>
<td>Body condition&lt;sup&gt;2,3&lt;/sup&gt;</td>
<td>Subcutaneous fat covering bony prominences</td>
<td>Not subcutaneous fat covering frame, emaciated appearance</td>
<td>Minimal serous exudates, palpable swelling, slight painful</td>
<td>Serous or purulent exudates, palpable swelling, painful</td>
</tr>
<tr>
<td>Navel&lt;sup&gt;2&lt;/sup&gt;</td>
<td>Dry, no exudates, no swelling</td>
<td>Minimal serous exudates, minimal swelling, no pain</td>
<td>Minimal serous exudates, palpable swelling, slight painful</td>
<td>Serous or purulent exudates, palpable swelling, painful</td>
</tr>
<tr>
<td>Attitude&lt;sup&gt;1&lt;/sup&gt;</td>
<td>Bright</td>
<td>Quiet</td>
<td>Depressed</td>
<td>Non-responsive or dead</td>
</tr>
</tbody>
</table>

<sup>1</sup>McGuirk, 2008; University of Wisconsin-Madison 2013a.
<sup>2</sup>Modified from Wilson et al., 2000.
<sup>3</sup>Palpating tail head, tuber coxae, spine, and ribs.
Table 4.2. Calf-level prevalence of diarrhea and respiratory disease from 17 dairy farms raising calves with automated milk feeders in southern Ontario for each of the 4 visits (one per season) to the farms.

<table>
<thead>
<tr>
<th>Seasonal visit</th>
<th>Calves, no.</th>
<th>Calf Diarrhea, %</th>
<th>Bovine respiratory Disease, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fall</td>
<td>366</td>
<td>23</td>
<td>15</td>
</tr>
<tr>
<td>Winter</td>
<td>343</td>
<td>27</td>
<td>16</td>
</tr>
<tr>
<td>Spring</td>
<td>364</td>
<td>25</td>
<td>15</td>
</tr>
<tr>
<td>Summer</td>
<td>415</td>
<td>16</td>
<td>19</td>
</tr>
<tr>
<td>Overall</td>
<td>1488</td>
<td>23</td>
<td>17</td>
</tr>
</tbody>
</table>
Table 4.3. Within herd- and within pen-level prevalence of calf diarrhea and respiratory disease by visit (seasonal) from 17 dairy farms raising calves in group housing with automated milk feeders in southern Ontario.

<table>
<thead>
<tr>
<th>Prevalence by visit</th>
<th>Calf diarrhea, %</th>
<th>Bovine respiratory disease, %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>Median</td>
</tr>
<tr>
<td>Within-herd prevalence</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fall</td>
<td>17</td>
<td>22</td>
</tr>
<tr>
<td>Winter</td>
<td>17</td>
<td>31</td>
</tr>
<tr>
<td>Spring</td>
<td>17</td>
<td>25</td>
</tr>
<tr>
<td>Summer</td>
<td>17</td>
<td>17</td>
</tr>
<tr>
<td>Within-pen prevalence</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fall</td>
<td>34</td>
<td>18</td>
</tr>
<tr>
<td>Winter</td>
<td>35</td>
<td>20</td>
</tr>
<tr>
<td>Spring</td>
<td>33</td>
<td>22</td>
</tr>
<tr>
<td>Summer</td>
<td>35</td>
<td>11</td>
</tr>
</tbody>
</table>

\(^1\)Interquartile range.
Table 4.4. Final generalized linear regression models of groups of factors associated with within-pen prevalence of calf diarrhea on farms (n = 17) raising calves in group pens with automated milk feeders in southern Ontario visited 4 times, seasonally, over 1 year period, and the least squares means of the adjusted prevalence (AP).

<table>
<thead>
<tr>
<th>Model and factors</th>
<th>ICC²</th>
<th>Coefficient</th>
<th>SE¹</th>
<th>df²</th>
<th>OR³</th>
<th>95% CI⁶</th>
<th>P-value</th>
<th>AP % (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Model 1.</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Seasonal visit</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fall</td>
<td>0.55</td>
<td>0.24</td>
<td>115</td>
<td>1.73</td>
<td>1.07</td>
<td>2.81</td>
<td>0.02</td>
<td>24 (17 – 33)</td>
</tr>
<tr>
<td>Winter</td>
<td>0.73</td>
<td>0.23</td>
<td>115</td>
<td>2.07</td>
<td>1.31</td>
<td>3.27</td>
<td>0.002</td>
<td>28 (20 – 37)</td>
</tr>
<tr>
<td>Spring</td>
<td>0.59</td>
<td>0.23</td>
<td>115</td>
<td>1.80</td>
<td>1.14</td>
<td>2.84</td>
<td>0.01</td>
<td>25 (18 – 34)</td>
</tr>
<tr>
<td>Summarer</td>
<td>Referent</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pen type⁷</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All ages pen</td>
<td>1.17</td>
<td>0.36</td>
<td>115</td>
<td>3.24</td>
<td>1.59</td>
<td>6.61</td>
<td>0.001</td>
<td>28 (18 – 41)</td>
</tr>
<tr>
<td>Young calf pen</td>
<td>1.51</td>
<td>0.22</td>
<td>115</td>
<td>4.55</td>
<td>2.95</td>
<td>7.01</td>
<td>&lt; 0.001</td>
<td>35 (27 – 45)</td>
</tr>
<tr>
<td>Older calf pen</td>
<td>Referent</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intercept</td>
<td>-2.57</td>
<td>0.28</td>
<td>16</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td><strong>Model 2. Newborn management⁸</strong></td>
<td>0.08</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exclusive calving pen⁹</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No</td>
<td>0.61</td>
<td>0.29</td>
<td>115</td>
<td>1.85</td>
<td>1.03</td>
<td>3.33</td>
<td>0.04</td>
<td>29 (20 – 41)</td>
</tr>
<tr>
<td>Yes</td>
<td>Referent</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>18 (14 – 23)</td>
</tr>
<tr>
<td>Vitamin E &amp; Selenium¹⁰</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No</td>
<td>0.57</td>
<td>0.28</td>
<td>115</td>
<td>1.77</td>
<td>1.01</td>
<td>3.10</td>
<td>0.04</td>
<td>28 (23 – 36)</td>
</tr>
<tr>
<td>Yes</td>
<td>Referent</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>19 (12 – 27)</td>
</tr>
<tr>
<td>Intercept</td>
<td>-1.31</td>
<td>0.34</td>
<td>14</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td><strong>Model 3. Milk feeding plan⁸</strong></td>
<td>0.09</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Milk additive</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>None</td>
<td>0.80</td>
<td>0.37</td>
<td>115</td>
<td>2.24</td>
<td>1.07</td>
<td>4.68</td>
<td>0.03</td>
<td>27 (21 – 35)</td>
</tr>
<tr>
<td>Antibiotic</td>
<td>0.45</td>
<td>0.46</td>
<td>115</td>
<td>1.56</td>
<td>0.63</td>
<td>3.90</td>
<td>0.33</td>
<td>21 (12 – 33)</td>
</tr>
<tr>
<td>Probiotic</td>
<td>Referent</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>14 (8 – 24)</td>
</tr>
<tr>
<td>Intercept</td>
<td>-1.21</td>
<td>0.38</td>
<td>14</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td><strong>Model 4. AMF cleaning practices⁸</strong></td>
<td>0.08</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Automatic cleaning, no./d</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Once</td>
<td>1.31</td>
<td>0.55</td>
<td>115</td>
<td>3.70</td>
<td>1.24</td>
<td>11.06</td>
<td>0.01</td>
<td>33 (19 – 52)</td>
</tr>
<tr>
<td>Twice</td>
<td>0.95</td>
<td>0.43</td>
<td>115</td>
<td>2.56</td>
<td>1.10</td>
<td>6.12</td>
<td>0.02</td>
<td>26 (18 – 37)</td>
</tr>
<tr>
<td>3 times</td>
<td>Referent</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>12 (7 – 21)</td>
</tr>
<tr>
<td>Frequency of cleaning hoses¹¹</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Every day</td>
<td>-0.59</td>
<td>0.57</td>
<td>115</td>
<td>0.55</td>
<td>0.17</td>
<td>1.71</td>
<td>0.30</td>
<td></td>
</tr>
<tr>
<td>1 to 2 times/week</td>
<td>0.33</td>
<td>0.48</td>
<td>115</td>
<td>1.40</td>
<td>0.54</td>
<td>3.65</td>
<td>0.48</td>
<td></td>
</tr>
<tr>
<td>Once/month or less often</td>
<td>-0.04</td>
<td>0.54</td>
<td>115</td>
<td>0.91</td>
<td>0.32</td>
<td>2.81</td>
<td>0.92</td>
<td></td>
</tr>
<tr>
<td>Never</td>
<td>Referent</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frequency of replacing teats¹¹</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Every 2 months or less often</td>
<td>-0.46</td>
<td>0.44</td>
<td>115</td>
<td>0.63</td>
<td>0.26</td>
<td>1.51</td>
<td>0.29</td>
<td></td>
</tr>
<tr>
<td>Every 4 to 6 weeks</td>
<td>0.57</td>
<td>0.41</td>
<td>115</td>
<td>1.78</td>
<td>0.78</td>
<td>4.05</td>
<td>0.16</td>
<td></td>
</tr>
<tr>
<td>At least every 3 weeks</td>
<td>Referent</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intercept</td>
<td>-1.35</td>
<td>0.69</td>
<td>9</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td><strong>Model 5. Pen dynamics and calf barn⁸</strong></td>
<td>0.04</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sharing air with</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Milk-fed calves only</td>
<td>-1.50</td>
<td>0.43</td>
<td>107</td>
<td>0.22</td>
<td>0.10</td>
<td>0.53</td>
<td>&lt; 0.001</td>
<td>13 (7 – 22)</td>
</tr>
<tr>
<td>Cattle up to 4 months old</td>
<td>-1.22</td>
<td>0.30</td>
<td>107</td>
<td>0.29</td>
<td>0.16</td>
<td>0.53</td>
<td>&lt; 0.001</td>
<td>17 (11 – 24)</td>
</tr>
<tr>
<td>Cattle up to 8 months old</td>
<td>-1.01</td>
<td>0.29</td>
<td>107</td>
<td>0.36</td>
<td>0.20</td>
<td>0.66</td>
<td>0.001</td>
<td>20 (13 – 29)</td>
</tr>
<tr>
<td>Cattle up to 9+ months old</td>
<td>Referent</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>40 (28 – 54)</td>
</tr>
<tr>
<td>Addition of bedding</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.01</td>
</tr>
</tbody>
</table>

141
<table>
<thead>
<tr>
<th>Frequency</th>
<th>Coefficient</th>
<th>SE</th>
<th>95% CI</th>
<th>Odds Ratio</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Every day</td>
<td>-0.87</td>
<td>0.48</td>
<td>107</td>
<td>0.42</td>
<td>1.09</td>
</tr>
<tr>
<td>Every 2 to 3 days</td>
<td>-0.85</td>
<td>0.29</td>
<td>107</td>
<td>0.34</td>
<td>0.76</td>
</tr>
<tr>
<td>Every 7 to &gt; 10 days</td>
<td>Referent</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Removal of bedding</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Every 10 to 20 days</td>
<td>-0.67</td>
<td>0.43</td>
<td>107</td>
<td>0.51</td>
<td>1.20</td>
</tr>
<tr>
<td>Every 45 to 60 days</td>
<td>-0.38</td>
<td>0.24</td>
<td>107</td>
<td>0.68</td>
<td>1.11</td>
</tr>
<tr>
<td>≥ Every 90 days</td>
<td>Referent</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intercept</td>
<td>0.68</td>
<td>0.40</td>
<td>9</td>
<td>---</td>
<td>---</td>
</tr>
</tbody>
</table>

a,b Means within a model within a factor with different superscripts differ \( P \leq 0.05 \).
1 32 to 35 pens were evaluated at each seasonal visit (137 observations in total).
2 Intra-class correlation coefficient for each model.
3 Standard error.
4 Degrees of freedom.
5 Odds ratio.
6 Confidence interval for the odds ratio, lower (LCL) and upper (UCL) confidence limits.
7 Young calf pen = pen housing calves up to 30 d old approx.; older calf pen = pen housing calves above 30 d old approx., all ages pen = pen housing all calves.
8 Adjusted for seasonal visit and pen type.
9 The use of calving pens exclusively for calving (not for sick cows).
10 Administration of both vitamin E and selenium at birth.
11 Retained in the final model because this variable acted as a confounder.
12 Frequency of removing all bedding from the pen to add fresh bedding.
Table 4.5. Final generalized linear regression models of group of factors associated with within-pen prevalence of bovine respiratory disease on farms (n = 17) raising calves in group pens\(^1\) with automated milk feeders in southern Ontario visited 4 times, seasonally, over 1 year period, and the least squares means of the adjusted prevalence (AP).

<table>
<thead>
<tr>
<th>Model and factors</th>
<th>ICC(^2)</th>
<th>Coefficient</th>
<th>SE(^3)</th>
<th>df(^4)</th>
<th>OR(^5)</th>
<th>95% CI(^6)</th>
<th>P-value</th>
<th>AP % (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Model 1.</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Seasonal visit</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fall</td>
<td>-0.37</td>
<td>0.21</td>
<td>117</td>
<td>0.69</td>
<td>0.44</td>
<td>1.06</td>
<td>0.09</td>
<td>13(^a) (8 – 19)</td>
</tr>
<tr>
<td>Winter</td>
<td>-0.25</td>
<td>0.22</td>
<td>117</td>
<td>0.77</td>
<td>0.49</td>
<td>1.21</td>
<td>0.26</td>
<td>14(^b) (9 – 21)</td>
</tr>
<tr>
<td>Spring</td>
<td>-0.36</td>
<td>0.22</td>
<td>117</td>
<td>0.70</td>
<td>0.45</td>
<td>1.08</td>
<td>0.11</td>
<td>13(^a) (8 – 19)</td>
</tr>
<tr>
<td>Summer</td>
<td>Referent</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>17(^b) (12 – 24)</td>
</tr>
<tr>
<td>Intercept</td>
<td>-1.55</td>
<td>0.21</td>
<td>16</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td><strong>Model 2. Newborn management(^7)</strong></td>
<td>0.18</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exclusive calving pen(^8)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.01</td>
</tr>
<tr>
<td>No</td>
<td>0.96</td>
<td>0.38</td>
<td>117</td>
<td>2.61</td>
<td>1.21</td>
<td>5.58</td>
<td>25(^a) (15 – 39)</td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>Referent</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>11(^b) (8 – 16)</td>
</tr>
<tr>
<td>No. of colostrum feeding days(^9)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.20</td>
</tr>
<tr>
<td>1</td>
<td>0.23</td>
<td>0.43</td>
<td>117</td>
<td>1.26</td>
<td>0.53</td>
<td>3.00</td>
<td>0.59</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0.87</td>
<td>0.51</td>
<td>117</td>
<td>2.40</td>
<td>0.86</td>
<td>6.67</td>
<td>0.09</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Referent</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intercept</td>
<td>-2.41</td>
<td>0.42</td>
<td>13</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td><strong>Model 3. Milk feeding plan(^7)</strong></td>
<td>0.22</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.01</td>
</tr>
<tr>
<td>Milk type</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Whole milk(^10)</td>
<td>-1.22</td>
<td>0.47</td>
<td>114</td>
<td>0.29</td>
<td>0.11</td>
<td>0.75</td>
<td>6(^a) (3 – 13)</td>
<td></td>
</tr>
<tr>
<td>Milk replacer</td>
<td>Referent</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>17(^b) (13 – 23)</td>
</tr>
<tr>
<td>Total solids, %</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.04</td>
</tr>
<tr>
<td>&lt; 10</td>
<td>0.73</td>
<td>0.28</td>
<td>114</td>
<td>2.07</td>
<td>1.17</td>
<td>3.66</td>
<td>0.01</td>
<td>14(^b) (8 – 24)</td>
</tr>
<tr>
<td>10 to 12.9</td>
<td>0.28</td>
<td>0.19</td>
<td>114</td>
<td>1.32</td>
<td>0.89</td>
<td>1.95</td>
<td>0.17</td>
<td>10(^b) (6 – 16)</td>
</tr>
<tr>
<td>≥ 13</td>
<td>Referent</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>8(^b) (4 – 13)</td>
</tr>
<tr>
<td>Intercept</td>
<td>-1.87</td>
<td>0.24</td>
<td>16</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td><strong>Model 4. Pen dynamics and calf barn(^7)</strong></td>
<td>&lt; 0.01</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.001</td>
</tr>
<tr>
<td>Sharing air with</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Milk-fed calves only</td>
<td>-1.06</td>
<td>0.55</td>
<td>89</td>
<td>0.34</td>
<td>0.11</td>
<td>1.04</td>
<td>0.05</td>
<td>9(^a) (4 – 19)</td>
</tr>
<tr>
<td>Cattle up to 4 months old</td>
<td>-0.81</td>
<td>0.41</td>
<td>89</td>
<td>0.44</td>
<td>0.19</td>
<td>1.01</td>
<td>0.05</td>
<td>11(^b) (8 – 16)</td>
</tr>
<tr>
<td>Cattle up to 8 months old</td>
<td>0.10</td>
<td>0.38</td>
<td>89</td>
<td>1.11</td>
<td>0.51</td>
<td>2.38</td>
<td>0.79</td>
<td>23(^b) (18 – 31)</td>
</tr>
<tr>
<td>Cattle up to 9+ months old</td>
<td>Referent</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>22(^b) (18 – 37)</td>
</tr>
<tr>
<td>Median age of introduction</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.01</td>
</tr>
<tr>
<td>&lt; 8 days old</td>
<td>-0.86</td>
<td>0.35</td>
<td>89</td>
<td>0.42</td>
<td>0.21</td>
<td>0.85</td>
<td>0.01</td>
<td>10(^b) (6 – 13)</td>
</tr>
<tr>
<td>8 to 13 days old</td>
<td>-0.07</td>
<td>0.33</td>
<td>89</td>
<td>0.92</td>
<td>0.48</td>
<td>1.79</td>
<td>0.82</td>
<td>19(^b) (12 – 27)</td>
</tr>
<tr>
<td>&gt; 13 days old</td>
<td>Referent</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>20(^b) (11 – 32)</td>
</tr>
<tr>
<td>Wet bedding pack, cm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.04</td>
</tr>
<tr>
<td>&gt; 16</td>
<td>0.78</td>
<td>0.39</td>
<td>89</td>
<td>2.18</td>
<td>1.00</td>
<td>4.78</td>
<td>0.05</td>
<td>19(^b) (12 – 27)</td>
</tr>
<tr>
<td>6 to 16</td>
<td>0.87</td>
<td>0.34</td>
<td>89</td>
<td>2.39</td>
<td>1.21</td>
<td>4.74</td>
<td>0.01</td>
<td>20(^b) (14 – 27)</td>
</tr>
<tr>
<td>≤ 5</td>
<td>Referent</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>9(^b) (5 – 17)</td>
</tr>
<tr>
<td>Space of bedding area per calf, m(^2)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.03</td>
</tr>
<tr>
<td>Dry matter of top bedding(^9), %</td>
<td>-0.01</td>
<td>0.008</td>
<td>89</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Intercept</td>
<td>-1.89</td>
<td>0.96</td>
<td>13</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
</tbody>
</table>

---

\(^{a,b}\) Means within a model within a factor with different superscripts differ (P ≤ 0.05).

\(^{1}\)32 to 35 pens were evaluated at each seasonal visit (137 observations in total).

\(^{2}\)Intra-class correlation coefficient for each model.

\(^{3}\)Standard error.

\(^{4}\)Degrees of freedom.

\(^{5}\)Odds ratio.

143
Confidence interval for the odds ratio, lower (LCL) and upper (UCL) confidence limits.

Adjusted for seasonal visit.

The use of calving pens exclusively for calving (not for sick cows).

Retained in the final model because this variable acted as a confounder.

Non-pasteurized.
Figure 4.1. Scatterplot of within pen prevalence of bovine respiratory disease (BRD) and calf diarrhea (CD) on farms (n = 17) raising calves in group pens with automated milk feeders in southern Ontario visited 4 times, seasonally, over 1 year period.

\[ y = 0.0811x + 13.081 \]

\[ R^2 = 0.0085 \]
Figure 4.2. Association between within-pen prevalence of calf diarrhea (error bars are 95% CI) and the interaction between seasonal visit and total bacteria counts (TBC) in milk samples taken from the mixing jar of automated milk feeders used to feed calves housed in groups on 17 dairy farms in southern Ontario. The TBC were considered acceptable or not acceptable if counts were < 100,000 cfu/mL or ≥ 100,000 cfu/mL, respectively. *Significant difference: P < 0.05.
CHAPTER 5

As submitted for publication

IMPACT OF AGE OF INTRODUCTION TO THE GROUP PEN WITH AN AUTOMATED MILK FEEDER ON CALF LEARNING AND PERFORMANCE, AND LABOUR REQUIREMENTS

5.1 ABSTRACT

Group housing of dairy calves with automated milk feeders (AMF) is increasingly being used, but the effect of introducing calves to the AMF at a very young age (< 24 hours) on calf performance, health and welfare, and farm personnel labour requirements are unknown. The objective of this controlled trial was to investigate whether early (< 24 hours after birth) introduction of calves affects the time to learn how to drink from the AMF, labour requirements for feeding milk during the learning phase, and average daily gain (ADG) during the milk-feeding period, compared with calves conventionally introduced at 5 days of age. Sixty Holstein calves (heifers and bulls) were assigned at birth to either early introduction (< 24 hours after birth) or conventional introduction (at 5 days of age) to the group pen with AMF. After birth, calves were housed in individual pens and then introduced, based on assigned treatment, to the group pen with an AMF and a “continuous flow” stocking approach. Calves were fed milk replacer and gradually weaned from day 47 to day 60 of age. Calves had access to starter from 5 days of age, and to water and straw right after colostrum feeding. We measured the time between first training to use the AMF and first unassisted visit to the AMF with milk intake, the number of assisted visits until the calf was independent in its use of the AMF (successful learning), and the total time required for milk feeding (labour) until successful learning. Calves were weighed at birth, 30, 46 and 61 days of age, and were monitored daily for signs of disease. Daily milk and starter intake per calf were automatically recorded. Early-introduced calves took longer to successfully learn to use the AMF (64.9 h [95% CI: 59.1 to 77.9] vs. 31.4 h [95% CI: 22.8 to 47.9]) and tended to require more assisted visits (7.8 visits [95% CI: 6.2 to 9.7] vs. 5.9 visits [95% CI: 4.8 to 7.5]) compared with conventionally-introduced calves. Labour for milk feeding was greater for conventionally-introduced calves relative to early-introduced calves (145.6 min [95% CI: 125.1 to 169.4] vs. 39.9 min [95% CI: 33.5 to 47.6]). Disease risk was similar between treatments but the risk of severe vs. mild diarrhea was greater for early- compared with
conventionally-introduced calves (odds ratio = 4.7; 95% CI 1.01 to 31.1). Early-introduced calves consumed less milk during the first days of life compared with conventionally-introduced calves (day 2: 5.5 vs. 6.4 L; day 3: 7.0 vs. 8.2 L; day 4: 7.0 vs. 8.4 L; day 6: 6.4 vs. 7.9 L; day 7: 6.0 vs. 7.0 L, respectively), with no differences after 8 days. There was no effect of treatment on ADG. Although introducing calves < 24 hours after birth required more assistance to use the AMF, total farm labour for milk feeding tasks was less for early-introduced calves. Thus, with early introduction to AMF, a trade-off may exist between reduced labour per calf, with no effect on weight gain, but potentially a higher risk of severe diarrhea (vs. mild).

5.2 INTRODUCTION

Labour requirements, calf health and performance, and the adaptation of calves to an automated milk feeder (AMF) are factors influencing the decisions around the age of introduction of calves to the group pen with an AMF. Jensen (2007) found that calves that were introduced at 6 days old had 2.3 times greater odds of needing guidance to drink from the AMF than calves introduced at 14 days of age, and spent significantly less time at the feeder and ingested less milk. Fujiwara et al. (2014) found that the more guidance given to a calf to drink from an AMF, the longer it took for that calf to drink independently from the feeder. Fujiwara et al. (2014) also showed heavier calves at introduction to the AMF (at 6 days of age) had a shorter latency to first voluntary drink. Svensson and Liberg (2006) found that the odds of respiratory disease increased as age of introduction to the group pen decreased.

Although research (Svensson and Liberg, 2006; Jensen, 2007) suggests that later introduction (i.e., > 2 weeks of age) to the group pen may be preferable in terms of calf health and farm labour, recent data indicate that on commercial dairy farms in North America, the median age of introduction to group pens with AMF is 5 days, and ranges from < 1 to 14 days (Jorgensen et al., 2017; Medrano-Galarza et al., 2017a); mean group size was 17 calves and ranged from 6 to 60). This may stem from producers seeking to minimize the labour required for manually feeding milk to calves when using AMF. In addition, there may be some longer-term advantages of providing calves with social contact at an earlier age (Duve and Jensen, 2001). Currently, there is insufficient research on the implications of introducing very young calves to a
group pen with AMF. Therefore, our objectives were to evaluate the effects of early introduction (within 24 hours after birth) to a group pen on calf latency to learn to use the AMF, number of assisted visits until successful learning, average daily gain (ADG), and farm personnel labour requirements regarding milk feeding chores, and compared this early introduction with the average age of introduction in the North America industry. It was hypothesized that calves introduced at an early age would take longer to learn to drink from the AMF and need more guidance (i.e., more assisted visits), but would require less overall labour for feeding milk compared with calves introduced at the conventional age. Additionally, it was hypothesized that age of introduction would not have an effect on ADG.

5.3 MATERIALS AND METHODS

This controlled trial was carried out at the University of Guelph Livestock Research and Innovation Centre – Elora Dairy Facility (Elora, ON, Canada) from January 12 (birth date of the first calf enrolled in the study) to July 23, 2017 (one day after last calf enrolled in the study was weaned). Procedures were reviewed and approved by the University of Guelph Animal Care Committee (AUP # 3477).

5.3.1 Animals and Treatments

All calves (bulls and heifers) that were born at the research centre were eligible for the study unless involved in other ongoing trials, which resulted in 11 calves being excluded from this study. A total of 60 calves were enrolled in this study (30 per treatment group). This sample size would allow for detection of a 24 h (SD = 32) difference in the latency to learn to use the AMF, a difference of 3 assisted visits (SD = 4), a 22 min (SD = 30) difference in labour regarding milk feeding tasks, and a 0.15 kg/d (SD = 0.2) difference in ADG between treatment groups, with 95% confidence and 80% power (WINPEPI version 11.62; Abramson, 2016).

Calves were randomly allocated at birth, based on a randomization table (created using random number generator in Excel, Microsoft Corp., Redmond, WA), to one of the two treatments: early introduction (< 24 hours after birth) or conventional introduction (at 5 days of age) to the group pen with AMF. As calves were born, they were enrolled in the study after their
second colostrum feeding. Calves from both treatments were co-mingled in each pen. Calves were offered 3 L of their dam’s colostrum within 2 hours of birth (or first thing in the morning if the calf was born between 2100 and 0500 h), and another 3 L was provided 6 to 12 hours after the first feeding. The total volume of colostrum consumed varied between calves, mainly dependent on calf size and vigor. Colostrum was always fed through a teat-bottle, unless the calf totally refused to suck, in which case an esophageal tube was used. Calves were allowed to be dried by the dam (first colostrum feeding was usually done in the maternity pen) and separation took place within 2 to 3 hours after birth (except for calves born overnight, where separation occurred between 0500 and 0700 h). All calves were placed in an individual pen (described below) where navel disinfection was performed, and vitamin E and selenium (Dystosel, 1.5 mL/45 kg of body weight s.c.; Zoetis, Kirkland, QC, Canada) and the second colostrum feeding were administered. From January to the end of March, all calves wore a jacket (Calf Jacket, SPECTRUM Nasco, Newmarket, ON, Canada) for approximately the first 3 weeks of life.

5.3.2 Housing and Management of Pens

Similar to the most common set-up of AMF on commercial dairy farms in Canada (Medrano-Galarza et al., 2017a), 1 AMF was used to deliver milk replacer into 2 feeding stations, each located in a separate pen (group pen 1 and 2; Figure 5.1). The AMF (DeLaval calf feeder CF1000+, DeLaval Canada, Peterborough, ON, Canada) had an extra pump to allow for the simultaneous feeding of calves in both pens. Although 1 AMF supplied milk to 2 pens, these 2 pens were located in 2 separate nursery rooms (room A and B; Figure 5.1), which were isolated from the cow barn. There were a total of 2 AMF machines at the research centre; therefore, there was a total of 4 nursery rooms (Figure 5.1). The nursery rooms were artificially ventilated through an automatic positive-pressure forced-air system. The air coming into the calf nursery rooms came from the attic and from the outdoors.

A “continuous flow” stocking approach was used (Figure 5.1). Each nursery room was built to house up to 15 calves. Room A (containing group pen 1 and 5 individual pens assembled within the group pen as needed, Figure 5.1) was used as the introductory room, where newborns were placed in an individual pen (2.4 m² lying surface), and then introduced to the group pen 1 based on age, which was determined by the randomly assigned treatment. Calves in individual
pens had visual, auditory, and limited physical contact with calves in the group pen and the neighboring individual pens. Group pen 1 housed up to 10 calves (2.8 m$^2$ lying surface per calf) when the 5 individual pens were assembled.

Calves were moved as they aged to group pen 2 (room B) at a mean (SD) age of 26 ± 8 days; age at movement depended on group size in each pen. Room B was identical to room A (Figure 5.1), but individual pens were permanently disassembled, which allowed group housing of up to 15 calves (2.8 m$^2$ lying surface per calf). Calves stayed in group pen 2 for at least 1 day and up to 1 week after weaning. Heifer calves were then moved to the heifer barn (in the same facility), and bull calves were transported off-site and sold.

The bedding material used in all pens (individual and group) was wood shavings on top of cement flooring. Every day, dirty bedding was removed with a shovel and fresh bedding was added. Once a week, the entire bedding material was removed and replaced. The floor of the milk and grain feeder stalls was washed with water and scrubbed daily.

5.3.3 Milk and Solid Feeding

5.3.3.1 Milk

After the second colostrum feeding, all calves were fed milk replacer at a concentration of 150 g/L (26% crude protein and 18% crude fat; Excel Pro-Gro, Grober Nutrition, Cambridge, ON, Canada) throughout the entire milk-feeding period. Daily milk allowance was the same in both treatment groups. The feeding method was different between treatment groups for the first 4 days after colostrum feeding. Calves assigned to the conventional introduction treatment were initially bottle-fed 3 L of milk replacer 3 times/d (at 0630, 1300, and 1800 h) when they were individually housed (start stage), then they were introduced to the group pen with the AMF. Calves assigned to the early introduction treatment were fed through the AMF during the entire milk feeding period; these calves were allowed to drink 9 L/d during the first 4 days in the feeder (maximum of 3 L per 2 h) (start stage). For the next 27 days, starting at 5 days old (day 5 on the feeder for early-introduced calves, and day 1 for conventionally-introduced calves), calves were allowed to drink milk replacer ad libitum from the AMF (maximum of 3 L per 2 h, thus a maximum of 36 L/d) (ad libitum stage). Then, at 32 days of age, milk allowance was reduced.
over 5 days from 12 L/d to 9 L/d (step down stage), and remained at 9 L/d for the following 10 days (between 37 and 46 days of age, plateau stage). Weaning was done gradually over a 14-day period from 9 L/d to 2 L/d, resulting in calves being completely weaned at 61 day of age. The AMF were programmed to prepare portions of milk of 0.5 L at a time.

The AMF were automatically cleaned 3 times/d (mixer cleaning) and a full manual circuit cleaning was performed daily. Automatic calibration for milk replacer was performed 2 times/d, and manual calibration was done at least once a week.

5.3.3.2 Solid feed

Calves had access to pelleted calf starter (22.2% crude protein and 2.4% crude fat on a DM basis; Floradale Feed Mill Limited, Floradale, ON, Canada) from 5 days of age. The starter was offered through an automated grain feeder (Figure 5.1; DeLaval concentrate station, DeLaval Canada, Peterborough, ON, Canada) and calves could consume up to 3 kg/d. Water and chopped wheat straw (2.5 cm length) were offered ad libitum in buckets to both treatments from day 1.

5.3.4 Introduction to the Group Pen and Training of Calves to Use the Automated Milk Feeder

Early-introduced calves were moved from the individual pen to the group pen right after the second colostrum feeding and conventionally-introduced calves were moved into the group pen right after their last bottle feeding at 5 days of age. Once calves were introduced to the group, they were left to explore the pen (allowing familiarization with the new environment and pen mates), and were first trained to use the AMF at the next bottle-feeding time (at a mean ± SD of 8.7 ± 3.5 h after introduction), unless the calf had drunk on its own without needing training. It was possible to determine whether a calf had visited the AMF on its own based on the information provided by the AMF. The AMF displays individual calf information, including milk and starter consumption, and time of the last visit of each calf to each feeder.

The training period for each calf started with the first training session and ended when the calf was able to use the AMF independently. A calf was classified as using the AMF independently (successful learning) if it visited the feeder on its own, consumed at least 1 L of
milk replacer (which implied that the calf had to stay in the stall and learn to wait for a new portion to be prepared), and did not require further assistance (defined below).

During the first training session, the calf was called or gently pushed into the AMF stall. A rubber strap was put on the back of the stall to avoid the calf stepping out of the stall; then the person guided the calf’s mouth towards the teat using their hands encouraging the calf to suck, and pushed the training button to pump milk into the teat. If the calf started sucking successfully, the person waited until the calf drank at least 2 L of milk replacer, then the strap was removed, the person left, and the calf could finish the meal on its own (up to 3 L). The training session was ended after 10 min if a calf refused to suck or when a calf stopped drinking and stood still not willing to drink more. In both cases, the rubber strap was removed and calf was let out of the stall. Once the first training was done, the person training the calves came at every scheduled bottle feeding time (0630, 1300, and 1800 h) to check if any first-trained calf had successfully learned to use the feeder. If the calf had not drunk on its own since the last assisted visit, the calf was guided to the feeder to drink at every scheduled bottle feeding time until successful learning was achieved. Calves that refused to drink from the AMF and had not consumed milk for 12 hours during the training period were fed 2 L of milk manually. All calves were trained by the same person (first author).

5.3.5 Data Collection

Birth weight and body weights at 30, 46 (start of weaning), and 61 days of age were measured using an individual calf scale (1-2-3 animal scale, Bosch GmbH & Co. KG, Damme, Germany) and ADG was calculated for these 3 points in time. Birth weight was measured when calves were moved from the calving pen to the nursery room, after first colostrum feeding. A sample of blood from the jugular vein was taken once between 1 and 5 days of age to measure serum total protein (STP) using a digital refractometer (KS-0050; Kernco Instruments, El Paso, TX, USA).

To assess total labour for milk feeding, excluding colostrum feeding, until the calf was totally independent in its use of the AMF (successful learning), we recorded the time (in minutes) the trainer spent at each bottle feeding episode (for conventionally-introduced calves), which included the time spent preparing the bottle (serving 3 L of milk replacer into a bottle
using the “extra portion” command in the AMF handheld terminal) and manually cleaning the bottle, feeding the calf (i.e., holding the bottle for the calf for manual feeding or guiding the calf to the teat-bottle for re-training), and the time spent in each AMF training session (for both early- and conventionally-introduced calves). Additionally, the total number of assisted visits to the AMF that each calf needed until successful learning was recorded.

The total amount of time (in hours) between the beginning of first training session and the beginning of the first voluntary (unassisted) visit to the AMF with > 1 L milk intake (successful learning) was measured to obtain the latency to learn to use the feeder for each calf. At this point the calf was considered as independent and no longer requiring assistance for the following visits. Additionally, we recorded the time of the day each calf was introduced to the group pen and the time of the day when the first training session took place (categories: morning, noon, and evening based on the scheduled bottle feeding time they took place: 0630, 1300, and 1800 h, respectively). The total amount of time (in hours) between introduction to the group and the beginning of the first training, and the total amount of milk consumed by each calf during the first voluntary visit to the AMF were also recorded.

Health records were kept daily. Any episode of diarrhea, respiratory disease, navel infection, or other health problem (as described by Windeyer et al., 2014) was recorded, as well as any treatments, relapses, and age of occurrence. A calf was considered sick when it had diarrhea (loose or watery feces; score 2 or 3, respectively, using the fecal score chart developed by McGuirk, 2008) and lost its appetite (i.e., no interest whatsoever in drinking milk). Diarrhea cases were considered “mild” or “severe” based on duration of treatment and calf’s attitude. Depressed calves (not bright/alert) that received oral electrolytes for > 2 days (Svensson et al., 2003) or received intravenous rehydration therapy (described below) were categorized as having severe diarrhea. A calf was considered to have pneumonia when it had a fever (> 39.5 ºC) and increased respiratory rate, sound or effort when breathing.

All sick calves were treated following the instructions provided by the farm veterinarian. Treatment for diarrhea consisted of oral rehydration therapy (Calf-Lyte II – Vetoquinol N.-A. Inc., Lavaltrie, QC, Canada) twice a day on the day of the onset, and subsequently as needed (once or twice a day to ensure that the sick calf was ingesting at least 6 L
of fluids in a day) until milk consumption was back to 6 L/d minimum. If the calf did not drink the electrolytes from the bottle, these were administered using an esophageal tube. Meloxicam (Metacam 20 mg/mL solution, Boehringer Ingelhein, Burlington, ON, Canada) was also administered s.c. at the onset of diarrhea. Intravenous rehydration therapy (Electrolyte Infusion and Physiological Saline, Bimeda – MTC Animal Health, Inc., Cambridge, ON, Canada) was administered by the farm veterinarian when a calf refused to drink milk replacer or electrolytes voluntarily and dehydration was moderate to severe (calf depressed, sunken eyes, skin tenting 6+ sec). If a calf was not drinking milk replacer from the AMF (due to illness), milk was manually fed using bottles, alternating with oral electrolytes. If 24 hours passed after last voluntary milk intake, the calf was fed 2 L of milk replacer using an oesophageal tube. Antibiotic therapy was given to calves with diarrhea before 7 days of age (Borgal 24% – trimethoprim and sulfadoxine – daily for 3 d, Merck Animal Health, Kirkland, QC, Canada). Treatment for respiratory disease consisted of a single s.c. dose of meloxicam and antibiotic (Nuflor 30% – florfenicol, Merck Animal Health, Kirkland, QC, Canada, or Draxxin 10% – tulathromycin, Zoetis, Kirkland, QC, Canada).

Information regarding calving and colostrum feeding were collected from farm records. The former involved time of birth, which was dichotomized to birth during (from 0430 to 2100 h) or outside staff work hours, season of birth (winter, Jan 12 to Mar 21 or spring, Mar 22 to May 24, 2017), and the level of assistance provided during calving (unassisted, easy pull, hard pull, or caesarian section; births outside work hours were classified as unsupervised). Regarding colostrum feeding, we collected information on total volume fed (among the 2 feedings) and method of feeding for each feeding (bottle-fed vs. tube-fed). Furthermore, we extracted daily milk and starter intake for each calf from the farm computer through the computer program KalbManagerWIN (Förster-Technik GmbH, Engen, Germany).

5.3.6 Data Management and Analysis

All analyses were performed with SAS version 9.3 (SAS Institute Inc., Cary, NC, USA) using calf as the experimental unit. For the level of assistance during calving, easy pull, hard pull, and caesarean section were grouped into a single category (assisted) due to low numbers of observations, resulting in 3 levels of assistance during calving (assisted, unassisted, and
unsupervised). Similarly, for the time of the day when introduced to the group pen, morning and noon times were merged, leaving this variable as dichotomous (day vs. evening).

Number of assisted visits, the latency to learn to use the feeder (time interval between the first training session and the first voluntary (unassisted) visit to the AMF with > 1 L milk intake), farm labour for milk feeding tasks, and ADG at 30, 46, and 61 days of age were considered as the main dependent variables (outcomes). Daily milk and starter intake, and disease incidence were considered secondary outcomes. The main independent variable of interest for all analysis was treatment (age of introduction: early vs. conventional).

Wilcoxon two-sample and Pearson chi-squared (or Fisher’s exact) tests were used to evaluate differences in baseline variables (i.e., calving- and colostrum-related factors, sex, birth weight, introduction time, and number of calves in the group pen when a new calf was introduced; Table 5.1). There were no differences between conventional- and early-introduced calves in any baseline variables except that there were more calves that were tube-fed colostrum in the conventional introduction group (Table 5.1). As a result, being tube-fed colostrum at least once was included in all multivariable models to control for confounding during data analysis, as described below (Dohoo et al., 2009).

Linear regression models (PROC MIXED in SAS) were used for the analysis of total labour and ADG at 30, 46, and 61 days of age. A negative binomial regression model (PROC GENMOD in SAS) (used to deal with over-dispersion (alpha ‘α’ or dispersion parameter = 0.196; P < 0.001; estimated through Maximum Likelihood-ratio test where H₀: α = 0)), was used to analyse the number of assisted visits. To adjust for the effect of pen (linked to an AMF), AMF was included as a fixed effect (Dohoo et al., 2009). Collinearity between 2 variables was considered to be present if their correlation was strong (Pearson and Spearman correlation coefficients r > 0.7); the least significant variable when tested in the univariable analysis was removed. Independent variables having an association (P < 0.20) with the outcome in univariable models were offered to the multivariable model. Treatment was included in all the models, regardless of significance. Besides treatment, the initial multivariable model for total labour included season of birth, tube feeding colostrum, weight at birth, and STP. The initial multivariable models for ADG at 30, 46, and 61 days of age included season of birth, sex, tube
feeding colostrum, STP and number of calves in the group pen at the moment of introduction (except for the model of ADG at 61 days of age), weight at birth (except for the model of ADG at 30 days of age), latency to learn to use the feeder, and diarrhea (no diarrhea vs. mild vs. severe). The initial multivariable model for the number assisted visits included season of birth, tube feeding colostrum, and weight at birth. A variable was considered a confounder if its removal caused > 20% change in the estimate of another variable in the model. The model was reduced through backward elimination and variables remained in the model when \( P < 0.1 \). Two-way interactions that involved the main independent variable (age of introduction) were tested and kept if \( P < 0.1 \). Homoscedasticity and normality of residuals were evaluated to assess modeling assumptions for the linear regression models. Homoscedasticity was evaluated graphically by plotting residuals against predicted values (Dohoo et al., 2009). Normality was evaluated using normal quantile plots as well as the Shapiro-Wilk test (Dohoo et al., 2009). Log transformation was used to normalize residuals for total labour. Back-transformed least square means (LSM) and 95% confidence intervals (CI) are presented. The fit of the negative binomial regression model was evaluated using the Deviance Goodness-of-fit test (SAS, 2017).

Univariable Cox proportional hazards models (PROC PHREG in SAS) were used to screen the effect of covariates (Table 5.1) on the latency to learn to use the feeder; none were significant and the assumption of proportional hazards was violated for treatment. Therefore, the effect of treatment on the latency to learn to use the feeder was assessed using Kaplan-Meier survival analysis (PROC LIFETEST in SAS). Median survival time and 95% CI are presented.

Exact logistic regression models (PROC LOGISTIC in SAS) were used to describe the effect of treatment on the odds of being diagnosed with diarrhea, and specifically with mild or severe diarrhea. The initial models included treatment and tube feeding colostrum as fixed effects. The latter was added for effective control of possible confounding effects, but removed as it was not significant and there was no confounding effect. AMF was included as a fixed effect. Kaplan-Meier survival analysis was used to view differences in the time from birth to first diarrhea occurrence by treatment, and the time from introduction to the group to first occurrence of diarrhea. The other disease events had too few occurrences for analysis (pneumonia: \( n = 2 \); navel infection: \( n = 3 \); and bloat: \( n = 1 \)).
Wilcoxon two-sample test was used to evaluate differences in milk replacer consumption during the first training session to use the AMF and during the visit when calves successfully learned to use the AMF between treatments. Differences in daily milk replacer and starter intake during the milk feeding period (60 days) between early- and conventionally-introduced calves were evaluated using linear regression models (PROC MIXED in SAS). The models included the fixed effects of calf age, treatment, and the interaction between time (age) and treatment, and the random effect of calf within treatment to adjust for the correlation between repeated observations of individual calves. To adjust for the effect of pen (linked to an AMF), AMF was included as a fixed effect (Dohoo et al., 2009). The variance-covariance matrix used an autoregressive structure. Homoscedasticity and normality of residuals were evaluated graphically to assess modeling assumptions.

Each variable had 60 observations; however, data regarding milk and starter intake, and ADG were incomplete because 3 calves died before the end of the trial. Two early-introduced calves’ deaths were associated with calf diarrhea and septicemia (at 10 days of age) and cecal infarction (post-mortem diagnosis; calf was euthanized at 9 days of age). One conventionally-introduced calf was removed from the herd due to a clinically diagnosed heart murmur (at 34 days of age). Removal of data from these 3 calves for the other outcomes did not affect the models, thus we chose to leave these data in the analyses.

5.4 RESULTS

Calves were enrolled in the study at a mean (±SD) rate of 3.1 ± 1.7 calves per week. The weekly mean (±SD) group size for group pens 1 (introductory group pens) was 7.3 ± 2.7 calves per group and the weekly mean group size for group pens 2 was 12 ± 4.1 calves per group. The weekly mean (±SD) age range between calves housed in group pens 1 was 15.5 ± 11.01 d, and for group pens 2 it was 22.5 ± 10.7 d. The following results are described based on the biological order of events.
5.4.1 Learning to Use the Automated Milk Feeder

During training to use the AMF, 6.7% of calves (1 early-introduced calf and 3 conventionally-introduced calves) had to be fed manually at least once because it had not consumed milk from the AMF for 12 hours. Only one calf (conventionally-introduced) drank milk from the AMF on its own without requiring training.

In multivariable analysis, the number of assisted visits to the AMF until successful learning tended to be greater (df = 56; Wald Chi-squared = 2.81; \( P = 0.09 \)) for early-introduced calves (LSM: 7.8 assisted visits; 95% CI: 6.2 to 9.7) than conventionally-introduced calves (5.9 assisted visits; 95% CI: 4.8 to 7.5). Birth weight also tended to be associated with the number of assisted visits (df = 56; Wald Chi-squared = 3.18; \( P = 0.07 \)) to the AMF, where for every kg of birth weight increase, the odds of an assisted visit decreased 0.96 times (95% CI: 0.93 to 1).

Age of introduction was associated with the latency to learn to use the feeder, with differences occurring earlier (Wilcoxon test: df = 1; Chi-squared = 9.38; \( P = 0.002 \)) rather than later (Log Rank test: df = 1; Chi-squared = 1.37; \( P = 0.24 \)) in the time period studied (Figure 5.2). When introduced to the group pen before 24 h of age, calves took longer to successfully learn to use the AMF (median: 64.9 h; 95% CI: 59.1 to 77.9 h) compared to calves introduced at 5 days of age (median: 31.4 h; 95% CI: 22.8 to 47.9 h).

5.4.2 Labour for Milk Feeding Tasks

In multivariable analysis, farm labour for milk feeding tasks after colostrum until calves successfully learned to use the AMF was greater (df = 55; \( t \)-value = 12.8; \( P < 0.001 \)) for calves introduced to the group at 5 days of age (LSM: 145.6 min; 95% CI: 125.1 to 169.4 min) compared with calves introduced before 24 hours of age (39.9 min; 95% CI: 33.5 to 47.6 min). Calves born in the winter (88.9 min; 95% CI: 77.8 to 101.7 min) required more farm personnel labour than calves born in the spring (65.3 min; 95% CI: 53.1 to 80.4 min) (df = 55; \( t \)-value = -2.64; \( P = 0.01 \)). Calves that were tube-fed colostrum at least once tended to require more labour than calves that voluntarily consumed colostrum (84.3 min; 95% CI: 68.8 to 103.3 min; and 68.9 min; 95% CI: 60.4 to 78.6, respectively; df = 55; \( t \)-value = -1.81; \( P = 0.07 \)).
5.4.3 Calf Health

Overall, 82% (n = 49) of all calves enrolled in the study had an episode of diarrhea, of which 71% of the cases were mild. Mild diarrhea occurred in 50% (n = 15) and 67% (n = 20) of early- and conventionally-introduced calves, respectively. Severe diarrhea occurred in 37% (n = 11) and 10% (n = 3) of early- and conventionally-introduced calves, respectively. Calves with severe diarrhea received treatment for a mean (± SD) of 5.7 ± 1.8 d. Three calves in the early-introduced group had a diarrhea relapse, while no conventionally-introduced calves had a diarrhea relapse.

In the exact logistic regression, the odds of having diarrhea or having mild diarrhea vs. not having diarrhea did not differ between treatments (Table 5.2). Among calves with diarrhea, the risk of having severe vs. mild diarrhea was higher for early-introduced calves compared with conventionally-introduced calves (Table 5.2). Early-introduced calves had onset of diarrhea at a younger age (median: 6 days; 95% CI: 5 to 7 days) compared with calves introduced at 5 days old (median: 10 days; 95% CI: 8 to 13 days) (Wilcoxon test P = 0.001; Log Rank test P = 0.002). However, the time from introduction to the group pen to the onset of diarrhea did not differ between treatments (median for early introduction was 6 days, 95% CI: 5 to 7 days and for conventional introduction was 6 days, 95% CI: 4 to 9 days; Wilcoxon test P = 0.53; Log Rank test P = 0.31).

5.4.4 Milk and Starter Intake

Overall, milk replacer consumed during the first training session to use the AMF differed between treatments (df = 1; Chi-squared = 27.49; P < 0.001). Early-introduced calves consumed a mean ± SD of 1.2 ± 0.9 L, while conventionally-introduced calves consumed a mean of 2.6 ± 0.8 L. On the other hand, milk consumption during the visit when calves successfully learned to use the AMF did not differ between treatments (mean ± SD, early introduction = 2.6 ± 0.6 L; conventional introduction = 2.6 ± 0.5; df = 1; Chi-squared = 0.048; P = 0.83).

In multivariable analysis, early-introduced calves consumed less milk compared with conventionally-introduced calves during the first 7 days of life, with no differences thereafter (Figure 5.3). There were no differences in the total amount of milk replacer consumed from birth.
to 1 day before starting weaning (mean ± SD, early introduction = 417.7 ± 54.9 L; conventional introduction = 425.7 ± 56.9 L; df = 1; Chi-squared = 0.33; \( P = 0.56 \)).

There were no differences in the starter intake between treatments. Overall, daily mean (LSM) starter intake among both treatments by each stage of the milk feeding period (where access to grain was allowed) and weaning period were: ad libitum: 0.04 kg/d (95% CI: 0 to 0.11 kg/d), step down: 0.17 kg/d (95% CI: 0.10 to 0.25 kg/d), plateau: 0.37 kg (95% CI: 0.29 to 0.44 kg/d), first week of weaning period: 0.97 kg/d (95% CI: 0.90 to 1.04 kg/d), and last week of weaning period: 2.0 kg/d (95% CI: 1.92 to 2.1 kg/d).

5.4.5 Average Daily Gain

In the multivariable analysis, there was no effect of treatment on the ADG at 30 days (early- vs. conventionally-introduced calves, LSM [95% CI]: 0.92 kg/d [0.83 to 1.02] vs. 0.88 kg/d [0.81 to 0.96], respectively, df = 50; \( t \)-value = -0.89; \( P = 0.38 \)), at 46 days (0.94 kg/d [0.88 to 0.99] vs. 0.90 kg/d [0.85 to 0.95]; df = 49; \( t \)-value = -1.30; \( P = 0.21 \)), or at 61 days (0.96 kg/d [0.91 to 1.01] vs. 0.93 kg/d [0.88 to 0.97]; df = 50; \( t \)-value = -1.11; \( P = 0.27 \)) of age. ADG was influenced by sex, season of birth, and diarrhea. Female calves (LSM [95% CI]: 0.88 kg/d [0.83 to 0.93]) ADG at 61 days – results at 30 and 46 days are not shown but were similar), calves born in the spring (0.89 kg/d [0.83 to 0.96]), or calves that had severe diarrhea (0.84 kg/d [0.79 to 0.90]) had a lower ADG at 61 days of age compared to male calves (1.0 kg/d [0.95 to 1.04]; df = 50; \( t \)-value = -4.36; \( P < 0.001 \)), calves born in the winter (0.98 kg/d [0.95 to 1.02] ;df = 50; \( t \)-value = -2.66; \( P = 0.01 \)), or calves that did not have diarrhea (0.97 kg/d [0.89 to 1.05]; df = 50; \( t \)-value = -2.65; \( P = 0.01 \)), respectively. Only up to 30 days of age, a 1 hour increase in the latency to learn to use the AMF was associated with 0.001 kg/d (SE: 0.0007 kg/d) lower ADG (df = 50; \( t \)-value = -2.12; \( P = 0.03 \)).

5.5 DISCUSSION

Many dairy producers prefer to introduce calves to an AMF as soon as possible (Jorgensen et al., 2017; Medrano-Galarza et al., 2017a), without clear evidence to inform the decision about the timing of introduction. This study is the first to provide information on the
effects on learning, performance, and farm personnel labour of introducing calves to a group pen with AMF within 24 hours after birth. The results demonstrate that, under housing conditions reflecting common practice on commercial farms, early introduction of calves was associated with a reduced farm personnel labour overall, despite the longer latency to learn to use the AMF, and had no effects on ADG to 61 days. Although age of introduction did not affect the odds of a calf having diarrhea (onset occurred 6 days after introduction to the group pen in both groups), early-introduced calves experienced higher odds of severe diarrhea (vs. mild diarrhea) at a younger age. We encourage larger-scale studies on multiple farms to confirm these findings.

Once calves were introduced to the group pen with the AMF, we found that early-introduced calves took longer to learn to use the AMF (65 vs. 31 h) and tended to require more assistance to use the feeder (7.8 vs. 5.9 assisted visits) until successful learning was achieved compared to conventionally-introduced calves. Similarly, Jensen (2007) found that younger calves (although introduced at 6 days of age) required guidance for 48 hours, while calves introduced at 14 days of age only required guidance for 24 hours. Fujiwara et al. (2014) also found that heavier 6-day-old calves (at introduction to the group pen) had a shorter latency to the first voluntary milk intake from the AMF. Although Fujiwara et al. (2014) introduced all their calves at a same age and examined the effects of their weight at introduction on the latency to learn, we could infer that in our study, a 5-day-old calf would be expected to weigh more than a < 1-day-old calf. Therefore, a 5-day-old calf would have a shorter latency to learn to use the AMF.

In the present study, we did not find an effect of group size on the latency to learn to use the AMF. The weekly mean group size of the introductory pens (group pens 1) was 7.3 calves, whereas in the majority of commercial farms in Canada use group sizes of 10 to 15 calves (Medrano-Galarza et al., 2017a) and in the Midwest United States the average is 17 calves (Jorgensen et al., 2017). Large group size increases the level of competition (Jensen, 2004), with older calves pushing small ones out of the feeder stall (Hepola, 2003). Thus, on commercial farms using larger group sizes, an increase in the latency to learn to use the AMF for early-introduced calves could be expected.
Labour for milk feeding chores until calves successfully learned to use the AMF was greater for conventionally-introduced calves compared to early-introduced calves after controlling for the effects of season and being tube-fed colostrum. The latter, which was identified as a potential confounder prior to analysis, had an effect on the labour but did not modify the association between introduction treatment and labour. While calves introduced < 24 hours after birth required more labour to train, assist, and re-train to use the AMF, that was still less than the time required to manually feed calves until introduction at day 5. Kung et al. (1997) found that labour required to care for an individually-fed and housed calf was 10 times greater than for an AMF-fed, group-housed calf. Kung et al. (1997) found a much greater difference than we did between treatments (10-fold vs. 3.7-fold) mainly because in their case, labour included not only the feeding of milk and teaching to nurse, but also teaching to consume grain, cleaning, and bedding of pens.

Additionally, we found that labour for milk feeding tasks tended to be greater for calves that were fed colostrum through an esophageal tube at least once, regardless of treatment (there was no interaction). These tube-fed calves were likely less vigorous at birth (Vasseur et al., 2009) and at sucking (Ventorp and Michanek, 1992). Poor vigor probably impaired the expression of neonatal behaviours (e.g., standing and searching for a teat to suck; Barrier et al., 2012).

The present study size was not designed to detect putative differences in the incidence of disease, and we found that the health problems among early- and conventionally-introduced calves were similar. The most frequent disease in our study was calf diarrhea, which affected a high but similar proportion of calves in both treatment groups, with a similar median time to onset of 6 days after introduction to the group. However, the risk of having more severe diarrhea cases was significantly greater, and the age at the first episode of diarrhea was earlier for early-introduced calves relative to calves conventionally-introduced at 5 days of age. Generally, newborn calves are more susceptible to pathogens and their responses to infection are weaker and slower compared to an older animal (Cortese, 2009). In the first 4 days after birth, immune responses (e.g., production of lymphocytes and interferon-γ) are blocked by different immunosuppressive factors contained in colostrum (e.g., cortisol and prostaglandins), making calves even more susceptible during this period (Rajaraman et al., 1997). Reflecting practice on
commercial farms, there was a range of 2 to 3 weeks in the ages of calves in a pen. This is a risk factor for transmission of pathogens from older calves to younger ones, especially those newly-arrived in the pen. While the time from introduction to the group pen to onset of diarrhea was the same between our treatments, our observation that the severity of diarrhea was greater among early-introduced calves is consistent with younger animals having less resilience in the face of a pathogenic challenge.

We did not evaluate farm labour related to time spent treating sick calves; however, the duration of treatment of calves with severe diarrhea in the present study (mean, SD: 5.7 ± 1.8 days) could potentially represent an increase in labour costs when introducing calves < 24 hours after birth, due to their higher risk of having severe diarrhea. In addition to the potential increase in labour costs, having diarrhea earlier in life has been found to be a risk factor for bovine respiratory disease (BRD) after 3 months of age (Svensson et al., 2006) and calf mortality (Sivula et al., 1996; Perez et al., 2009).

The incidence of diarrhea in our study (82%) was higher than the prevalence reported on commercial dairy farms using AMF (23%; Medrano-Galarza et al., 2018). This high incidence may have been due to cross-contamination of pens with Cryptosporidium parvum, which was detected in fecal samples of 2 severely ill calves. In addition, this study used a “continuous flow” stocking approach, and the prevalence of diarrhea has been found to be at least twice as high for “continuous flow” vs. “all-in/all-out” stocking approach (Pedersen et al., 2009) due to a decreased ability to disinfect the pens. Concerning the external validity of our results, the lack of differences between ages of introduction in the risk of having diarrhea could differ from a situation in which the incidence of diarrhea was lower. A reduced load of pathogens in the environment could perhaps result in only more susceptible calves having clinical disease (Cho and Yoon, 2014). On the other hand, the results regarding the higher risk of having severe (vs. mild) diarrhea among early-introduced calves could be generalized to commercial farms, because the severity of diarrhea cases is likely to be linked to calves exposed to pathogens at an early age (as discussed above).

The age of introduction influenced daily milk intake only during the first week of life, with early-introduced calves consuming less milk than conventionally-introduced calves. These
differences in milk intake, especially on day 3 and day 4 (Figure 5.3), likely resulted from a combination of factors related to the feeding method and the age at training to use the AMF. During this period, conventionally-introduced calves were bottle-fed, while early-introduced calves were in their training process to use the AMF. Overall, the training of calves to use the AMF was a smooth process but based on the quantity of milk consumed during the first training session (1.2 vs. 2.6 L for early- and conventionally-introduced calves, respectively) and the differences in intake during those first days of life, we infer that very young calves were less successful at drinking from the AMF than calves being fed through a bottle. Jensen (2007) also found differences in milk intake between calves introduced to an AMF in a group pen at 6 vs. 14 days of age, although they compared intake by days in the group and not by days of age. In the present study, once learning was achieved, there were no differences in milk intake, and overall milk intake from birth to weaning did not differ. This compensation might have been possible due to the fact that calves in this experiment were allowed to drink milk ad libitum, which allowed them to gradually increase their milk consumption, especially during the first 2 weeks of the ad libitum stage, until reaching their maximum intake. This feeding pattern has been previously shown in calves fed high milk allowances (Borderas et al., 2009).

Average daily gain across the milk feeding period was not affected by age of introduction in the present study. Similarly, Svensson and Liberg (2006) did not find any effect of age of introduction (i.e., < 8 days, > 8 ≤ 12 days, < 12 ≤ 19 days, or > 19 days of age) on growth rate. However, we found that ADG was negatively affected when calves, regardless of treatment, experienced severe diarrhea. Likewise, Donovan et al. (1998) found that as diarrhea became more severe (i.e., as number of treatment days increased), the weight gain from birth to 6 months of age decreased.

We also found that as the time to successfully learn to use the AMF increased, ADG at 30 days of age, but not later, decreased. Milk intake is positively associated with ADG (Miller-Cushon et al., 2013). Thus, calves that took longer to successfully learn to drink milk from the AMF consumed less milk during those first days after introduction, affecting weight gain during the first month of life. Fujiwara et al. (2014) found a negative correlation between the latency to first voluntary milk intake from the AMF and milk intake during the first week in the group pen, and a tendency with lower ADG.
5.6 CONCLUSIONS

Under a “continuous flow” stocking approach for raising calves in groups with AMF, calves introduced to the group pen within 24 hours after birth required more assistance to use the AMF and took longer to achieve independent use of the feeder than calves introduced at 5 days of age. However, this longer latency to learn to use the AMF did not entail an increase in overall labour, as calves introduced at 5 days of age required more labour overall than early-introduced calves due to the chores involved with manual feeding for 4 days. Although milk intake during the first days of life was less for calves introduced earlier compared with at 5 days of age, ADG to 61 days of age was not affected by age at introduction to the group. The risk of diarrhea also did not differ between treatments, but early-introduced calves had onset of diarrhea at a younger age and a greater risk of severe diarrhea vs. mild. Our results show that introduction to group housing with AMF as early as the first day after birth may be a viable option in reducing farm labour requirements without affecting calf growth. However, the health risks of doing so require more investigation, and more attention may need to be paid to disease prevention. Therefore, under conditions similar to our study, we recommend adoption of early introduction only when steps are taken to minimize any potential adverse effects on the health of the calves. In addition, because there is less labour required to feed milk to early-introduced calves, producers currently using this practice could spend more time doing calf health checks and maintaining good hygiene in the pens. Further research is needed on the longer-term consequences of providing early social contact on calf welfare before firm recommendations can be made about the optimum age of introduction.

5.7 ACKNOWLEDGEMENTS

This research was funded by Dairy Farmers of Canada (Ottawa, ON, Canada) as part of the Dairy Research Cluster 2 program and the Ontario Ministry of Agriculture, Food, and Rural Affairs (OMAFRA; Guelph, ON, Canada). The first author also thanks the Administrative Department of Science, Technology and Innovation – Colciencias (Bogota, Cundinamarca, Colombia) for the Ph.D. scholarship granted. The authors also thank Laura Wright, Joe Parkison, Jeff Mcfarlane and the staff at the University of Guelph Dairy Research and Innovation Center.
(Elora, ON, Canada) for their help and contributions to this work. Special thanks to Larissa Martins (Universidade de São Paulo, Pirassununga, SP, Brazil) and Pauline Denis (Agro Campus Ouest, Rennes, France) for their invaluable help during the data collection, and to Gail Ritchie (University of Guelph) for her support during the data collection.
5.8 REFERENCES


Table 5.1. Calving- and colostrum-related factors, sex, birth weight, introduction time and number of calves in the group pen for Holstein calves assigned to conventional introduction (5 days of age) or early introduction (< 24 hours after birth) to a group pen with an automated milk feeder (AMF)

<table>
<thead>
<tr>
<th>Baseline variables</th>
<th>Treatments</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of calves</td>
<td>Conventional</td>
<td>Early</td>
</tr>
<tr>
<td>Sex, % (n)</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>Female</td>
<td>47 (14)</td>
<td>53 (16)</td>
</tr>
<tr>
<td>Male</td>
<td>53 (16)</td>
<td>47 (14)</td>
</tr>
<tr>
<td>Season of birth, % (n)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Winter</td>
<td>57 (17)</td>
<td>53 (16)</td>
</tr>
<tr>
<td>Spring</td>
<td>43 (13)</td>
<td>47 (14)</td>
</tr>
<tr>
<td>Calving location, % (n)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Individual maternity pen</td>
<td>93 (28)</td>
<td>100 (30)</td>
</tr>
<tr>
<td>Dry cow free stall</td>
<td>7 (2)</td>
<td>0</td>
</tr>
<tr>
<td>Level of assistance at calving¹, % (n)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unsupervised</td>
<td>17 (5)</td>
<td>23 (7)</td>
</tr>
<tr>
<td>Unassisted</td>
<td>53 (16)</td>
<td>47 (14)</td>
</tr>
<tr>
<td>Assisted</td>
<td>30 (9)</td>
<td>30 (9)</td>
</tr>
<tr>
<td>Twin calves, % (n)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>During work hours</td>
<td>83 (25)</td>
<td>77 (23)</td>
</tr>
<tr>
<td>Outside work hours</td>
<td>17 (5)</td>
<td>23 (7)</td>
</tr>
<tr>
<td>Birth BW², kg</td>
<td>43.6 (33.5 – 58.5)</td>
<td>43.9 (36.5 – 50)</td>
</tr>
<tr>
<td>Tube-fed for 1st colostrum feeding, % (n)</td>
<td>27 (8)</td>
<td>7 (2)</td>
</tr>
<tr>
<td>Tube-fed for 2nd colostrum feeding, % (n)</td>
<td>33 (10)</td>
<td>13 (4)</td>
</tr>
<tr>
<td>Tube-fed at least once for colostrum feeding, % (n)</td>
<td>43 (13)</td>
<td>17 (5)</td>
</tr>
<tr>
<td>Total volume of colostrum fed, L</td>
<td>5.9 (4.5 – 7.5)</td>
<td>5.8 (4.5 – 8)</td>
</tr>
<tr>
<td>Serum total protein², g/dL</td>
<td>6.5 (5.6 – 8.6)</td>
<td>6.2 (5 – 7.7)</td>
</tr>
<tr>
<td>Time of introduction³, % (n)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Day</td>
<td>50 (15)</td>
<td>70 (21)</td>
</tr>
<tr>
<td>Evening</td>
<td>50 (15)</td>
<td>30 (9)</td>
</tr>
<tr>
<td>Number of calves in the group pen³, ⁴</td>
<td>7.1 (1 – 11)</td>
<td>6.5 (0 – 11)</td>
</tr>
<tr>
<td>Time between introduction and first training², ⁵, hours</td>
<td>9.1 (4.1 – 13.1)</td>
<td>8.3 (1.6 – 17.2)</td>
</tr>
</tbody>
</table>

¹Unsupervised = births overnight (outside farm staff work-hours); unassisted = births during work-hours but no assistance was given; Assisted = easy pull, hard pull, and caesarian section.

²Mean and (minimum – maximum) are presented.

³Time of the day a calf was introduced into the group pen with an AMF.

⁴Number of calves already in the group pen with an AMF at the moment of introducing a new calf.

⁵Total amount of time between introduction to the group and first training to use the AMF.
Table 5. Univariable exact logistic regression models describing the effect of introduction to the group pen with an automated milk feeder < 24 h ours after birth (early) or at 5 days old (conventional) on the risk of having diarrhea at least once < 60 days of age.

<table>
<thead>
<tr>
<th>Models</th>
<th>Estimate</th>
<th>SE</th>
<th>OR</th>
<th>95% CI²</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Odds of having diarrhea³ vs. no diarrhea (n = 60)</td>
<td>0.67</td>
<td>0.68</td>
<td>1.95</td>
<td>0.43</td>
<td>10.33</td>
</tr>
<tr>
<td>Treatment: Early vs. conventional</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Odds of having mild diarrhea vs. no diarrhea (n = 46)</td>
<td>0.27</td>
<td>0.71</td>
<td>1.31</td>
<td>0.27</td>
<td>7.24</td>
</tr>
<tr>
<td>Treatment: Early vs. conventional</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Odds of severe diarrhea vs. no diarrhea (n = 25)</td>
<td>1.77</td>
<td>0.88</td>
<td>5.89</td>
<td>0.84</td>
<td>55.19</td>
</tr>
<tr>
<td>Treatment: Early vs. conventional</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Odds of having severe vs. mild diarrhea (n = 49)</td>
<td>1.55</td>
<td>0.72</td>
<td>4.73</td>
<td>1.01</td>
<td>31.08</td>
</tr>
<tr>
<td>Treatment: Early vs. conventional</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

¹Odds ratio.
²Confidence interval for the odds ratio, lower confidence limit (LCL), and upper confidence limit (UCL).
³All diarrhea cases (mild or severe).
Figure 5.1. Layout of experimental rooms and pens to house calves randomly assigned to either 1 of 2 treatments: early (< 24 hours of age) or conventional introduction (5 days of age) to the group pen with an automated milk feeder (AMF) with a “continuous flow” stocking approach.
**Figure 5.2.** Kaplan-Meier survival analysis graph: Time interval (in hours) between the first training session to use the automated milk feeder (AMF) and the first voluntary (unassisted) visit to the AMF with > 1 L milk intake, indicative of successful learning) for the 60 calves randomly assigned to early (< 24 hours of age) or conventional introduction (5 days of age) to the group pen with an AMF. Wilcoxon test: $P = 0.002$; Log Rank test: $P = 0.24$. 
Figure 5.3. Mean daily milk intake (± SE) across the 5 stages of the milk feeding period (from 1 to 60 days of age) for 60 calves introduced to a group with an automated milk feeder at 5 days of age (conventional introduction) and before 24 hours of age (early introduction). Milk allowance for each milk feeding stage: Start = 9 L/d; Ad libitum = up to 36 L/d; Step down period = gradual reduction from 12 to 9 L/d; Plateau before to weaning = 9 L/d; and weaning: gradual reduction from 9 to 2 L/d. *P < 0.05, †P < 0.1.
CHAPTER 6

GENERAL DISCUSSION

The overall purpose of my thesis was to build knowledge on the use and management of automated milk feeders (AMF) for raising group-housed dairy calves, and to investigate potential determinants of calf health on commercial Canadian dairy farms using this system. This research can provide practical information that the dairy industry, veterinary practitioners, extension agents, and AMF manufacturers can use to help farmers using AMF systems to improve their management practices, and guide decision-making of future adopters so the implementation of these systems is successful.

6.1 SUMMARY OF FINDINGS

To better understand the management of calves raised in groups with AMF systems and be able to estimate impacts on calf health and welfare, it was necessary to first assess current management and feeding practices for raising calves on dairy farms in Canada. Prior to this thesis, the previous most-recent survey in Canada on this topic was done between 2005 and 2007 (Vasseur et al., 2010), and only surveyed producers from the province of Quebec. To determine a baseline for calf management and feeding practices, a cross-sectional online survey of dairy farmers across Canada was conducted (Chapter 2). The results from this survey showed that the main differences in management practices between farms using AMF systems and farms using manual milk feeding (MMF) systems to raise calves were practices exclusively related to housing and milk feeding once calves were separated from the dam (i.e., newborn calves were managed similarly). All farms using AMF housed calves in groups from a median age of 5 days, whereas, more than 75% of farms using MMF housed calves individually from birth, and the median age of introduction to a group of calves on these farms was 60 days. However, the majority of farms using AMF had larger groups of calves (between 10 and 20 calves per group).
compared to farms using MMF for group-housed calves (≤ 9 calves per group). While producers who used AMF implemented group housing systems, they also housed and fed calves in group sizes larger than recommended, which is known to be potentially detrimental for calf health (Svensson et al., 2003; Svensson and Liberg, 2006) and welfare (Jensen, 2004). Regarding milk feeding practices, farms using AMF offered more milk to calves during the first month of life than farms using MMF systems. In addition, the proportion of MMF farms feeding milk with teats (53%) was higher compared with the proportion of farms using open buckets (36%) in the present study, and with participants in Vasseur et al. (2010) (92%). On the other hand, the most common frequency of feeding still continues to be twice daily in MMF farms surveyed in the present study.

The survey also revealed that the adoption of AMF may have increased in Canada in recent years (Chapter 2). Sixteen percent of our respondents used an AMF while no farms in the survey of Vasseur et al. (2010) had adopted AMF at that time. In addition, only 3% of 890 farms surveyed in Ontario in 2012 used AMF (Ken Leslie, University of Guelph, ON, Canada; personal communication). In the present work, the adoption of AMF was associated with farm size, the adoption of other technology, and age of the producer. Larger farms, regardless of barn type (loose housing or tie-stall), and loose housing farms already using other technologies such as automatic milking systems (AMS) were more likely to be using AMF as well. The latter could have been caused by a desire for increasing the work flexibility and workload reductions that have been previously achieved by having an AMS on the farm (de Jong et al., 2003; Butler et al., 2012; Bergman and Rabinowicz, 2013). Specifically for tie-stall farms, it appeared that if producers were 55 years old or older, the likelihood of having an AMF was lower compared to younger producers. Associations of age and adoption of technology in the literature have been inconsistent; however, older producers might abstain from acquiring new technology because of their shorter working horizon in comparison with younger producers (Pierpaoli et al., 2013).

When trying to understand the use of certain practices for raising calves, it is important to comprehend what motivated producers to adopt a rearing system, and to recognize the different benefits and shortcomings each system brings to producers. There is no published research available on reasons for adoption of AMF systems. Therefore, the survey included questions to help determine the factors that influenced producers to continue feeding calves.
manually (MMF systems) or to switch to automation, and to determine producers’ perceived advantages and disadvantages with both feeding systems (Chapter 3). The findings showed that producers who adopted AMF were driven by the desire to improve the quality of life for the calves by offering them higher daily milk allowances, and for themselves through reducing physical labour and improving working conditions. Interestingly, the adoption of AMF, like the adoption of AMS (de Jong et al., 2003; Butler et al., 2012; Bergman and Rabinowicz, 2013), was not driven by factors related to profit, which has been the case for the adoption of health and behaviour monitoring technologies elsewhere (Russell and Bewley, 2013).

When comparing the reasons behind the adoption of AMF and the perceived advantages once the AMF were in use, AMF systems appeared to have fulfilled the expectations that producers had when deciding to adopt this technology. The reduction of direct contact with calves was the main perceived disadvantage of AMF systems, whereas being able to interact daily with calves while being fed was the main advantage of MMF perceived by producers using MMF systems. Thus, what was perceived as lost in the AMF system, was one of the main reasons to decide to keep using MMF. In addition to this, producers using MMF systems indicated that barriers for adopting AMF were the economic investment and having a small farm. Indeed, the findings in Chapter 2 demonstrated that 50% of producers who adopted an AMF renovated an existing barn, while 41% built a new one, which showed that investment beyond to the cost of purchasing the machine was required as well.

Findings from Chapter 2 and Chapter 3 showed that the adoption of AMF is increasing among producers who are seeking an easier way to feed higher milk allowances to calves in a group housing system without increasing physical labour, and to improve working conditions. However, some producers reported being reluctant to switch from individual feeding and housing to automation and group housing because of the potential increased risk of disease transmission with group housing. In addition, some producers who adopted AMF had switched back to their previous raising system (i.e., abandoned AMF) due to increased health problems. Research on Swedish farms has indeed shown that large-sized group housing systems with AMF was detrimental for calf health compared to individual housing and feeding (Svensson et al., 2003); however, in North America, such research is scarce. Therefore, to be able to help current users of AMF and group housing systems improve their management practices and calf health, as
well as to assist those who are thinking of adopting AMF to be aware of the factors that could contribute to successful implementation or failure, an observational, cross-sectional study was developed to estimate the prevalence of calf diarrhea (CD) and bovine respiratory disease (BRD), and to investigate factors that could impact disease frequency on dairy farms using this system in Southern Ontario (Chapter 4).

Calf diarrhea was detected in 23% of the calves, and 17% experienced BRD (Chapter 4). The herd-level prevalence ranged from 8 to 46% for CD (median = 24%), and from 3 to 31% for BRD (median = 14%), showing the large variability between farms. The herd-level incidence risk of calf mortality up to 3 months of age (excluding stillbirths) ranged from 0 to 21% (median = 4%). Disease frequency estimates for North American farms using individual housing and feeding systems reported an incidence risk of CD and BRD of 23% and 22%, respectively (Windeyer et al., 2014), a herd-level BRD prevalence of 14% (range from 0 to 37%; Lago et al., 2006), a herd-level incidence risk of CD and BRD of 10% (range from 0 to 44%) and 22% (range from 0 to 55%), respectively (Windeyer et al., 2014), and a mortality risk of 3% (Windeyer et al., 2014). A recent meta-analysis of cattle mortality reported a calf mortality risk of 5 to 11% (Compton et al., 2016). Therefore, our findings on disease and mortality frequency suggested that calf health in AMF systems was not worse than that on farms housing calves individually. Producers should be aware that calf health is more dependent on management practices and commitment to achieve good results than on a specific type of calf raising system. For example, multiple factors were associated with the prevalence of CD and BRD at the pen level, but specifically having exclusive calving pens, isolating calves from older cattle, and good quality of bedding and milk fed to calves were found to be protective factors. This work adds more evidence to the literature to support the following: the relevance of separating the maternity area from the hospital area (Cobbold et al., 2006), the importance of older animals as potential source of infection for younger calves (Virtala et al., 1999; Radostits et al., 2007; Gulliksen et al., 2009), and that one of the key rules of calf management is to always provide dry and clean bedding (Mohammed et al., 1999; McGuirk, 2008). This study (Chapter 4) also showed that the quality of milk fed to calves with AMF is associated with calf health. In pens where bacteria counts were $\geq 100,000$ cfu/mL or the percentage of total solids was $< 10\%$, the prevalence of CD and BRD were higher, respectively. The former shows the importance of feeding equipment as a source of enteric pathogens (McGuirk, 2008), and the latter shows the importance of feeding
milk or milk replacer to calves with a similar content of solids to whole milk for calf development and performance (McGuirk, 2015).

Across Chapters 2 and 4, it was found that in Canada, the median age of introduction to the group pen with AMF was 5 days (similar to findings in the Midwest United States from Jorgensen et al., 2017), but some producers were introducing calves as early as the first day after birth without knowing the possible implications of this early introduction on calf performance and farm labour. Thus, a trial was carried out to test the differences between calves introduced to the group pen with AMF < 24 hours after birth and calves introduced at 5 days of age (early vs. conventional introduction) on calf adaptation to use the feeder, average daily gain (ADG) by the end of the milk feeding period, and labour required for milk feeding tasks until independent use of the AMF by the calf (Chapter 5). This trial showed that although calves introduced to the group pen before 24 hours after birth required more assistance to use the AMF and had longer latencies to learn to use the AMF independently than conventionally-introduced calves, the labour required for milk feeding tasks was greater for conventional calves. Average daily gain at 61 days of age and the risk of diarrhea did not differ by age of introduction; however, the time of onset and the severity of the diarrhea differed. Introducing very young calves to the group pen was associated with experiencing diarrhea at a younger age (6 vs. 10 days of age) and with 4.7 times greater risk of having a more severe case. These findings suggest that early introduction (< 24 hours) to the group with AMF did not affect growth, but required more labour during the training of calves to use the AMF. However, this required labour for training early-introduced calves to use the AMF did not exceed the amount of labour required to manually feed calves during the 4 days prior to introduction to the group with AMF. On the other hand, there may be trade-offs between labour and calf health risks when introduced 24 hours after birth.

6.2 MAIN LIMITATIONS

One of the main limitations of the survey presented in the Chapter 2 is that the way participants were recruited could have led to different types of selection bias. The fact that this survey was only available to dairy producers via internet and that it was voluntary could have potentially led to non-response bias by excluding participation of producers who had limited or
had no access to internet, or were not interested in participating. This type of bias could have caused a deviation of our estimates from the true values in the target population (all Canadian dairy farms). Nonetheless, when comparing participants’ data with non-participants’ characteristics extracted from incomplete surveys (i.e., age, gender, barn type, milking system, farm size and region), we did not find any differences. In contrast, when comparing our study population with the target population (Tables 2.1, 2.2, and 2.3), we had higher representation of producers in Ontario and western provinces, which led to a lower percentage of tie-stall farms when compared to the national average. This may limit the generalizability of our results.

In addition, social desirability bias may have been introduced via respondents tailoring their answers towards what they deem researchers would find “acceptable”. Nevertheless, producers were also aware that the survey was anonymous and that there was no risk of identifying individuals. Further, it was not possible to cover in detail every different type of milk feeding system (e.g., the use of nurse cows by some organic farmers); therefore, some producers might have felt excluded while completing the questionnaire, thus giving up completing the survey.

By using Likert scale questions in Chapter 3, we could quantify attitudes and opinions towards milk feeding systems and allow producers to indicate a level of importance or agreement with statements rather than forcing them to take a particular position about given statement. However, we could only give limited number of statements, reducing producers’ opinions to the options given. The use of open-ended questions helped to limit this drawback and allow producers to expand their responses, if desired. Nevertheless, more thorough understanding of producers’ perceptions and factors related to their decisions around milk feeding systems could be obtained with the use of qualitative research methods.

The study presented in Chapter 4 was constrained by the fact that participant farms were not a random but rather, a convenience sample from the target population (dairy farms using AMF to feed milk to group-housed calves). This type of enrolment could have potentially led to selection bias, limiting extrapolation of the results to the larger target population. Another limitation of this study was that prevalence was the measure of disease frequency used rather than incidence risk because it was not economically or logistically feasible to visit each farm
more often to follow calves during the entire milk-feeding period. Therefore, causal inferences cannot be made regarding risk factors identified in this study (Dohoo et al., 2009). In addition, by using prevalence based on quarterly visits, we likely underestimated the presence of disease as the duration of CD and BRD are much shorter than the interval between our visits (Waltner-Toews et al. 1986; McGuirk, 2008). Because of concerns for the quality and consistency of detecting and recording disease in calves, we elected not to base our assessments on producer-recorded disease incidence.

Logistically, there was a limit to the number of farms, and thus, pens, that we could include in the study in Chapter 4. This relatively small sample size could have limited the statistical power in the analysis and increased the possibility of having Type II error. Farm recruitment was further constrained by logistics in terms of the limited number of farms using AMF in Ontario and producers’ willingness to participate in the study.

For the trial on age of introduction to the group pen with AMF systems in Chapter 5, a single person was used as the only caregiver in charge of feeding and training all calves enrolled in this study. Although having a single caregiver reduced variation we might have expected if multiple caretakers were involved, this could also limit the generalizability of the results. On commercial farms more than one person might be in charge of the calves, and they could differ in methods of feeding and training, patience handling calves, and time available for calf care compared to other farm chores. Further, because a single person was used to feed and train calves, blinding to treatment group was not possible. This lack of blinding could, in principle, have led to some detection bias. However, farm staff and veterinarians of the research centre were blind to treatment, therefore, the management of individual and group pens, and diagnosis and treatment for disease was the same for all calves enrolled in the study.

We underline that this study was not designed to detect differences in disease incidence, so the association that we found between treatment and severity of diarrhea should be explored in larger studies with sufficient power to test this hypothesis. In addition, the generalizability of our results is limited to farms using “continuous flow” housing, which is known to have a higher prevalence of diseases compared with stable groups (all-in/all-out; Pedersen et al., 2009).
6.3 RECOMMENDATIONS AND FUTURE WORK

As technology advances to improve productivity and efficiency in different aspects of farming, society is evolving with an increased concern for how food is produced and how animals are treated during this process (Fraser, 2010). Pressure on the dairy industry for changes in practices that scientists show to be detrimental for calf welfare and that the public is concerned about, is likely to keep increasing. If the industry does not track progress, improvement of farming procedures and encouragement for implementing best practices will be hard to achieve. Thus, it is important to investigate management practices and implementation of research findings on Canadian dairy farms. For example, the Canadian National Dairy Study (NDS, 2015) opens the door to continue developing studies focused on monitoring and benchmarking, following the example of the National Health Monitoring System in the USA (USDA, 2017a), which has been carried out about every 5 years (USDA, 2017b). The Canadian National Dairy Study should dedicate a section to newborn management and pre-weaned calf feeding and housing management practices so benchmarking, changes in these practices, and the tracking of AMF adoption can be identified.

This thesis explored the motivations and expectations behind the adoption of AMF or the use of individual feeding and housing systems for raising calves, and investigated the management factors impacting calf health on farms with AMF systems. This information could be used by extension agents and veterinary practitioners to understand the needs and goals of farmers regarding the rearing of their calves, and to guide farmers who are contemplating the idea of group housing and AMF systems to be aware of all the factors that can potentially contribute to a successful implementation or failure of AMF systems. Veterinarians should be involved in farmers’ decision-making process for adopting an AMF, because they should be able to identify whether the producer is ready to switch to group housing with automation and all the changes in management which that implies, or whether the producers must improve other aspects of facilities and management before they switch.

The four main factors identified in Chapter 4 to be associated with reduced prevalence of CD and BRD on AMF farms (Chapter 4) were the use of exclusive calving pens, isolating calves from older cattle, ensuring good quality of milk (by running the automatic cleaning of the
AMF at least 3 times/day and ensuring that TS of milk is $\geq 13\%$), and providing fresh bedding (every 2 to 3 days) while keeping the depth of saturated bedding $\leq 16$ cm. These factors could be used as a checklist to either guide producers currently struggling with high disease frequency to identify possible sources of infection affecting their calves, or to provide producers looking for room for improvement with specific areas where they can enhance their management practices. On the other hand, these factors should be further investigated in controlled intervention studies so direct evidence of causality and knowledge of the efficacy of certain interventions can be discovered (Green et al., 2010). The interventions to be tested should be initially related to those factors that could be cheap and easy to implement, especially those practices related to cleaning the AMF. There is scarce research on the optimal frequency of running the automatic cleaning and the manual cleaning of other parts (e.g., hoses and teats) of the AMF; manufacturers only specify in their manuals that start times, frequency, and duration of the automatic cleaning can be set by the producer as desired, which could lead to inadequate practices. Thus, there is a need for research on this area and for the development of a guide for producers that describes the steps needed to have a clean AMF and low bacteria counts in the milk that calves are ingesting. In addition, results from Chapter 4 showed that pens where calves drank milk mixed with probiotics had lower prevalence of CD, so it would be useful to investigate different types of probiotics, timing, and dosage through the AMF to be able to provide producers with advice on the use and possible benefits of probiotics in these systems.

Dairy producers using AMF systems want to make the most out of these devices and reduce labour required for manually feeding calves prior to introduction to the group pen with AMF. Thus, the potential impacts of introducing young calves (< 24 hours after birth) to the group pen with AMF on calf health and welfare still require further investigation through larger-scale studies on multiple farms. Moreover, results from the age of introduction trial (Chapter 5) might have differed if the stocking approach used was “all-in/all-out” instead of “continuous flow”. Therefore, it would be interesting to carry out a similar experiment but with stable groups, which have been found to be associated with lower prevalence of CD and BRD (Pedersen et al., 2009).

In addition, it would be prudent to carry out a controlled trial where different ages of introduction (e.g., < 24 hours after birth, 5 days old [North America median], and 2 weeks old
[minimum age recommended by Rasmussen et al., 2006; Svenson and Liberg, 2006; Jensen 2007]) are compared to an introduction based on calf-based criteria such as vigor at birth, attitude, sucking reflex, milk intake, and milk drinking speed during the first hours or days of life rather than an specific age. A more individualized introduction, dependent on the calf’s willingness and ability to suck, might be more beneficial, in terms of calf adaptation to the group and calf health, than an introduction based on a fixed age. Similar to the variability found in calves’ willingness to start eating solid feed (de Passillé and Rushen, 2016), it would be expected that there would be variability between calves in their readiness to vigorously consume milk. Thus, some calves might be introduced to the group pen with AMF later than other calves. However, the latter might help compensate the increase in manual labour that a late introduction would imply.

6.4 IMPLICATIONS

This thesis has practical implications for the dairy industry, veterinary practitioners, extension agents, and AMF dealers. The survey, presented in Chapters 2 and 3, is the first study in Canada to provide insights into calf management and feeding practices by comparing farms using MMF and AMF systems. The results of the survey showed that the adoption of AMF was driven by the producers’ desire to improve working conditions, reduce labour, and allow calves to have access to higher milk allowances while being group-housed. The latter could potentially evidence that AMF producers were positively influenced by extrinsic factors related to public pressure on improving animal welfare on farms and the recommendations of the Codes of Practice, where isolation of calves and the feeling of hunger are key concerns. Nevertheless, producers using MMF systems were also influenced by factors beyond costs of investing in new equipment and facilities. They perceived that MMF systems allowed them to have healthier calves (due to reduced transmission of disease between calves) that were easier to handle and to more easily detect sick calves, which are also important factors for calf welfare. However, the survey showed that farms using MMF system and housing calves individually, introduced them to a group at median age of 60 days, which is at the edge of the age (8 weeks) established by The European Union (Council Directive 2008/119 EC) as the maximum age limit to have calves.
individually-housed. This was not the case for AMF farms, where calves were group-housed from a median age of 5 days. In addition, the median daily milk allowance for MMF farms throughout the first month of life was 6.5 L/d, indicating that restricted milk diets are still common in Canada, whereas for AMF farms, median daily milk allowance was 8.2 L/d. The survey also showed that producers with AMF systems were using practices, such as large group sizes with larger variability in calves’ age within the group, which could be negatively affecting calf welfare. Larger group sizes and variability in calves’ age can increase the risk of disease and the level of competition among calves, making group size one of the “Achilles’ heels” of AMF systems. These negative effects of large group sizes can be worsened when housing calves in poorly ventilated environments. Therefore, producers and veterinarians assisting farms with AMF should be aware of the risks of housing more than 10 calves in a group, and implement best management and feeding practices to mitigate the risk.

Before this thesis research, there were no data on the frequency of disease in calves in groups raised with AMF systems in Canada. The median and ranges of herd-level prevalence of CD (17%; 8 to 46%) and BRD (14%; 3 to 31%), and incidence risk of calf mortality (4%; 0 to 21%) showed that calf health on farms using group housing with AMF systems was not worse than on farms housing calves individually. The ranges showed the large variability between farms, but also showed that excellent calf health is achievable. The latter can be used for benchmarking and to incentivize AMF producers who are struggling with high frequency of disease and mortality in their farms.

The main factors identified to be associated with reduced prevalence of both diseases on AMF farms (Chapter 4; exclusive calving pens, isolate calves from older cattle, ensure good quality of milk, and provide clean and dry bedding), have added evidence that calf health is more dependent on management than on a type of system per se. Ventilation, quality of bedding and quality of milk fed to calves are key determinants for a successful calf rearing system. Therefore, a producer thinking of adopting AMF for group-housed calves should be aware not only of the risks that group housing could bring and how to minimize them, but also of the importance of the different practices identified in Chapter 4 that could be implemented before transitioning to group housing with automation.
Prior to this work on introducing calves to a group pen with AMF as early as the first day after birth presented in Chapter 5, the implications of this practice on calf performance and farm labour requirements were unknown. The results of this trial showed that calves introduced before 24 hours old required less overall labour for milk feeding despite requiring more assistance to learn to drink from the AMF. Early introduction of calves to the group with AMF did not impact calf growth or disease risk, so it could be said that this age of introduction can be successful. However, there could still be a trade-off between the benefits in reduced labour and calf health. Early introduced calves were found to develop diarrhea at a younger age and to have a higher risk of developing a severe case of diarrhea (vs. mild) compared with calves introduced at 5 days of age. Based on these findings, producers who currently use early introduction might have a reduction in labour for manual feeding, but there could be hidden increases in labour to treat sick calves. Hence, producers using this practice should be more careful and be sure to implement best practices regarding milk and bedding quality to reduce the pathogen load in the group pens.

6.5 OVERALL CONCLUSION

In its totality, my thesis showed that the main differences in calf management and feeding practices between MMF and AMF farms were exclusively related to housing and daily milk allowances. This work also revealed that the desire to improve the quality of life of both calves and farm personnel, along with a desire to reduce labour were highly influential factors considered by producers when adopting AMF systems. The results of my thesis also suggested that, moving forward, AMF producers should focus their efforts to maintain good calf health on appropriately managing calving facilities, ensuring calves have access to good quality milk and bedding, and keeping milk-fed calves isolated from (not sharing air/space with) older cattle. In addition, my findings showed that introducing calves to the group pen with AMF at < 1 day of age could be a viable option to reduce labour overall. However, it is important that producers using this practice be aware of the potential greater risk of severe diarrhea calves might experience when introduced at this age, and that those savings in labour should perhaps be
redirected to performing more frequent health checks and ensuring good hygiene of pens, bedding, and the AMF.
6.6 REFERENCES


Appendix 2. 1. Survey to compare management and feeding practices of milk-fed calves when fed manually vs. by automated milk feeders.

A survey to compare management and feeding practices of milk-fed dairy calves when fed manually vs. by automated milk feeders

Project funded by: Dairy Farmers of Canada

Those who complete the survey and provide their e-mail when submitting it, enter into a draw for the chance to WIN 1 of 3 $250!!!

Consent to participate in research
First, you need to consent to participate in this research

Your time is valuable!!!
Completing the survey can be done in stages if you wish; you can save what you have done and come back to it later between your farm chores or when you have more time!!!

As you answer questions, a bar will appear above the survey telling you how close you are to being finished. For technical reasons beyond our control, for producers with automated feeders this may appear to move quite slowly at the beginning - but please know that once you reach 55% completion you are almost done and it will go quite quickly from there, we promise!

I have read the information provided below and I agree to participate in this survey.
○ Yes
○ No

Section 1. Farm description (for both, producers feeding milk manually and using an automated milk feeder)

1. Farm’s location
   Town: __________, Province: __________

2. Producer’s Age
   Years old
   ○ Under 18
   ○ 18-24
   ○ 25-34
   ○ 35-44
   ○ 45-54
   ○ 55-64
   ○ 65 or Above
3. Gender
- Male
- Female

Cattle at your farm
4. What is the main breed?
- Holstein
- Jersey
- Guernsey
- Ayrshire
- Brown Swiss
- Milking shorthorn
- Canadian
- Other

5. Average number of milking cows: __________

6. Average number of calves born/month: ______

7. What type of housing do you have for your heifers and cows?
   Please select the type of housing and check the box if they have access to pasture

   Type of housing:
   - Heifers
     - Tie-stall
     - Free-stall
     - Bedded-pack (loose housing)
   - Dry cows
   - Lactating cows
   - Pasture access

8. What type of milking system do you have?
- Automatic milking system (robots)
- Milking parlour
- Pipeline milking system

   How many milking robots do you have? __________

   What type of milking parlour do you have?
   - Tandem parlour
   - Herringbone parlour
   - Parallel parlour
   - Rotary parlour
9. Do you currently use any of the following automated devices?
Check all that apply
☐ Automated grain feeders for un-weaned calves
☐ Activity collars
☐ Pedometers
☐ Automated manure scraper systems
☐ Feed pushers
☐ Cow brushes
☐ Automated milk/milk replacer feeders for calves

PRODUCERS USING AUTOMATED MILK FEEDERS
(The following sections where only for producers with automated milk feeders)

Section 2. Factors of influence
Reasons for deciding to change to automated milk feeding systems

1. Factors that influenced you to change from manual feeding to automated milk feeders
For the following points please indicate the degree of importance based on how they influenced you to take the decision to switch to automated milk feeders

Scale: Very important, Important, Neutral, Somewhat Important, Not at all Important, Not Applicable.

• Visited a farm with auto feeders/farmer testimonial.
• Heard about them at a meeting.
• Read about them online or in farm press.
• You wanted to improve working conditions.
• You wanted to modernize the barn.
• You wanted to increase interest of next generation by installing high-tech devices.
• To facilitate feeding more milk to calves without increasing labour.
• To facilitate group-housing.
• To reduce labour.
• To raise better calves.

If you had other reasons for changing to automated milk feeders not mention above, please give us details:

☐
Section 3. Producers' perceptions about automated milk feeders

1. Advantages that automated milk feeders have offered to your farm
For the following points please indicate your level of agreement based on your experience and the advantages that automated milk feeders have brought to dairy farms

Scale: Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree, Not Applicable.

- Staff spends less time feeding milk or cleaning bottles/buckets/teats.
- Improved working conditions (e.g. not having to feed outside in bad weather).
- Ability to feed more milk to calves without increasing labour.
- Easy way to record calf milk consumption information.
- Earlier detection of sick calves.
- Calves are healthier.
- Calves grow better.
- Calves can express more natural feeding behaviour (i.e. teat-feeding, more meals/day, more milk, gradual weaning).
- Easier group-housing management.
- Calves are more playful.

Based on your experience, are there other advantages of using automated milk feeders not listed above? If so, please write them here:


2. Shortcomings of using automated milk feeders at dairy farms?
For the following points please indicate your level of agreement based on your experience and the shortcomings you have found out using automated milk feeders

- No clear savings in labour.
- The cleaning process is time consuming.
- To be able to offer milk ad libitum (no milk amount limitation), the feeder will not record individual data.
- Feeders break down often.
- Difficulty getting technical support when needed.
- Management of the feeders requires a lot of training.
- Less direct contact with calves.
- Calves are more fearful and aggressive.
Based on your experience, are there other shortcomings associated with using automated milk feeders not listed above? If so, please write them here:

3. Now that you have automated milk feeder(s), what do you think about feeding calves manually (by hand)?
For the following points please indicate your level of agreement based on your experience.

- It was inefficient.
- It made me more tied to a set schedule.
- It was fine when we were feeding a small number of calves.
- It is fine for only feeding milk during the first days of life of a calf.
- Using manual feeding would make it more difficult to follow the Recommendations of the Dairy Code of Practice regarding calves’ care using.
- It is tiring (more work/effort).
- It was limiting the growth and performance of my calves.
- If could still be okay for calves, if they were fed manually 3 times per day, or more.

Based on your experience, are there other opinions you have about manual milk feeding after having now automated milk feeders at your farm? If so, please write them here:

4. Overall, how satisfied do you feel with the automated milk feeders at your farm?
   □ Very Satisfied  □ Satisfied  □ Neutral  □ Dissatisfied  □ Very Dissatisfied

5. Would you recommend the use of automated milk feeders to other producers still using manual feeding?
   ○ Yes
   ○ No
Section 4. Setting up the automated milk feeder

1. What is the make of your automated milk feeders? Please select the make of your feeders from the list. If other, please specify in the box below.
   Make:
   - DeLaval - Förster Technik
   - Lely - Förster Technik
   - GEA - Förster Technik
   - Urban
   - Holm & Laue
   Other, please specify: ____________________

2. What year did you start using automated milk feeders at your farm? _______

3. Before installing automated milk feeders, what was the last MAIN method you used to feed milk to your calves?
   - Open bucket
   - Teat bucket
   - Teat bottle
   - Milk bar (a single milk source [i.e. big bucket] with multiple teats)
   - Other, please specify: __________

4. Before installing automated milk feeders, how often did you feed your calves?
   - 1 time/day
   - 2/day
   - 3/day
   - 4/day
   - Other, please specify: __________

5. Before installing automated milk feeders, on average how much milk in total did you normally offer to each calf per day? Litres of milk/day/calf: __________

6. Did you build a new barn to accommodate the automated milk feeder(s)?
   - Yes
   - No

7. Did you renovate an existing barn or facility to accommodate the automated milk feeder(s)?
   - Yes
   - No

8. How many pens have access to an automated milk feeder? __________
9. How many automated milk feeders and milk feeding stations (teats) per feeder do you have?
   - Automated milk feeders: __________
   - Milk feeding stations (teats) per feeder: __________

10. Do you have more than one milk feeding station (teats) per pen?
   - Yes
   - No

11. Do your automated milk feeders that serve multiple pens offer simultaneous feeding (i.e. have a pump so that multiple milk feeding stations (teats) can feed at the exact same time)?
   - Yes
   - No

   If no, do you use the "preference mode" to give priority to certain calves to access the feeder?
   - Yes
   - No

   If yes, what criteria do you use to set up "priority"?
   Please check all that apply
   - Priority for calves that have triggered an alarm because low milk consumption
   - Priority for calves receiving a special treatment (i.e. medicated)
   - Priority for calves up to certain age or feeding day (e.g. calves under 7 days old)
   - Priority for a specific milk feeding station (teat) (i.e. all calves fed at that station)
   - Priority for calves that have triggered an alarm because poor weight gain
   - Priority for calves that have triggered an alarm because of illness

12. Do you use specific software (e.g. Kalfmanager) to visualize feeder data on your desktop or laptop computer?
   - Yes
   - No, I check data directly from hand held terminals

Section 5. Management and care of calves during first days of life

- General care and colostrum feeding practices

1. Do you disinfect the umbilical cord (navel)?
   - Yes
   - No
2. How many times do you give colostrum to each newborn calf?
   # days of colostrum feeding:  
   - Only during 1st 24 hours of life
   - During first 2 days of life
   - During first 3 days of life
   - During first 4 days of life
   
   # colostrum feedings/day:  

3. When is the first meal of colostrum usually given?
   - Within 6 hours of birth
   - Within 12 hours
   - Within 24 hours
   - Other, please specify:  

4. How much colostrum in total do you give in the first 12 hours of life?
   - 2 litres or less
   - 4 litres
   - 6 litres
   - Other, please specify:  

5. Do you assess colostrum quality?
   - Yes
   - No
   - Sometimes

6. What do you use to assess colostrum quality?
   Please select all that apply
   - Colour/consistency
   - Colostrometer
   - Refractometer
   - Other, please specify:  

7. How do you offer colostrum to the calves?
   Please select all that apply
   - Open bucket
   - Teat bucket
   - Teat bottle
   - Esophageal tube
   - Other, please specify:  

Housing practices during the first days of life

8. How long do you keep the calf with the dam?
   □ Immediate removal
   □ Between 1-2 hours
   □ Between 3-6 hours
   □ Between 7-12 hours
   □ Between 12-24 hours
   □ Other, please specify: __________

9. What is the main reason for you to have this practice?
   Explain briefly: ____________________________________________

10. After dam-calf separation, do your calves go right away into the automated milk feeder pen?
    □ Yes
    □ No

11. Once the dam and calf are separated, where do you house your calves?
    Indoor vs. outdoor  Individual vs. group
    Housing          □ Indoor pen   □ Individual
                      □ Outdoor pen  □ Pair
                      □ Outdoor hutch □ Group

   If other type of housing is used, please specify here: ________________

12. What bedding material do you use for calves during first days of life?
    □ Straw
    □ Sawdust
    □ Dried manure solids
    □ Sand
    □ Mix of straw and sawdust
    □ Other, please specify
• Milk feeding practices before introducing calves into the automated feeder pen

13. What is the main type of milk you use to feed calves before they go to automated milk feeders?
   Please select the MAIN type you use at your farm.
   ○ Whole milk (saleable)
   ○ Waste milk (transition cow milk, milk from treated cows)
   ○ Milk replacer
   ○ Other

14. Do you pasteurize the milk before feeding calves?

15. Do you acidify the milk or milk replacer before feeding calves?
   ○ Yes
   ○ No
   ○ Not necessary because I use commercial acidified milk replacer

16. Do you use another type of additive to preserve the milk or milk replacer (e.g., Hydrogen peroxide)?
   ○ Yes, please specify: ________________
   ○ No

17. How much milk per day do you offer to calves during the period prior to introduction to the automated feeder pen?
   Litres/day: ________

18. How many times per day do you feed your calves during the period prior introduction to the automated feeder pen?
   # meals/day: ________

19. How do you offer milk to your calves during the period prior introduction to the automated feeder pen?
   ○ Open bucket
   ○ Teat bucket
   ○ Teat bottle
   ○ Milk bar (a single milk source [i.e. big bucket] with multiple teats)
   ○ Other, please specify: ____________________

20. Do you warm up the milk before feeding?
   ○ Yes
   ○ No
Section 6. Transitioning calves to the automated milk feeder

1. What criteria do you use to decide when to move a calf to automated milk feeder pen?
   You move your calves to automated milk feeding based on:
   Select all that apply.
   □ Age
   □ Health (vigor)
   □ Smartness
   □ Weight
   □ Amount of milk consumed per day before introduction
   □ Disbudding day
   □ Other, please specify: ____________

2. On average, at what age do you usually move calves to automated milk feeding?
   ____________ days old.

3. How do you train the calves to use the automated milk feeder?
   Please check all the steps that apply. If none is applicable or you have additional steps,
   please select "Other" and use the box below to complement the answer.
   □ Calf does not get fed before going into the automated milk feeder pen.
   □ Calf is manually fed and immediately introduced into the automated milk feeder pen.
   □ Calf is introduced into the automated milk feeder pen and it is allowed to explore.
   □ Calf is introduced and is immediately pushed into the automated milk feeding station
     until it starts to suck.
   □ Calf is introduced and is manually fed in the automated milk feeding station.
   □ Other. Please explain in the box below.

Other ways of training calves to use automated milk feeders:

4. How many times per day during the first day of introduction, do you push the calf
   into the automated milk feeder chute?
   □ Once
   □ Twice
   □ 3 times
   □ As many as required until calf drinks by its own
   □ Other, please specify:
5. How many days do you help the calf to go into the automated milk feeder chute and suck?
- Only during the first day
- During 2 days
- During 3 days
- As many as required until calf drinks by its own

6. On average, would you say that the majority of calves start drinking from the feeder without problem the first day of introduction and no more pushing is required the following days?

7. Based on your experience on how fast calves learn to use the automated milk feeder, write what percentage of your calves fall into each of the 3 following categories:
   - Percentage of calves that learn the first day of introduction (fast learning): ___%
   - Percentage of calves that take a couple of days to learn: ___%
   - Percentage of calves that take more than 3 days to learn: ___%

8. If a calf definitely does not learn how to use the feeder, what do you do?
- Move it to an individual pen and feed it manually during all the milk feeding period
- Discard the calf
- I do not know, it has never happened in my farm
- Other, please specify: ___________

9. How much is the maximum time you wait for deciding that a calf did not learn how to use the feeder and remove it from the group? ___________
Section 7. Management and care of automated milk-fed calves

• Feeding Practices

We previously asked you about type of milk fed to calves during first days of life. If the same type of milk is fed to calves through automated milk feeders select YES, if it is different select NO. (If no, person will be directed to questions on milk type, pasteurization and acidification)

1. What is your milk feeding program?
Please for each of the periods that compose your milk feeding schedule specify the length (# of days) and the volume of milk offered per day per calf

<table>
<thead>
<tr>
<th>Period</th>
<th># of days in each period</th>
<th>Milk volume (litres/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2. What is the minimum meal size?
Litres: __________

3. What is the maximum meal size?
Litres: __________

4. What other feed do you offer to automated milk-fed calves and at what age do you start offering it?
Amount: Restricted amount or Ad Libitum (calf can eat/drinks all she wants)

- □ Calf starter (concentrate): Amount: ________ Age: ________
- □ Hay: Amount: ________ Age: ________
- □ Total Mixed Ration: Amount: ________ Age: ________
- □ Straw: Amount: ________ Age: ________
- □ Water: Amount: ________ Age: ________
- □ Other: Please specify: ________ Amount: ________ Age: ________
• Housing and pen management

5. What type of housing do you have for automated milk-fed calves?
  o Indoor housing
  o Outdoor housing

6. What is the bedding material for pens with automated milk feeders?
   Winter   Summer
   Straw     □    □
   Sawdust   □    □
   Dried manure solids □    □
   Sand      □    □
   Other: __________ □    □

7. How often do you add more bedding material to pens with automated milk feeders?
  o Once a day
  o Once a week
  o Twice a week
  o 3 times a week
  o Every 2 weeks
  o Every 3 weeks
  o Once a month
  o When necessary. Please specify what criteria you use: __________________________
  o Other, please specify: __________________________

8. What is the maximum number of calves you keep in a group pen?
   Average of the maximum number of calves per pen with automated milk feeders:

9. What is the maximum age difference within a group of calves in a pen (approximately)?

10. What type of ventilation do you have for calves fed with automated milk feeders?
    Please select all that apply
    □ Natural ventilation - outdoor
    □ Natural ventilation - open barn/pen
    □ Natural ventilation - curtain barn
    □ Artificial ventilation - positive pressure ventilation
    □ Artificial ventilation - negative pressure ventilation
    □ Other, please specify: __________________________
11. Do calves share airspace with heifers and/or cows? 

12. During cold months, do you allow deeper bedding for insulation?
   ○ Yes
   ○ No

13. Do you have another source of heating in the calf barn?
   ○ Yes. Please specify: ______________________
   ○ No

14. Do you provide an outdoor shelter?
   ○ Yes. Please specify: ______________________
   ○ No

15. How often are automated milk feeder pens cleaned (all bedding removed)?
   ○ Never
   ○ Weekly
   ○ Every 2 weeks
   ○ Monthly
   ○ Every 2 months
   ○ When all calves in the pen are weaned
   ○ Other, please specify: ______________________

16. How often are automated milk feeder pens disinfected? 

* Weaning program

17. How do you decide when to start weaning a calf?
   Please select all that apply
   □ Based on age
   □ Based on starter intake
   □ Based on weight
   □ Based on general appearance
   □ Based on previous illness

18. Are weaned calves removed immediately from the pen? 

19. For how long after weaning do calves stay in the pen?
   ○ Between 1-2 days
   ○ Between 3-4 days
   ○ Between 5-7 days
   ○ 2 weeks
   ○ 3 weeks
20. Where do the weaned calves go?
   - To another outdoor pen
   - To another pen in the same barn
   - To heifer barn
   - To lactating or dry cow barn
   - Other, please specify: ______________________

• Monitoring calves’ health

1. How often do you perform physical health checks?
   Checking the calves closely
   - Daily
   - Once a week
   - Twice a week
   - Every two weeks
   - Every four weeks
   - Other, please specify: ______________________

2. How often do you check the hand held terminal of the feeder to monitor calves’ performance data (feeding behaviour data)?
   - Once a day
   - Twice a day
   - 3 times a day
   - Every time person in charge is in the barn.
   - Other, please specify: ______________________

3. What performance data from the automated milk feeder do you use more often to identify sick calves?
   Please rank in order of importance based on your experience.
   
<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
</table>
   Milk intake |   |   |   |   |
   Number of visits to the feeder |   |   |   |   |
   Drinking speed |   |   |   |   |
   ______________________

4. When do you decide to do a physical health check to a calf that shows negative changes in performance based on the hand held terminal data?
   Please explain briefly (for example when milk intake has decrease 50% over certain period of time you go and examine the calf)

   ______________________
5. When performing physical health check, what are the top 3 signs you check first?
- Position of ears
- Attitude (weak, depressed)
- Signs of diarrhea
- Runny nose
- Body temperature
- Coughing
- Dehydration
- Eye secretion

6. What do you think are the main health problems in your calf barn?
Please rank the given options in order of importance based on your experience. "Other" options are provided in case you have health problems not listed.

- Diarrhea
- Respiratory problems
- Navel infections
- Injuries
- Other #1: __________
- Other #2: __________
- Other #3: __________
- Not applicable

Please specify what specific health problems you meant for "Other", above.

Final section (8). Person in charge of calves' care

The following demographic data are collected only for the purpose of determining features of people in charge of looking after the calves at dairy farms.

1. In a given year, how many people are in charge of calves' care on your farm?
- 1 person
- 2 people
- 3 people
- 4 people
- 5 people
- Other, please specify: __________
2. Who is the person looking after the calves?
   - Producer/Owner/family member
   - Farm hired staff
   - Volunteers
   - Other, please specify: __________

3. Age, gender and education level of the person(s) looking after the calves
   Specify for each person:
   - Gender: Male, female
   - Education level: none, primary school, high school, college or higher
   - Age

4. In a given year, do the people in charge of calves’ care tend to be the same?
   Check all that apply
   - Yes, personnel is pretty constant
   - No, personnel rotates quite often

Would you like to be part of the second part of this project? (question only for producers with automated milk feeders)

We are especially interested in the experiences of dairy farmers using automated calf feeders. In the second stage of our project we will be visiting some of these farms.

If you might be willing to let us visit your farm please provide us with your contact details and we will be in touch.

Providing your contact information is in no way a commitment on your part to be involved in the second part of this project it is just to say that you may be willing to have us visit your farm, and answer a few more questions.

Name
Email
Telephone
Number
Good time(s) to try and reach you
PRODUCERS USING MANUAL FEEDING FOR MILK-FED CALVES

Section 2. Factors of influence
Reasons for using manual feeding to offer milk to calves

1. Factors that have influenced you to use manual feeding methods
For the following points please indicate the degree of importance based on how much they influence you to continue using manual milk feeding

Scale: Very important, Important, Neutral, Somewhat Important, Not at all Important, Not Applicable.

* This method has been in the family for generations
* Small farm size
* Manual feeding is low input cost
* Have heard no positive experiences with automated milk feeders from other producers
* High cost of investing in new facilities for group housing
* High cost of investment in new equipment (i.e. automated milk feeders)

If you have other reasons that have influenced you to use manual feeding, please give us details:


Section 3. Producers’ perceptions about their milk feeding system (manual)

1. Advantages that manual feeding has offered to your farm
For the following points please indicate your level of agreement based on your experience and the advantages that manual feeding has brought to your farm

Scale: Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree, Not Applicable.

* Direct contact with calves every day facilitates detection of illness.
* Direct contact with calves every day facilitates handling of animals.
* Feeding calves is relatively straightforward for staff to learn to do.
* Manual feeding can be done without concerns about technical issues (e.g. power failure).
* Individual feeding (e.g. one bottle/calf) reduces risk of disease transmission.
* Individual housing reduces risk of disease transmission.
Based on your experience, are there other advantages of using manual feeding not listed above? If so, please write them here:


2. Shortcomings of using manual feeding for offering milk to calves
For the following points please indicate your level of agreement based on your experience and the shortcomings you have found out using manual feeding

- No savings in labour.
- Cleaning process of buckets, bottles and/or teats is time consuming.
- Time consuming to feed each calf.
- Difficult working conditions in winter if calves are in outdoors housing (e.g. hutches).
- Difficult to give more than 2 or 3 feedings per day.
- Difficult to give large milk amounts to calves per day.
- Measuring milk amount or milk replacer powder quantity is time consuming.
- Difficult to get time off from farm activities.

Based on your experience, are there other shortcomings associated with using manual feedings not listed above? If so, please write them here:


3. Overall, how satisfied do you feel with your manual milk feeding system?
☐ Very Satisfied  ☐ Satisfied  ☐ Neutral  ☐ Dissatisfied  ☐ Very Dissatisfied

4. Have you heard about automated milk feeders for rearing calves?
Please select all that apply
☐ No, I have never heard about automated milk feeders
☐ Yes, I learned about them on a farm tour/visit.
☐ Yes, I learned about them from another farmer who uses one.
☐ Yes, I heard about them at a dairy meeting.
☐ Yes, I read about them online or in farm press.
☐ Yes, a veterinarian told me about them
5. What benefits do you think automated milk feeders could potentially bring to your farm?
Please select all that apply
- They could improve labour working conditions (e.g., not having to feed outside in bad weather, or lifting heavy buckets).
- They could make calf feeding more interesting for the next generation (installing high-tech devices).
- They could facilitate feeding more milk to calves without increasing labour.
- They could facilitate group-housing.
- They could potentially reduce labour.
- Detecting sick calves would be easier.
- Calves could be healthier.
- Calves could grow better.
- They will allow calves to express more natural feeding behaviour (i.e. more meals/day, more milk, gradual weaning).

6. Are you considering changing to automated milk feeding system? ______

7. When would you hope to start using automated milk feeders?
- This year (before 2014 ends)
- Next year (in 2015)
- In a couple of years (before 2017)
- Other, please specify: ______

Section 4. Management and care of un-weaned calves

- General care and colostrum feeding practices

1. Do you disinfect the umbilical cord (navel)?
- Yes
- No

2. How many times do you give colostrum to each newborn calf?
# days of colostrum feeding: 
- Only during 1st 24 hours of life
- During first 2 days of life
- During first 3 days of life
- During first 4 days of life

# colostrum feedings/day: _______________
3. When is the first meal of colostrum usually given?
   ○ Within 6 hours of birth
   ○ Within 12 hours
   ○ Within 24 hours
   ○ Other, please specify: ____________

4. How much colostrum in total do you give in the first 12 hours of life?
   ○ 2 litres or less
   ○ 4 litres
   ○ 6 litres
   ○ Other, please specify: ____________

5. Do you assess colostrum quality?
   ○ Yes
   ○ No
   ○ Sometimes

6. What do you use to assess colostrum quality?
   Please select all that apply
   □ Colour/consistency
   □ Colostrometer
   □ Refractometer
   □ Other, please specify: ____________

7. How do you offer colostrum to the calves?
   Please select all that apply
   □ Open bucket
   □ Teat bucket
   □ Teat bottle
   □ Esophageal tube
   □ Other, please specify: ____________

   * Housing practices

1. How long do you keep the calf with the dam?
   □ Immediate removal
   □ Between 1-2 hours
   □ Between 3-6 hours
   □ Between 7-12 hours
   □ Between 12-24 hours
   □ Other, please specify: ________________
2. What is the main reason for you to have this practice? 
Explain briefly:

3. Once the dam and calf are separated, where do you house your calves? 
   Indoor vs. outdoor   Individual vs. group
   Housing            o Indoor pen    o Individual
                        o Indoor hutch  o Pair
                        o Outdoor pen   o Group
                        o Outdoor hutch

If other type of housing is used, please specify here

4. For how long do calves stay in this type of housing?
   o Until they are weaned
   o 1 day
   o 2 days
   o 3 days
   o 4 days
   o 5 days
   o 6 days
   o 7 days
   o Other, please specify: _______

5. Where are they moved after?
   Indoor vs. outdoor   Individual vs. group
   Housing             o Indoor pen    o Individual
                        o Indoor hutch  o Pair
                        o Outdoor pen   o Group
                        o Outdoor hutch
If other type of housing is used, please specify here

6. What is the maximum number of calves you keep in a group pen?
(Only for those using pair/group housing)

- 2
- 3
- 4
- 5
- 6
- 7
- 8
- 9
- 10
- Between 11 and 15
- Between 16 and 20
- Between 21 and 25
- Between 26 and 30
- Between 31 and 35
- Between 36 and 40
- Between 41 and 45
- Between 46 and 50
- Between 51 and 55
- Between 56 and 60
- More than 60

What is the maximum age difference within a group of calves in a pen (approximately)?

- Less than a week
- 1 week
- 2 weeks
7. What is the primary bedding material for the milk-fed calves?
   Winter   Summer
   Straw     □   □
   Sawdust   □   □
   Dry manure □   □
   Sand      □   □
   Other     □   □

   If other bedding material not listed above is used please specify it:
   ________________________________

8. How often do you add more bedding material?
   ○ Once a day
   ○ Once a week
   ○ Twice a week
   ○ 3 times a week
   ○ Every 2 weeks
   ○ Every 3 weeks
   ○ Once a month
   ○ When necessary. Please specify what criteria you use: ________________________________
   ○ Other, please specify: ________________________________
9. How often are un-weaned calves’ pens cleaned (all bedding removed)?  
- Never  
- Weekly  
- Every 2 weeks  
- Monthly  
- Every 2 months  
- When calves are weaned  
- Other, please specify...  

10. How often are un-weaned calves’ pens disinfected?  
- Never  
- Weekly  
- Every 2 weeks  
- Monthly  
- Every 2 months  
- When calves are weaned  
- Other, please specify...  

11. What type of ventilation do you have?  
Select all that apply  
- Natural ventilation - outdoor housing  
- Natural ventilation - open barn  
- Natural ventilation - curtain barn  
- Artificial ventilation - positive pressure tubes  
- Artificial ventilation - negative pressure ventilation  
- Other, please specify...  

12. Do calves share airspace with heifers and/or cows?  
- Yes  
- No
13. During cold months, do you allow deeper bedding for insulation?
   - Yes
   - No

14. Do you have another source of heating for the calves?
   - Yes. Please specify: ______________________
   - No

15. Do you provide an outdoor shelter?
   - Yes. Please specify: ______________________
   - No

* Feeding practices

16. How do you offer milk to the calves after colostrum feeding has finished?
    Please select all the methods you use to feed milk to your calves during the milk feeding period:
    - Open bucket
    - Teat bucket
    - Teat bottle
    - Milk bar (a single milk source [i.e. big bucket] with multiple teats)
    - Other, please specify: ______________________

17. Has this always been your method of feeding, or have you switched?
    - Yes, this has always been the method of feeding at our farm
    - No, I switched from ________________
18. For your choices above, please specify when you use each of your methods of feeding throughout the milk feeding period

<table>
<thead>
<tr>
<th>Method</th>
<th>1 week old</th>
<th>2 weeks old</th>
<th>3 weeks old</th>
<th>4 weeks old</th>
<th>5 weeks old</th>
<th>6 weeks old</th>
<th>7 weeks old</th>
<th>8 weeks old</th>
<th>9 weeks old</th>
<th>10 weeks old</th>
<th>11 weeks old</th>
<th>12 weeks old</th>
<th>13 weeks old</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open bucket</td>
<td>o</td>
<td>o</td>
<td>o</td>
<td>o</td>
<td>o</td>
<td>o</td>
<td>o</td>
<td>o</td>
<td>o</td>
<td>o</td>
<td>o</td>
<td>o</td>
<td>o</td>
</tr>
<tr>
<td>Text bucket</td>
<td>o</td>
<td>o</td>
<td>o</td>
<td>o</td>
<td>o</td>
<td>o</td>
<td>o</td>
<td>o</td>
<td>o</td>
<td>o</td>
<td>o</td>
<td>o</td>
<td>o</td>
</tr>
<tr>
<td>Text bottle</td>
<td>o</td>
<td>o</td>
<td>o</td>
<td>o</td>
<td>o</td>
<td>o</td>
<td>o</td>
<td>o</td>
<td>o</td>
<td>o</td>
<td>o</td>
<td>o</td>
<td>o</td>
</tr>
<tr>
<td>Milk bar</td>
<td>o</td>
<td>o</td>
<td>o</td>
<td>o</td>
<td>o</td>
<td>o</td>
<td>o</td>
<td>o</td>
<td>o</td>
<td>o</td>
<td>o</td>
<td>o</td>
<td>o</td>
</tr>
<tr>
<td>Not applicable</td>
<td>o</td>
<td>o</td>
<td>o</td>
<td>o</td>
<td>o</td>
<td>o</td>
<td>o</td>
<td>o</td>
<td>o</td>
<td>o</td>
<td>o</td>
<td>o</td>
<td>o</td>
</tr>
</tbody>
</table>

19. Reasons for using open buckets (for those using buckets)

Please for the following indicate your level of agreement based on your experience at your farm:

Scale: Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree, Not Applicable.

- Easier to clean and disinfect
- Easier to fill up with milk
- Calves drink faster reducing time required to feed calves
- They are cheaper
- They do not need to be replaced that often
- Teaches calves to drink earlier so they will also drink water from an early age

Based on your experience, are there other reasons for using open buckets not listed above? If so, please write them here:

20. Do your un-weaned calves perform sucking behaviour?

☐ Yes, they suck walls/bars
☐ Yes, they suck other calves (cross-sucking)
☐ Yes, they suck a teat provided at their pen (enrichment)
☐ No, they do not
☐ Other, please specify
21. Reasons for using teats (for those using teat bucket/bottle/milk bar)
Please for the following indicate your level of agreement based on your experience at your farm:

Scale: Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree, Not Applicable.
- They allow calves to have a more natural feeding
- When sucking from a teat, calves have less diarrhea
- Allows calves to have longer meals
- Helps to reduce sucking frequency of bars and walls
- Helps to reduce frequency of cross-sucking

Based on your experience, are there other reasons for using teats not listed above? If so, please write them here:

22. Is the teat left available for calves to suck after milk intake has finished?
- Yes
- No
- No necessary because calves have an extra teat attached to the pen (enrichment)

23. What is the main type of milk you use to feed calves?
Please select the MAIN type of milk you use
- Whole milk (saleable)
- Waste milk (transition cow milk, milk from treated cows)
- Milk replacer
- Other, please specify... 

24. Do you pasteurize the milk before feeding calves?
- Yes
- No

25. Do you acidify the milk or milk replacer before feeding calves?
- Yes
- No
- Not necessary because I use commercial acidified milk replacer
26. Do you use another type of additive to preserve the milk or milk replacer (e.g., Hydrogen peroxide)?
   ○ Yes. Please specify: ____________________
   ○ No

27. How much milk per day do you feed to a calf during the first week of life?
   Please indicate the amount of milk offered to each calf at each age listed:
   
<table>
<thead>
<tr>
<th>Age</th>
<th>1 L</th>
<th>2 L</th>
<th>3 L</th>
<th>4 L</th>
<th>5 L</th>
<th>6 L</th>
<th>7 L</th>
<th>8 L</th>
<th>9 L</th>
<th>10 L</th>
<th>11 L</th>
<th>12 L</th>
<th>&gt;12 L</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 day</td>
<td>O</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 days</td>
<td>O</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 days</td>
<td>O</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 days</td>
<td>O</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 days</td>
<td>O</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 days</td>
<td>O</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7 days</td>
<td>O</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

28. How much milk per day do you feed to a calf from 2 weeks old to the end of the milk feeding period?
   Please indicate the amount of milk offered to each calf at each age listed:
   
<table>
<thead>
<tr>
<th>Age</th>
<th>0 Lims</th>
<th>1 L</th>
<th>2 L</th>
<th>3 L</th>
<th>4 L</th>
<th>5 L</th>
<th>6 L</th>
<th>7 L</th>
<th>8 L</th>
<th>9 L</th>
<th>10 L</th>
<th>11 L</th>
<th>12 L</th>
<th>&gt;12 L</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 weeks</td>
<td>O</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 weeks</td>
<td>O</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 weeks</td>
<td>O</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 weeks</td>
<td>O</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 weeks</td>
<td>O</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7 weeks</td>
<td>O</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8 weeks</td>
<td>O</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9 weeks</td>
<td>O</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 weeks</td>
<td>O</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11 weeks</td>
<td>O</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12 weeks</td>
<td>O</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
29. In how many meals per day do you split the total amount of milk offered to the calves?
- 1 meal/day
- 2 meals/day
- 3 meals/day
- 4 meals/day
- Other, please specify: __________

30. Do you warm up the milk before feeding?
- Yes
- No

31. What other feed do you offer to automated milk fed calves and at what age do you start offering it?
Amount: Restricted amount or Ad Libitum (calf can eat/drinks all she wants)
- Calf starter (concentrate): Amount: _______ Age: _______
- Hay: Amount: _______ Age: _______
- Total Mixed Ration: Amount: _______ Age: _______
- Straw: Amount: _______ Age: _______
- Water: Amount: _______ Age: _______
- Other. Please specify: __________: Amount: _______ Age: _______

* Weaning period

32. How do you decide when to start weaning a calf?
Select all that apply
- Based on age
- Based on starter intake
- Based on weight
- Based on general appearance
- Based on previous illness

33. If you wean primarily based on age, what age would you start weaning your calves?
Weeks old: __________
34. How long is the weaning period? _______ days

35. What method do you use for weaning?
   o Diluting the concentration of the milk/milk replacer gradually, over time
   o Reducing the volume of milk the calf is fed gradually, over time

Please explain how you dilute the milk throughout the weaning period

Please explain how you reduce the milk volume throughout the weaning period
   For example: "I decrease 1 L of milk every day"

36. Are weaned calves moved immediately to other pen?
   o Yes
   o No

37. For how long after weaning do calves stay in their pen?
   o Between 1-2 days
   o Between 3-4 days
   o Between 5-7 days
   o 2 weeks
   o 3 weeks
   o Other, please specify: ______________________

38. Where do the weaned calves go?
   o To another pen outdoors
   o To another pen in the same barn
   o To a group hutch
   o To heifer barn
   o To lactating or dry cow barn
   o Other, please specify... ______________________
• Monitoring calves' health

39. How often do you perform physical health checks?
Checking the calves closely
○ Daily
○ Once a week
○ Twice a week
○ Every two weeks
○ Every four weeks
○ Other, please specify... ______________________

40. Out of your physical health check routine, what makes you go and do a physical evaluation of a specific calf?
Please rank the options in order of importance based on your experience.

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>I do not used it</th>
</tr>
</thead>
<tbody>
<tr>
<td>Milk intake is decreasing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>o o o o</td>
</tr>
<tr>
<td>Calf drinks milk slower than usual</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>o o o o</td>
</tr>
<tr>
<td>Calf is weak/depressed</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>o o o o</td>
</tr>
<tr>
<td>Hair coat is dull and rough</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>o o o o</td>
</tr>
</tbody>
</table>

Please, write up other aspects that are important for you and we did not cover above ______________________

41. When performing physical health check, what are the top 3 signs you check first?

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Position of ears</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Attitude (weak, depressed)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Signs of diarrhea</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Runny nose</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Body temperature</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Coughing ○ ○ ○
Eye secretion ○ ○ ○
Dehydration ○ ○ ○
Decrease milk intake ○ ○ ○

Please, write up other signs of illness that are important for you and we did not cover above.
Please write in brackets the level of importance like for the ones above.

42. What do you think are the main health and performance problems of your milk-fed calves?
Please rank the given options in order of importance based on your experience. "Other" options are provided in case you have health problems not listed.

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>Not applicable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diarrhea</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Respiratory problems</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Navel infections</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Injuries</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Other #1: _______</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Other #2: _______</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Other #3: _______</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
</tbody>
</table>

Final section (5). Person in charge of calves' care

The following demographic data are collected only for the purpose of determining features of people in charge of looking after the calves at dairy farms.

1. In a given year, how many people are in charge of calves' care on your farm?
   ○ 1 person
   ○ 2 people
   ○ 3 people
   ○ 4 people
   ○ 5 people
   ○ Other, please specify: __________

2. Who is the person looking after the calves?
   ○ Producer/Owner/family member
   ○ Farm hired staff
3. Age, gender and education level of the person(s) looking after the calves
   Specify for each person:
   Gender: Male, female.
   Education level: none, primary school, high school, college or higher
   Age

4. In a given year, do the people in charge of calves' care tend to be the same?
   Check all that apply
   ○ Yes, personnel is pretty constant
   ○ No, personnel rotates quite often

Don't forget... by submitting the survey you have the chance to WIN 1 of 3 $250 prizes!!!!

Please give us your email address and winners will be notified via email once the survey is closed.

Thank you so much!!! We know how valuable your time is! Thus, we really appreciate you took the time and patience to fill up this survey and contribute with our research!
Appendix 2.2. Summary of newborn and colostrum management practices by farms with automated milk feeders (AMF) and farms using manual milking feeding (MMF) systems for raising dairy calves derived from an online questionnaire completed by 670 dairy producers in Canada

<table>
<thead>
<tr>
<th>Management practices</th>
<th>AMF</th>
<th>95% CI</th>
<th>MMF</th>
<th>95% CI</th>
<th>All participant farms</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>%</td>
<td>LCL</td>
<td>UCL</td>
<td>n</td>
<td>%</td>
</tr>
<tr>
<td>Navel disinfection</td>
<td>95</td>
<td>64</td>
<td>54</td>
<td>74</td>
<td>545</td>
<td>58</td>
</tr>
<tr>
<td>Cow-calf separation within 24 h after birth</td>
<td>95</td>
<td>100</td>
<td>96</td>
<td>100</td>
<td>535</td>
<td>97</td>
</tr>
<tr>
<td>First meal of colostrum within 6 h after birth</td>
<td>95</td>
<td>87</td>
<td>79</td>
<td>93</td>
<td>544</td>
<td>86</td>
</tr>
<tr>
<td>Colosstm feeding method</td>
<td>96</td>
<td></td>
<td></td>
<td></td>
<td>563</td>
<td></td>
</tr>
<tr>
<td>Teat</td>
<td></td>
<td>88</td>
<td>80</td>
<td>94</td>
<td>81</td>
<td>77</td>
</tr>
<tr>
<td>Esophageal tube</td>
<td></td>
<td>10</td>
<td>5</td>
<td>18</td>
<td>7</td>
<td>5</td>
</tr>
<tr>
<td>Open bucket</td>
<td></td>
<td>1</td>
<td>0</td>
<td>6</td>
<td>8</td>
<td>6</td>
</tr>
<tr>
<td>Colostrum amount fed in the first 12 h of life</td>
<td>92</td>
<td></td>
<td></td>
<td></td>
<td>557</td>
<td></td>
</tr>
<tr>
<td>3 L or less</td>
<td>11</td>
<td>5</td>
<td>19</td>
<td></td>
<td>14</td>
<td>11</td>
</tr>
<tr>
<td>4 to 5 L</td>
<td>53</td>
<td>42</td>
<td>64</td>
<td></td>
<td>50</td>
<td>46</td>
</tr>
<tr>
<td>6 L or above</td>
<td>31</td>
<td>22</td>
<td>42</td>
<td></td>
<td>29</td>
<td>25</td>
</tr>
<tr>
<td>Ad lib colostrum</td>
<td>4.3</td>
<td>1</td>
<td>11</td>
<td></td>
<td>2</td>
<td>0.9</td>
</tr>
<tr>
<td>Colostrum quality is evaluated always</td>
<td>96</td>
<td>25</td>
<td>17</td>
<td>35</td>
<td>546</td>
<td>22</td>
</tr>
</tbody>
</table>

\(^1\)Confidence interval (CI), lower confidence limit (LCL) and upper confidence limit (UCL).
Appendix 2.3. Summary of housing practices of calves during the milk feeding period by farms with automated milk feeders (AMF) and farms using manual milking feeding (MMF) systems for raising dairy calves derived from an online questionnaire completed by 670 dairy producers in Canada

<table>
<thead>
<tr>
<th>Management practices</th>
<th>AMF n</th>
<th>AMF %</th>
<th>AMF 95% CI LCL</th>
<th>AMF 95% CI UCL</th>
<th>MMF n</th>
<th>MMF %</th>
<th>MMF 95% CI LCL</th>
<th>MMF 95% CI UCL</th>
<th>All participant farms n</th>
<th>All participant farms %</th>
<th>All participant farms 95% CI LCL</th>
<th>All participant farms 95% CI UCL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group housing</td>
<td>105</td>
<td>100</td>
<td>96</td>
<td>100</td>
<td>526</td>
<td>24</td>
<td>20</td>
<td>28</td>
<td>631</td>
<td>36</td>
<td>33</td>
<td>41</td>
</tr>
<tr>
<td>Among farms using group housing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group size</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pair housing</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>125</td>
<td>26</td>
<td>18</td>
<td>34</td>
<td>211</td>
<td>15</td>
<td>11</td>
<td>21</td>
</tr>
<tr>
<td>Groups of 3 to 9 calves</td>
<td>86</td>
<td>25</td>
<td>16</td>
<td>35</td>
<td>125</td>
<td>64</td>
<td>55</td>
<td>72</td>
<td>211</td>
<td>48</td>
<td>41</td>
<td>55</td>
</tr>
<tr>
<td>Groups of 10 to 15 calves</td>
<td>86</td>
<td>58</td>
<td>47</td>
<td>69</td>
<td>125</td>
<td>8</td>
<td>4</td>
<td>14</td>
<td>211</td>
<td>28</td>
<td>22</td>
<td>35</td>
</tr>
<tr>
<td>Groups of 16 to 20 calves</td>
<td>86</td>
<td>14</td>
<td>7</td>
<td>23</td>
<td>125</td>
<td>2</td>
<td>0.2</td>
<td>6</td>
<td>211</td>
<td>7</td>
<td>4</td>
<td>11</td>
</tr>
<tr>
<td>Groups of 21 to 40 calves</td>
<td>86</td>
<td>3</td>
<td>1</td>
<td>10</td>
<td>125</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>211</td>
<td>2</td>
<td>0.2</td>
<td>4</td>
</tr>
<tr>
<td>Age range</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 weeks or less</td>
<td>88</td>
<td>12</td>
<td>6</td>
<td>21</td>
<td>122</td>
<td>54</td>
<td>45</td>
<td>63</td>
<td>210</td>
<td>37</td>
<td>30</td>
<td>44</td>
</tr>
<tr>
<td>Between 3 to 4 weeks</td>
<td>88</td>
<td>48</td>
<td>37</td>
<td>59</td>
<td>122</td>
<td>32</td>
<td>24</td>
<td>42</td>
<td>210</td>
<td>38</td>
<td>32</td>
<td>45</td>
</tr>
<tr>
<td>Between 5 to 6 weeks</td>
<td>88</td>
<td>15</td>
<td>8</td>
<td>24</td>
<td>122</td>
<td>11</td>
<td>6</td>
<td>17</td>
<td>210</td>
<td>12</td>
<td>8</td>
<td>18</td>
</tr>
<tr>
<td>7 weeks or more</td>
<td>88</td>
<td>25</td>
<td>16</td>
<td>35</td>
<td>122</td>
<td>3</td>
<td>1</td>
<td>8</td>
<td>210</td>
<td>12</td>
<td>8</td>
<td>18</td>
</tr>
<tr>
<td>Indoor housing</td>
<td>86</td>
<td>98</td>
<td>92</td>
<td>100</td>
<td>543</td>
<td>70</td>
<td>66</td>
<td>74</td>
<td>629</td>
<td>74</td>
<td>70</td>
<td>77</td>
</tr>
<tr>
<td>Bedding material</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Winter – straw</td>
<td>87</td>
<td>80</td>
<td>70</td>
<td>88</td>
<td>525</td>
<td>83</td>
<td>79</td>
<td>86</td>
<td>612</td>
<td>82</td>
<td>79</td>
<td>85</td>
</tr>
<tr>
<td>Winter – sawdust</td>
<td>87</td>
<td>14</td>
<td>7</td>
<td>23</td>
<td>525</td>
<td>17</td>
<td>14</td>
<td>20</td>
<td>612</td>
<td>16</td>
<td>14</td>
<td>20</td>
</tr>
<tr>
<td>Summer – straw</td>
<td>85</td>
<td>72</td>
<td>61</td>
<td>81</td>
<td>512</td>
<td>74</td>
<td>70</td>
<td>77</td>
<td>597</td>
<td>73</td>
<td>70</td>
<td>77</td>
</tr>
<tr>
<td>Summer – sawdust</td>
<td>85</td>
<td>21</td>
<td>13</td>
<td>31</td>
<td>512</td>
<td>24</td>
<td>21</td>
<td>28</td>
<td>597</td>
<td>24</td>
<td>20</td>
<td>28</td>
</tr>
</tbody>
</table>

1Confidence interval (CI), lower confidence limit (LCL), upper confidence limit (UCL).
2Maximum age difference between calves in a group.
Appendix 2.4. Summary of milk feeding practices of calves during the milk feeding period by farms with automated milk feeders (AMF) and farms using manual milking feeding (MMF) systems for raising dairy calves derived from an online questionnaire completed by 670 dairy producers in Canada

<table>
<thead>
<tr>
<th>Management practices</th>
<th>AMF</th>
<th></th>
<th>MMF</th>
<th></th>
<th>All participant farms</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>%</td>
<td>LCL</td>
<td>UCL</td>
<td>n</td>
</tr>
<tr>
<td>Type of milk fed</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Milk replacer</td>
<td>93</td>
<td>89</td>
<td>81</td>
<td>95</td>
<td>525</td>
</tr>
<tr>
<td>Saleable whole milk</td>
<td>93</td>
<td>5</td>
<td>2</td>
<td>12</td>
<td>525</td>
</tr>
<tr>
<td>Waste milk(^2)</td>
<td>93</td>
<td>4</td>
<td>1</td>
<td>11</td>
<td>525</td>
</tr>
<tr>
<td>Combination of saleable and waste</td>
<td>93</td>
<td>2</td>
<td>0</td>
<td>6</td>
<td>525</td>
</tr>
<tr>
<td>Pasteurization(^3)</td>
<td>9</td>
<td>44</td>
<td>14</td>
<td>79</td>
<td>312</td>
</tr>
<tr>
<td>Acidification</td>
<td>90</td>
<td>4</td>
<td>1</td>
<td>11</td>
<td>527</td>
</tr>
<tr>
<td>Method of feeding milk</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of automated milk feeders</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 feeder</td>
<td>105</td>
<td>86</td>
<td>78</td>
<td>92</td>
<td>618</td>
</tr>
<tr>
<td>2 feeders</td>
<td>105</td>
<td>11</td>
<td>5</td>
<td>19</td>
<td>618</td>
</tr>
<tr>
<td>3 feeders</td>
<td>105</td>
<td>2</td>
<td>0.3</td>
<td>7</td>
<td>618</td>
</tr>
<tr>
<td>6 feeders</td>
<td>105</td>
<td>1</td>
<td>0</td>
<td>6</td>
<td>618</td>
</tr>
<tr>
<td>Feeding stations per feeder</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 feeding station</td>
<td>105</td>
<td>31</td>
<td>21</td>
<td>41</td>
<td>618</td>
</tr>
<tr>
<td>2 feeding stations</td>
<td>105</td>
<td>65</td>
<td>55</td>
<td>75</td>
<td>618</td>
</tr>
<tr>
<td>3 feeding stations</td>
<td>105</td>
<td>2</td>
<td>0.3</td>
<td>8</td>
<td>618</td>
</tr>
<tr>
<td>4 feeding stations</td>
<td>105</td>
<td>1</td>
<td>0</td>
<td>6</td>
<td>618</td>
</tr>
<tr>
<td>Teat(^4)</td>
<td>531</td>
<td>53</td>
<td>48</td>
<td>57</td>
<td></td>
</tr>
<tr>
<td>Open bucket</td>
<td>531</td>
<td>36</td>
<td>32</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td>Combination of teat and open bucket</td>
<td>531</td>
<td>11</td>
<td>8</td>
<td>14</td>
<td></td>
</tr>
</tbody>
</table>

1Confidence interval (CI), lower confidence limit (LCL), upper confidence limit (UCL).
2Non-saleable milk from sick or antibiotic-treated cows.
3Among farms feeding saleable or waste milk.
4Bottles, teat buckets and/or milk bars.
Appendix 4.1. Imaginary “W” track (red line) used as a guide to select the 8 test-sampling spots (red crosses) for the wetness paper towel scoring system, dry matter of top bedding estimation, and bed deepness measurement across the group pen.
Appendix 4. 2. Management of un-weaned calves, group housing, and automated milk feeders at the farm; Questionnaire 1

Producer Questionnaire
Management of pre-weaned calves, group-housing pen and automated feeder

FARM: ___________________ Town: ___________________
Date: ___________________

A. Calving and the Newborn

• Calving area

1. Do you have a calving pen (apart from primary herd)?
   - [ ] Yes
   - [ ] No
   - If so, is this pen exclusively used for calving?
     - [ ] Yes
     - [ ] No, it is also used as a hospital pen (house sick animals)
     - [ ] No, it is also used as a quarantine pen for new animals
   - Where do they calve? ___________________

2. Is this calving pen:
   - [ ] Individual pen (calf has only contact with her mother)
   - [ ] Group pen

3. Is the calving area exposed to environmental conditions (e.g. rain, wind)?
   - [ ] Yes
   - [ ] No

4. Between births, do you change bedding and wash the calving pen?
   - [ ] Only change bedding
   - [ ] Yes, I change bedding and wash pen
   - [ ] No
   - If no, How often do you clean the calving pen? ___________________
Producer Questionnaire
Management of pre-weaned calves, group-housing pen and automated feeder

- **Birth surveillance**

5. How many times do you monitor cows about to calve (during the 24 hours period before calving)?
   Select (✓) how many times you check cows close to calve for the following periods:

<table>
<thead>
<tr>
<th>Periods of the day</th>
<th>Monitoring times</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between morning milking and afternoon milking</td>
<td>Once</td>
</tr>
<tr>
<td>Between afternoon milking and next morning milking</td>
<td></td>
</tr>
</tbody>
</table>

6. Do you have video cameras to monitor calving pen continuously?
   - Yes
   - No

- **Cow-calf separation**

7. When do you separate cow and calf?
   - Immediate separation (before 2 hours)
   - Early separation between 3 and 12 hours after birth
   - Early separation between 12 and 24 hours after birth
   - Delayed separation (after 14 days)
   - Other: __________________________

8. Before separating cow and calf, do you allow the cow to dry and stimulate the calf?
   - Yes
   - No

   If no, how is calf dried and stimulated? ________________________________
B. Colostrum management

9. How long after birth is the first meal of colostrum given? For each time of day that calving might occur select (✓) the approximated time when first colostrum is given.

<table>
<thead>
<tr>
<th>Calving Time</th>
<th>Hours after birth that first meal of colostrum is given</th>
</tr>
</thead>
<tbody>
<tr>
<td>Night (10 pm to 5 am)</td>
<td>Within 2 hours</td>
</tr>
<tr>
<td></td>
<td>2-4 hours</td>
</tr>
<tr>
<td></td>
<td>6-12 hours</td>
</tr>
<tr>
<td></td>
<td>More than 12 h later</td>
</tr>
<tr>
<td></td>
<td>When calf gets up and suckle</td>
</tr>
</tbody>
</table>

10. What type of colostrum do you use? Select (✓) from the options at the table below.
   If you use more than one type, please write up in percentage the frequency of use for each one (for example 80% fresh colostrum from dam and 20% refrigerated colostrum).

<table>
<thead>
<tr>
<th>Colostrum type</th>
<th>✓</th>
<th>% of use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fresh colostrum from dam only</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fresh colostrum from other cow</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Refrigerated colostrum</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frozen colostrum from other cow (how long in the freezer)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pooled colostrum</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pasteurized colostrum</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acidified colostrum</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Commercial colostrum (replacer)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

If refrigerated colostrum is used, for how long is the colostrum kept in the fridge? ________________

If frozen colostrum is used, for how long is the colostrum kept in the freezer? ________________

11. Is the colostrum fed to calves always from the first milking after birth?
   - [ ] Yes
   - [ ] No
Producer Questionnaire
Management of pre-weaned calves, group-housing pen and automated feeder

12. Is passive immunity transfer status regularly verified by checking calf serum IgG or total protein concentrations?
   ☐ Always
   ☐ Sometimes
   ☐ Never

   Is the test performed between 24 and 48 hours after birth?
   ☐ Yes
   ☐ No, it is done at: ______________________

C. Postnatal procedures

13. When is disbudding/dehorning done?
   ☐ _____ days old

14. What technique do you use?
   ☐ Caustic paste
   ☐ Hot iron
   ☐ Wire
   ☐ Other: __________

15. When disbudding or dehorning, do you control pain?

   ☐ Yes
   ☐ No

   If so, how do you control pain? Check all if apply
   ☐ By using local anaesthetic. Product ______________________
   ☐ By using a sedative. Product ______________________
   ☐ By using analgesic (anti-inflammatory drug). Product ______________________
Producer Questionnaire
Management of pre-weaned calves, group-housing pen and automated feeder

D. Management of whole/waste milk used to feed calves (if applies)

***If you **only** feed Milk Replacer, go to Section E

16. What type of milk do you feed to calves with the automated milk feeder? Select from the options at the table below. If you use more than one, write up in percentage the frequency of use for each.

<table>
<thead>
<tr>
<th>Milk type</th>
<th>% of use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Whole milk (saleable)</td>
<td></td>
</tr>
<tr>
<td>Waste milk from transition cows</td>
<td></td>
</tr>
<tr>
<td>Waste milk from treated cows</td>
<td></td>
</tr>
<tr>
<td>Milk replacer</td>
<td></td>
</tr>
<tr>
<td>Other:</td>
<td></td>
</tr>
</tbody>
</table>

If multiple milk types are used: please describe their usage (for example if you give whole milk the first week of life and then transition to milk replacer doing a gradual mix or, depending of quota utilization, certain months you give milk mixed with the milk replacer)?

________________________________________________________________________
________________________________________________________________________
________________________________________________________________________

17. How do you collect the milk?
   - [ ] Directly from milking machine to big pails
   - [ ] Directly from bulk tank to big pails
   - [ ] Other: ________________________________

18. How long does the milk collected remain at room temperature before being fed to calves or before pasteurization?
   - [ ] _______ hours.

19. What is the procedure for cleaning the milk collection pails?
   ____________________________________________
   ____________________________________________
Producer Questionnaire
Management of pre-weaned calves, group-housing pen and automated feeder

20. How often do you clean the pails?

__________________________________________________________

21. How is the milk stored in the calf barn while waiting to be fed through the automated feeder?

__________________________________________________________

22. At what temperature is this milk stored while waiting to be fed through the automated feeder?

__________________________________________________________

23. What is the procedure for cleaning this milk storage chamber?

__________________________________________________________

__________________________________________________________

24. How often is it clean?

__________________________________________________________

25. How often is the left over milk discarded?

☐ Once per day
☐ Twice per day
☐ Other: ____________________________

E. Automated feeders and feeding

• Cleaning and calibration:

26. Do you have automatic calibration system installed in your feeder(s)?

☐ Yes
☐ No
☐ Don’t know

27. How often do you manually calibrate the feeder?

☐ Never
☐ Once a day
☐ Once a week
☐ Once a month
☐ Once a year
☐ Twice a day
☐ Twice a week
☐ Twice a month
☐ Twice a year

☐ Other: ____________________________
28. How often is the automatic cleaning set up for?

<table>
<thead>
<tr>
<th>Part of the feeder</th>
<th>How often</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mixer jar</td>
<td>□ Never</td>
</tr>
<tr>
<td></td>
<td>□ Once a day</td>
</tr>
<tr>
<td></td>
<td>□ Twice a day</td>
</tr>
<tr>
<td></td>
<td>□ 3 times a day</td>
</tr>
<tr>
<td></td>
<td>□ Once a week</td>
</tr>
<tr>
<td></td>
<td>□ Twice a week</td>
</tr>
<tr>
<td></td>
<td>□ 3 times a week</td>
</tr>
<tr>
<td></td>
<td>□ Other:</td>
</tr>
<tr>
<td>Heat exchanger</td>
<td>□ Never</td>
</tr>
<tr>
<td></td>
<td>□ Once a day</td>
</tr>
<tr>
<td></td>
<td>□ Twice a day</td>
</tr>
<tr>
<td></td>
<td>□ 3 times a day</td>
</tr>
<tr>
<td></td>
<td>□ Once a week</td>
</tr>
<tr>
<td></td>
<td>□ Twice a week</td>
</tr>
<tr>
<td></td>
<td>□ 3 times a week</td>
</tr>
<tr>
<td></td>
<td>□ Other:</td>
</tr>
</tbody>
</table>

29. How often do you manually clean each of the following parts of the feeder?

<table>
<thead>
<tr>
<th>Part of the feeder</th>
<th>How often</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hoses</td>
<td>□ Never</td>
</tr>
<tr>
<td></td>
<td>□ Once a day</td>
</tr>
<tr>
<td></td>
<td>□ Twice a day</td>
</tr>
<tr>
<td></td>
<td>□ 3 times a day</td>
</tr>
<tr>
<td></td>
<td>□ Once a week</td>
</tr>
<tr>
<td></td>
<td>□ Twice a week</td>
</tr>
<tr>
<td></td>
<td>□ 3 times a week</td>
</tr>
<tr>
<td></td>
<td>□ Once a month</td>
</tr>
<tr>
<td></td>
<td>□ Twice a month</td>
</tr>
<tr>
<td></td>
<td>□ 3 times a month</td>
</tr>
<tr>
<td></td>
<td>□ Other:</td>
</tr>
<tr>
<td>Teats</td>
<td>□ Never</td>
</tr>
<tr>
<td></td>
<td>□ Once a day</td>
</tr>
<tr>
<td></td>
<td>□ Twice a day</td>
</tr>
<tr>
<td></td>
<td>□ 3 times a day</td>
</tr>
<tr>
<td></td>
<td>□ Once a week</td>
</tr>
<tr>
<td></td>
<td>□ Twice a week</td>
</tr>
<tr>
<td></td>
<td>□ 3 times a week</td>
</tr>
<tr>
<td></td>
<td>□ Once a month</td>
</tr>
<tr>
<td></td>
<td>□ Twice a month</td>
</tr>
<tr>
<td></td>
<td>□ 3 times a month</td>
</tr>
<tr>
<td></td>
<td>□ Other:</td>
</tr>
<tr>
<td>Area under the teat (feeding station)</td>
<td>□ Never</td>
</tr>
<tr>
<td></td>
<td>□ Once a day</td>
</tr>
<tr>
<td></td>
<td>□ Twice a day</td>
</tr>
<tr>
<td></td>
<td>□ 3 times a day</td>
</tr>
<tr>
<td></td>
<td>□ Once a week</td>
</tr>
<tr>
<td></td>
<td>□ Twice a week</td>
</tr>
<tr>
<td></td>
<td>□ 3 times a week</td>
</tr>
<tr>
<td></td>
<td>□ Once a month</td>
</tr>
<tr>
<td></td>
<td>□ Twice a month</td>
</tr>
<tr>
<td></td>
<td>□ 3 times a month</td>
</tr>
<tr>
<td></td>
<td>□ Other:</td>
</tr>
<tr>
<td>Floor on calf side</td>
<td>□ Never</td>
</tr>
<tr>
<td></td>
<td>□ Once a day</td>
</tr>
<tr>
<td></td>
<td>□ Twice a day</td>
</tr>
<tr>
<td></td>
<td>□ 3 times a day</td>
</tr>
<tr>
<td></td>
<td>□ Once a week</td>
</tr>
<tr>
<td></td>
<td>□ Twice a week</td>
</tr>
<tr>
<td></td>
<td>□ 3 times a week</td>
</tr>
</tbody>
</table>
Producer Questionnaire
Management of pre-weaned calves, group-housing pen and automated feeder

30. How often are the hoses replaced?

31. How often are teats replaced?
# Appendix 4.3. Management of un-weaned calves, group housing, and automated milk feeders at the farm; Questionnaire 2

## Producer Questionnaire 2

Management of pre-weaned calves, group-housing pen and automated feeder

### Walking with the calf! Extra Questions – Farm: ____________________________

#### A. Previous housing
1. Before you installed the feeders, what was the housing for milk-fed calves? ____________________________
2. If individual, when calves were introduced to a group? ____________________________

#### B. Colostrum and milk/milk replacer transition (if used) before introduction to feeder
1. Day 1 of life: First colostrum feeding: ____________________________
   Then, more colostrum feedings? _______ How many Lt? ____________________________
2. Day 2: Colostrum____ or Milk____ or MR____; Lt____/day; # meals______/day
3. Day 3: Colostrum____ or Milk____ or MR____; Lt____/day; # meals______/day

#### C. Transportation of calf
1. From maternity pen to newborn pen, how is it done? ____________________________
2. From newborn pen to group pen, how is it done? ____________________________

#### D. Bedding at the newborn pens
1. Is bedding removed between calves? ____________________________
2. Is pen washed between calves? ____________________________

#### E. Additives to milk or milk replacer
1. Do you add anything to the milk or milk replacer? ____________________________
2. Timing ____________________________

#### F. Cleaning of pens
1. How often do you add more bedding to the pen with the feeder? ____________________________

---

1
Producer Questionnaire 2
Management of pre-weaned calves, group-housing pen and automated feeder

2. How often do you remove all the bedding?

2.1. Do you wash the pen after removing the bedding?

2.2. How? Describe:

G. Movements between pens with AMF
1. When is a calf moved from baby pen to big pen with the feeder?

How long the calf stays in baby pen?

Must the calf fulfil any criteria to be moved?

Is the calf moved alone or in groups?

2. When is a calf moved out from big pen to a weaned pen?

Must the calf fulfil any criteria to be moved?

Is the calf moved alone or in groups?

H. Shared air:
1. What type of cattle share air with calves?

2. Maximum age of these animals?

I. Vaccinations:
1. What is your calf vaccination plan?
Appendix 4.4. Distribution of independent variables regarding calving and newborn management potentially associated with within-pen prevalence of calf diarrhea and bovine respiratory disease measured during 4 seasonal visits to a maximum of 35 pens (no. of pens: fall 2015 = 34, winter 2016 = 35, spring 2016 = 33, and summer 2016 = 35) across 17 farms in southern Ontario raising calves in group pens with automated milk feeders (137 observations in total at the pen level)

<table>
<thead>
<tr>
<th>Variable</th>
<th>No. of Farms (%)</th>
<th>Pen-level obs. (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calving pen type</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group pen</td>
<td>13 (76)</td>
<td>113 (83)</td>
</tr>
<tr>
<td>Individual pen</td>
<td>4 (23)</td>
<td>24 (17)</td>
</tr>
<tr>
<td>Exclusive calving pen</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>12 (71)</td>
<td>105 (77)</td>
</tr>
<tr>
<td>No</td>
<td>5 (29)</td>
<td>32 (23)</td>
</tr>
<tr>
<td>Cow-calf separation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Immediately</td>
<td>9 (53)</td>
<td>85 (62)</td>
</tr>
<tr>
<td>Within 12 h</td>
<td>4 (23.5)</td>
<td>24 (18)</td>
</tr>
<tr>
<td>Within 24 h</td>
<td>4 (23.5)</td>
<td>28 (20)</td>
</tr>
<tr>
<td>Antibody bolus at birth&lt;sup&gt;1&lt;/sup&gt;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>5 (29)</td>
<td>40 (29)</td>
</tr>
<tr>
<td>No</td>
<td>12 (71)</td>
<td>97 (71)</td>
</tr>
<tr>
<td>Intranasal viral vaccine at birth&lt;sup&gt;2&lt;/sup&gt;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>10 (59)</td>
<td>80 (58)</td>
</tr>
<tr>
<td>No</td>
<td>7 (41)</td>
<td>57 (42)</td>
</tr>
<tr>
<td>Vitamin E and Selenium&lt;sup&gt;3&lt;/sup&gt;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>5 (29)</td>
<td>44 (32)</td>
</tr>
<tr>
<td>No</td>
<td>12 (71)</td>
<td>93 (68)</td>
</tr>
<tr>
<td>Navel disinfection at birth</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>10 (63)</td>
<td>89 (67)</td>
</tr>
<tr>
<td>No</td>
<td>6 (37)</td>
<td>44 (33)</td>
</tr>
<tr>
<td>No. of colostrum feeding days</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Only during 1&lt;sup&gt;st&lt;/sup&gt; 24h of life</td>
<td>8 (47)</td>
<td>70 (51)</td>
</tr>
<tr>
<td>During first 2 d of life</td>
<td>4 (24)</td>
<td>31 (23)</td>
</tr>
<tr>
<td>During first 3 d of life</td>
<td>5 (29)</td>
<td>36 (26)</td>
</tr>
<tr>
<td>Colostrum at first feeding, L</td>
<td></td>
<td></td>
</tr>
<tr>
<td>≤ 3 L</td>
<td>3 (18)</td>
<td>20 (15)</td>
</tr>
<tr>
<td>4 L</td>
<td>8 (47)</td>
<td>74 (54)</td>
</tr>
<tr>
<td>6 L</td>
<td>6 (35)</td>
<td>43 (31)</td>
</tr>
<tr>
<td>Type of pre-housing&lt;sup&gt;4&lt;/sup&gt;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Directly introduced to group with AMF&lt;sup&gt;5&lt;/sup&gt;</td>
<td>2 (12)</td>
<td>16 (12)</td>
</tr>
<tr>
<td>Individual pen</td>
<td>9 (53)</td>
<td>71 (52)</td>
</tr>
<tr>
<td>Individual Hutch</td>
<td>4 (23)</td>
<td>38 (28)</td>
</tr>
<tr>
<td>Group pen</td>
<td>2 (12)</td>
<td>12 (8)</td>
</tr>
<tr>
<td>Pre-housing location</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Indoors</td>
<td>15 (88)</td>
<td>115 (84)</td>
</tr>
<tr>
<td>Outdoors</td>
<td>2 (12)</td>
<td>22 (16)</td>
</tr>
</tbody>
</table>

<sup>1</sup>First defense, bovine *Coronavirus- Escherichia coli* antibody.<br><sup>2</sup>Inforce 3, bovine Rhinotracheitis-Parainfluenza3-Bovine Respiratory Syncytial virus vaccine.<br><sup>3</sup>Administration of both vitamin E and selenium at birth.<br><sup>4</sup>Housing for calves before introduction to the group pen with the automated milk feeder.<br><sup>5</sup>Automated milk feeder.
Appendix 4.5. Distribution of explanatory variables regarding the milk feeding plan potentially associated with within-pen prevalence of calf diarrhea and bovine respiratory disease measured during 4 seasonal visits to a maximum of 35 pens (no. of pens: fall 2015 = 34, winter 2016 = 35, spring 2016 = 33, and summer 2016 = 35) across 17 farms in southern Ontario raising calves in group pens with automated milk feeders (137 observations in total at the pen-level)

<table>
<thead>
<tr>
<th>Variable</th>
<th>No. of Farms (%)</th>
<th>Pen-level obs. (%)</th>
<th>Median</th>
<th>IQR</th>
<th>Min - Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prior to introduction to the group pen with AMF(^1)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Milk allowance, L/d</td>
<td>15</td>
<td>121</td>
<td>6</td>
<td>5 – 8</td>
<td>4 - 9</td>
</tr>
<tr>
<td>Feedings per day</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>11 (73)</td>
<td>97 (80)</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>3</td>
<td>3 (20)</td>
<td>20 (17)</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>4</td>
<td>1 (7)</td>
<td>4 (3)</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Milk type</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Whole milk(^2)</td>
<td>7 (47)</td>
<td>40 (33)</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Milk replacer(^3)</td>
<td>8 (53)</td>
<td>81 (77)</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>In the group pen with AMF</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Milk type</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fall visit</td>
<td>17</td>
<td>34</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Whole milk(^2)</td>
<td>2 (12)</td>
<td>3 (9)</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Milk replacer(^3)</td>
<td>15 (88)</td>
<td>31 (91)</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Winter, spring, and summer visits</td>
<td>17</td>
<td>103</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Whole milk(^2)</td>
<td>3 (18)</td>
<td>12 (12)</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Milk replacer(^3)</td>
<td>14 (82)</td>
<td>91 (88)</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Milk additive</td>
<td>17</td>
<td>137</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>None</td>
<td>10 (59)</td>
<td>71 (52)</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Probiotic</td>
<td>4 (23)</td>
<td>28 (20)</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Antibiotic</td>
<td>3 (18)</td>
<td>38 (28)</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Start milk allowance, L</td>
<td>17</td>
<td>137</td>
<td>6</td>
<td>5 - 10</td>
<td>4.4 - 12</td>
</tr>
<tr>
<td>Peak milk allowance, L</td>
<td>17</td>
<td>137</td>
<td>10</td>
<td>8 – 11</td>
<td>6 – 15</td>
</tr>
<tr>
<td>Latency to peak, d</td>
<td>17</td>
<td>137</td>
<td>14</td>
<td>5 - 17</td>
<td>0 - 45</td>
</tr>
<tr>
<td>Length of peak, d</td>
<td>17</td>
<td>137</td>
<td>28</td>
<td>1 - 31</td>
<td>1 – 51</td>
</tr>
<tr>
<td>Age at weaning, d</td>
<td>17</td>
<td>137</td>
<td>47</td>
<td>35 – 52</td>
<td>11 – 56</td>
</tr>
<tr>
<td>Duration of weaning, d</td>
<td>17</td>
<td>137</td>
<td>19</td>
<td>14 – 27</td>
<td>10 – 56</td>
</tr>
<tr>
<td>Age when weaned, d</td>
<td>17</td>
<td>137</td>
<td>66</td>
<td>61 – 70</td>
<td>49 – 77</td>
</tr>
<tr>
<td>Total solids, %</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt; 10</td>
<td>---</td>
<td>18 (13)</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>10 to 12.9</td>
<td>---</td>
<td>59 (43)</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>≥ 13</td>
<td>---</td>
<td>60 (44)</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
</tbody>
</table>

\(^1\)AMF = automated milk feeder.
\(^2\)Non-pasteurized.
\(^3\)73% of farms used a commercial milk replacer with 26% crude protein content and 16-18% crude fat content, 20% of farms used a milk replacer with 22% crude protein content and 17-18% crude fat content, and 7% of farms used a milk replacer with 20% content of both crude protein and crude fat.
Appendix 4. 6. Distribution of explanatory variables regarding calibration and cleaning practices of the automated feeder potentially associated with within-pen prevalence of calf diarrhea and bovine respiratory disease measured during 4 seasonal visits to a maximum of 35 pens (no. of pens: fall 2015 = 34, winter 2016 = 35, spring 2016 = 33, and summer 2016 = 35) across 17 farms in southern Ontario raising calves in group pens with automated milk feeders (137 observations in total at the pen-level)

<table>
<thead>
<tr>
<th>Variable</th>
<th>No. of Farms (%)</th>
<th>Pen-level obs. (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Automatic calibration</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>6 (35)</td>
<td>52 (38)</td>
</tr>
<tr>
<td>No</td>
<td>10 (59)</td>
<td>83 (61)</td>
</tr>
<tr>
<td>Not sure</td>
<td>1 (6)</td>
<td>2 (1)</td>
</tr>
<tr>
<td>Manual calibration, frequency</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Once/wk</td>
<td>1 (6)</td>
<td>8 (6)</td>
</tr>
<tr>
<td>2 times/mo</td>
<td>2 (12)</td>
<td>24 (17)</td>
</tr>
<tr>
<td>Once/mo</td>
<td>7 (41)</td>
<td>61 (45)</td>
</tr>
<tr>
<td>6 times/year or less often</td>
<td>6 (35)</td>
<td>40 (29)</td>
</tr>
<tr>
<td>Never</td>
<td>1 (6)</td>
<td>4 (3)</td>
</tr>
<tr>
<td>Automatic cleaning, no./d</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Once</td>
<td>5 (29)</td>
<td>36 (26)</td>
</tr>
<tr>
<td>Twice</td>
<td>7 (42)</td>
<td>47 (34)</td>
</tr>
<tr>
<td>3 times</td>
<td>5 (29)</td>
<td>54 (40)</td>
</tr>
<tr>
<td>Frequency of cleaning hoses</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Every day</td>
<td>5 (29)</td>
<td>32 (24)</td>
</tr>
<tr>
<td>1 to 2 times/wk</td>
<td>4 (24)</td>
<td>31 (23)</td>
</tr>
<tr>
<td>Once/mo or less often</td>
<td>3 (18)</td>
<td>30 (21)</td>
</tr>
<tr>
<td>Never</td>
<td>5 (29)</td>
<td>44 (32)</td>
</tr>
<tr>
<td>Frequency of cleaning teats</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Every day</td>
<td>5 (29)</td>
<td>44 (32)</td>
</tr>
<tr>
<td>2 times/wk</td>
<td>3 (18)</td>
<td>24 (18)</td>
</tr>
<tr>
<td>Once/wk</td>
<td>5 (29)</td>
<td>41 (30)</td>
</tr>
<tr>
<td>Once/mo or less often</td>
<td>4 (24)</td>
<td>28 (20)</td>
</tr>
<tr>
<td>Frequency of replacing hoses</td>
<td></td>
<td></td>
</tr>
<tr>
<td>At least every mo</td>
<td>4 (25)</td>
<td>32 (26)</td>
</tr>
<tr>
<td>Every 2 to 3 mo</td>
<td>3 (19)</td>
<td>27 (22)</td>
</tr>
<tr>
<td>Every 6 mo or less often</td>
<td>9 (56)</td>
<td>64 (52)</td>
</tr>
<tr>
<td>Frequency of replacing teats</td>
<td></td>
<td></td>
</tr>
<tr>
<td>At least every 3 wk</td>
<td>5 (30)</td>
<td>36 (26)</td>
</tr>
<tr>
<td>Every 4 to 6 wk</td>
<td>6 (35)</td>
<td>58 (42)</td>
</tr>
<tr>
<td>Every 2 mo or less often</td>
<td>6 (35)</td>
<td>43 (32)</td>
</tr>
</tbody>
</table>
Appendix 4. 7. Distribution of explanatory variables regarding pen management and calf barn features potentially associated with within-pen prevalence of calf diarrhea and bovine respiratory disease measured during 4 seasonal visits to a maximum of 35 pens (no. of pens: fall 2015 = 34, winter 2016 = 35, spring 2016 = 33, and summer 2016 = 35) across 17 farms in southern Ontario raising calves in group pens with automated milk feeders (137 observations in total at the pen-level)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Pen-level obs. (%)</th>
<th>Median</th>
<th>IQR</th>
<th>Min - Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pen area, m²</td>
<td>137</td>
<td>45</td>
<td>38 – 52</td>
<td>5 – 196</td>
</tr>
<tr>
<td>Pen with both bedded and not bedded areas¹</td>
<td>48 (35)</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Bedded area, m²</td>
<td>137</td>
<td>39</td>
<td>33 – 50</td>
<td>5 – 196</td>
</tr>
<tr>
<td>Pen location</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Against an outer wall</td>
<td>77 (56)</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Separated from the outer wall</td>
<td>60 (44)</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Pen shape</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Triangle</td>
<td>4 (3)</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Square</td>
<td>43 (31)</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Rectangle</td>
<td>90 (66)</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Pen type</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Young calf pen</td>
<td>58 (42)</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Older calf pen</td>
<td>56 (41)</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>All ages pen</td>
<td>23 (17)</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Bedding material</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Straw</td>
<td>116 (85)</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Chopped straw</td>
<td>13 (9)</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Soybean straw</td>
<td>4 (3)</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Sand</td>
<td>3 (2)</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Shavings</td>
<td>1 (1)</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Overall bed nesting score</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>84 (61)</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>2</td>
<td>50 (37)</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>3</td>
<td>3 (2)</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Dry matter of top bedding, %</td>
<td>136</td>
<td>73</td>
<td>61 – 79</td>
<td>31 – 94</td>
</tr>
<tr>
<td>Percentage of dry bedding surface</td>
<td>135</td>
<td>87</td>
<td>87 -100</td>
<td>0 – 100</td>
</tr>
<tr>
<td>Depth of wet bedding pack, cm</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt; 16</td>
<td>30 (24)</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>6 to 16</td>
<td>50 (60)</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>≤ 5</td>
<td>31 (26)</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Addition of bedding</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Every day</td>
<td>24 (17)</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Every 2 to 3 d</td>
<td>78 (57)</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Every 7 to &gt; 10 d</td>
<td>35 (26)</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Removal of bedding</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Every 10 to 20 d</td>
<td>27 (20)</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Every 45 to 60 d</td>
<td>78 (57)</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>≥ Every 90 d</td>
<td>32 (23)</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Mean age of introduction²</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt; 8 d old</td>
<td>80 (58)</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>8 to 13 d old</td>
<td>43 (31)</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>&gt; 13 d old</td>
<td>14 (11)</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Group size, no. of calves</td>
<td>137</td>
<td>10</td>
<td>8 – 13</td>
<td>1 – 33</td>
</tr>
<tr>
<td>Age range, d</td>
<td>137</td>
<td>40</td>
<td>27 – 50</td>
<td>0 – 92</td>
</tr>
<tr>
<td>Space of bedded area per calf, m²</td>
<td>137</td>
<td>4</td>
<td>3 – 5</td>
<td>2 – 13</td>
</tr>
</tbody>
</table>

244
Sharing air with

<table>
<thead>
<tr>
<th>Age Group</th>
<th>Count (Percentage)</th>
<th>Ventilation Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Milk-fed calves only</td>
<td>16 (12)</td>
<td>---</td>
</tr>
<tr>
<td>Cattle up to 4 mo old</td>
<td>51 (40)</td>
<td>---</td>
</tr>
<tr>
<td>Cattle up to 8 mo old</td>
<td>42 (33)</td>
<td>---</td>
</tr>
<tr>
<td>Cattle up to 9+ mo old</td>
<td>20 (15)</td>
<td>---</td>
</tr>
</tbody>
</table>

Ventilation type

<table>
<thead>
<tr>
<th>Type</th>
<th>Count (Percentage)</th>
<th>Ventilation Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural ventilation</td>
<td>24 (18)</td>
<td>---</td>
</tr>
<tr>
<td>Positive pressure ventilation</td>
<td>36 (56)</td>
<td>---</td>
</tr>
<tr>
<td>Both</td>
<td>77 (26)</td>
<td>---</td>
</tr>
</tbody>
</table>

1 The bedded area was considered the lying surface.
2 Introduction to the group pen with automated milk feeder.
Appendix 4. 8. Distribution of explanatory variables regarding bacteria counts in milk (sampled from the mixing jar and at the end of the hose [where it connects to the teat]) potentially associated with within_pen prevalence of calf diarrhea and bovine respiratory disease measured during 4 seasonal visits to a maximum of 35 pens (no. of pens: fall 2015 = 34, winter 2016 = 35, spring 2016 = 33, and summer 2016 = 35) across 17 farms in southern Ontario raising calves in group pens with automated milk feeders.

<table>
<thead>
<tr>
<th>Variable x seasonal visit</th>
<th>Mixing jar</th>
<th>End of hose</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No. pens (%)</td>
<td>No. pens (%)</td>
</tr>
<tr>
<td>Fall</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total bacteria count</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt; 100,000 cfu/mL</td>
<td>10 (29)</td>
<td>5 (15)</td>
</tr>
<tr>
<td>≥ 100,000 cfu/mL</td>
<td>24 (71)</td>
<td>29 (85)</td>
</tr>
<tr>
<td>Total coliform count</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt; 10,000 cfu/mL</td>
<td>31 (91)</td>
<td>30 (88)</td>
</tr>
<tr>
<td>≥ 10,000 cfu/mL</td>
<td>3 (9)</td>
<td>4 (12)</td>
</tr>
<tr>
<td>Winter</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total bacteria count</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt; 100,000 cfu/mL</td>
<td>7 (20)</td>
<td>6 (17)</td>
</tr>
<tr>
<td>≥ 100,000 cfu/mL</td>
<td>28 (80)</td>
<td>29 (83)</td>
</tr>
<tr>
<td>Total coliform count</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt; 10,000 cfu/mL</td>
<td>32 (91)</td>
<td>29 (83)</td>
</tr>
<tr>
<td>≥ 10,000 cfu/mL</td>
<td>3 (9)</td>
<td>6 (17)</td>
</tr>
<tr>
<td>Spring</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total bacteria count</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt; 100,000 cfu/mL</td>
<td>9 (27)</td>
<td>6 (19)</td>
</tr>
<tr>
<td>≥ 100,000 cfu/mL</td>
<td>24 (73)</td>
<td>26 (81)</td>
</tr>
<tr>
<td>Total coliform count</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt; 10,000 cfu/mL</td>
<td>31 (94)</td>
<td>28 (88)</td>
</tr>
<tr>
<td>≥ 10,000 cfu/mL</td>
<td>2 (6)</td>
<td>4 (12)</td>
</tr>
<tr>
<td>Summer</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total bacteria count</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt; 100,000 cfu/mL</td>
<td>13 (37)</td>
<td>9 (26)</td>
</tr>
<tr>
<td>≥ 100,000 cfu/mL</td>
<td>22 (63)</td>
<td>26 (74)</td>
</tr>
<tr>
<td>Total coliform count</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt; 10,000 cfu/mL</td>
<td>26 (74)</td>
<td>29 (83)</td>
</tr>
<tr>
<td>≥ 10,000 cfu/mL</td>
<td>9 (26)</td>
<td>6 (17)</td>
</tr>
</tbody>
</table>
Appendix 4.9. Number of automated milk feeders (AMF), pens with AMF, and number of feeding stations per pen among 17 farms in southern Ontario raising dairy calves in group pens with AMF visited 4 times, seasonally, over 1 year period

<table>
<thead>
<tr>
<th>Seasonal visit</th>
<th>No. farms</th>
<th>No. AMF per farm</th>
<th>No. pens per AMF</th>
<th>No. feeding stations per pen</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fall(^1)</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>1</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Other(^2)</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>1</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>

\(^1\)Set-up of the AMF system at the first visit (fall - 2015)

\(^2\)Set-up of the AMF system during the next 3 visits (winter, spring, and summer – 2016)