

**An Outdoor Method of Housing Dairy Calves in Pairs Using Individual
Calf Hutches**

by

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**A Thesis
Presented to
The University of Guelph**

**In partial fulfilment of requirements
for the degree of
Master of Science
in
Animal Biosciences**

Guelph, Ontario, Canada

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ABSTRACT

AN OUTDOOR METHOD OF HOUSING DAIRY CALVES IN PAIRS USING INDIVIDUAL CALF HUTCHES

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The objective of this thesis was to determine whether pair housing dairy calves in hutches outdoors would result in similar weight gain and milk intake compared with individual housing in hutches, as well as determining use of the pen and interactions between pairs. Single calves (n=6/season) were housed in one hutch with an attached outdoor environment; paired calves (n=6 pairs/season) were given twice the resources. Calves were fed up to 16 L/d of milk replacer; daily milk intake and weekly weight gains were recorded. Behavioural observations were recorded live once per week for 5 (summer) or 4 (winter) non-consecutive periods. Paired and single calves had similar weight gain and milk intake, showing no difference in performance between treatments. Low occurrences of cross sucking and displacements at the teat were found. Housing calves in pairs using hutches can be a suitable alternative to housing calves individually in hutches outdoors.

FORWARD

This thesis is composed of 3 chapters. The first chapter is a literature review of calf housing systems in North America, which discusses calf health, calf feeding and growth, calf behaviour and the calf rearing environment. The second chapter presents the experiment conducted during the thesis, on an outdoor method of housing dairy calves in pairs using individual calf hutches. The third chapter is a general discussion on the results from the study and their potential implications as well as the study limitations and future work.

Lisa Wormsbecher was responsible for organizing the calf area and for arranging feed deliveries and hutch sourcing with help from Elise Shepley. Lisa Wormsbecher was also responsible for daily care of the calves, behavioural observations and data analysis. Dr. Renée Bergeron and Dr. Elsa Vasseur, advisor and co-advisor, supervised all steps of this work. Dr. Derek Haley and Dr. Anne Marie de Passillé served on Lisa Wormsbecher`s advisory committee. Dr. Roger Cue was consulted with regard to the statistics run on the space usage behaviour as well as milk intake and weight gain data.

Due to the labour involved in feeding and caring for the calves, research assistants were hired for both the summer and winter trials. Elise Shepley was hired as a primary research assistant for both trials and was second in charge with regard to calf health and feeding. Jessica St. John was primary calf research assistant for the summer trial and was the second observer during this trial as well. Emmanuel Laplante was the primary calf research assistant during the winter trial and was also the second observer during this trial.

DEDICATION

To my parents,
Doris and Frank Wormsbecher
For their continued support and encouragement.

And to my partner,
Jack Hinds
For consistently supporting me emotionally.

ACKNOWLEDGEMENTS

Completing my master's has been an adventure and a half, and I would like to thank everyone who has helped me along the way. Dr. Renée Bergeron and Dr. Elsa Vasseur, you have been excellent advisors and have helped me grow as a researcher and as a person throughout this whole process. I have learned much from each of you and truly appreciate the time that you have put in helping me with the trials and the editing. Thank you as well to Dr. Derek Haley and Dr. Anne Marie de Passillé, the two of you have consistently given me different things to think about and I truly appreciate the time and effort you have expended to help me in this endeavour. Special thanks also to Dr. Jeff Rushen, who even though was not on my committee, took the time to review documents and give his input.

My research trials were a completely new experience for me, and I thank everyone who had a hand in helping to plan them out and bring them along. Elise Shepley was invaluable with her previous calf experience in all the feeding, health checks and training of the research assistants through both trials as well as the preparation. I also want to thank Santiago Palacio and Nancy Franco-Gendron, for helping me stay sane through both trials and all that data analysis while we were in Alfred. Having the two of you there and going through the process with me definitely helped. I want to thank all the research assistants that were hired over the two trials: Jessica St. John, Hugo Racine, Maureen O'Brien, Jean-Michel Beaudoin as well as Nancy Franco-Gendron helped with the summer trial; and Emmanuel Laplante, Tania Brunette, Stephanie Duhamel, Sabrina Plante, Julie Beaulieu, Anne Bastien, and Emilie Desjardins all helped out with the winter trial. Without them to help with the feeding and data entry, I would still be struggling to enter all those lines. On that note I must also thank all the calves that came through the Alfred farm for my trial; I learned from each and every one of them and appreciate the opportunity to work with so many calves that taught me so much. I also want to thank the Alfred farm staff, especially Serge Courchesne and Denis Simard for their continued support through the trials, even with the biosecurity protocols in place; they made effort to help examine calves and taught me what to look for in order to prevent illness when the calves were very young.

I would never have been able to complete my trials and finish my masters if it weren't for the continued advice and help from the all the people and animals listed above. However, I made it through all this sane and in control because of my close friends and family. My parents were continued support in almost every sense of the word, always encouraging me to pursue my dreams to the completion of this degree. My best friend Serena, who supported me and helped out whenever she could when she was in Ontario, to the Skype calls and emotional support she gave me since she moved away. And a massive thanks to my partner, Jack, who has been my rock through this whole adventure, helping me to see perspective when I needed it and was a shoulder to cry on when I needed that as well. He helped with everything from the trial to letting me bounce ideas off him when I was writing and working things out (even though he may not have understood much). I will be forever grateful for the support he gave me.

All those mentioned have helped me along in this wonderful adventure, and I am forever grateful for the person I am now because of them.

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Chapter 1: General Introduction

In recent years the dairy industry has been moving toward a more welfare-friendly approach to managing their dairy calves. This includes feeding higher amounts of milk and housing calves in groups to allow for social interactions. Ventura *et al.* (2015) conducted a focus group interview with different stakeholders in the dairy industry including: producers, veterinarians, students, industry leaders, service providers, and academics. These focus groups looked over multiple areas of the dairy industry. With regard to calf care, they found that the overall care of the calves was a concern for 3 out of 5 focus groups with people from all different stakeholder groups making comments (Ventura *et al.*, 2015). The concern for the management and housing of calves was prominent for almost all stakeholders. Overall, the focus groups noted that while farmers do take care of their calves, it is not their priority (Ventura *et al.*, 2015). This leads to the understanding that there is room for improvement of the housing and management of dairy calves.

There are many different methods for housing dairy calves on farm, each with its own pros and cons, and each with different considerations that need to be taken into account. Calf health and well-being should be integral to the housing and management of producers' calves. Ensuring that calves are fed enough and are able to maintain a good growth rate is important to the calves health and welfare. Many calves are fed a restricted amount of milk (4 – 6 L/d), and while producers are starting to understand that calves need more to grow properly there are still many that are feeding only ten percent of the calf's body weight (Jasper and Weary, 2002; Vasseur *et al.*, 2010). The Canadian Dairy Code of Practice suggests in its recommended best practices that calves should be provided whole milk, or equivalent milk replacer ad libitum and if not able to offer calves milk ad libitum then they should be provided with a minimum of 20 % of the calf's body weight until 28 days of age (approximately 8 L/d for Holstein calf) (NFACC, 2009).

Many producers are also still housing their calves individually (Vasseur *et al.*, 2010), even though much research has come out in favour of group housing. Group housing allows for social interaction between calves, which has been shown to improve calf welfare (Holm *et al.*, 2002; Stull and Reynolds, 2008; Jensen and Larsen, 2014). The Code of Practice suggests that calves should be housed individually or in well managed groups (with less than ten calves) however, it

also states that calves should be provided with the opportunity to exercise and express social behaviour (NFACC, 2009). A calf's housing environment can play a large role in the calves' health. Ensuring that the calves have a clean and dry living environment will help reduce respiratory or digestive health problems (Stull and Reynolds, 2008).

This review will go over the needs of pre-weaned dairy calves, including the range in feeding amounts and potential health risks. It will give information on different housing methods currently in use and will outline how the environment affects calf behaviour. The impact of how the addition of at least one companion can contribute to the social development and welfare of dairy calves will also be discussed at length. The review will also touch on how temperature affects the thermoregulation of calves and considerations that need to be taken into account for both indoor and outdoor housing methods.

1.1 Calf Health

Problems with calf health, such as respiratory disease or diarrhea, are one of the major costs that producers incur with their calves (Tozer and Heinrichs, 2001). Losses due to sick calves (either through calf morbidity or mortality) impose a significant burden on the producer, be it economic (Tozer and Heinrichs, 2001) or performance based. A high level of morbidity can also negatively affect profitability of the animal later on in life (Svensson and Hultgren, 2008). Out of a sample of 80 farms (information taken from the Valacta database) in Quebec, Canada, Vasseur *et al.* (2012) found that there was a median total calf mortality in the first week of life of 9.6%, while they found a maximum of 19.4% during the first week of life. These authors also looked at producer estimates of pre-weaned heifer mortality and found that out of 61 farms (number of farms that replied to the survey), there was a median of 0 % and a maximum of 20.0 % during the first week of life. Vasseur *et al.* (2012) also found much variation in the differences between mortality levels on farms. With regard to calf mortality and morbidity in the United States, the USDA (2010) reports an average pre-weaned calf morbidity of 7.8 %. The majority of calf deaths were caused by digestive disorders (scours and diarrhea) at 56.5 %, and 22.5 % of deaths were due to respiratory disease. Across all herds in the United States, 23.9 % of pre-weaned calves were reported to have had diarrhea, with 74.9 % of those calves having been treated for diarrhea with antibiotics. In addition, 12.4 % of all pre-weaned calves were reported

to have been affected by respiratory disease, with 91.9 % of afflicted calves being treated with antibiotics (USDA, 2010).

Diarrhea is considered the most important disease in young calves (< 30 days of age), while pneumonia is considered the most important disease for older calves (> 30 days of age) (McGuirk, 2008). Calf diarrhea has been shown to have an effect on calf growth (Lundborg *et al.*, 2003), and has also been associated with decreased milk yield in the first lactation (Svensson and Hultgren, 2008). Early detection and treatment of diarrhea is essential to making sure that there are no negative impacts to the calf's growth (McGuirk, 2008). Calves that have had diarrhea have also been known to be more susceptible to respiratory disease (Lundborg *et al.*, 2003). Heifers that had bovine respiratory disease before first calving were more likely to not complete their first lactation than heifers that had never had respiratory disease (Bach, 2011). Earlier research also suggests that respiratory disease or diarrhea before 90 days of age is associated with an increased age at first calving (Warnick *et al.*, 1994). This would lead to a direct financial loss to the producer.

Keeping calves healthy by reducing the incidence of respiratory disease and diarrhea can influence how producers house their calves. One primary reason for housing calves individually on farm is to control disease transmission (Stull and Reynolds, 2008). When housed individually, calves are unable to interact physically, which theoretically should decrease the transmission of bacteria and other pathogens. However, recent research has shown that when the environment is managed well, there are no differences in respiratory disease or diarrhea between individually housed and group housed animals (Jensen and Larson, 2014). Jensen and Larsen (2014) found no effect of pair housing compared to individual housing, on the health of calves, assessed with fecal and respiratory scores.

1.2. Calf Feeding and Growth

In Canada, replacement dairy calves are typically fed twice a day and are generally provided around 10 % of their body weight/d over two feedings (Vasseur *et al.*, 2010), with buckets being the primary method of delivery (Vasseur *et al.*, 2010). Vasseur *et al.* (2010) conducted an epidemiological study surveying 115 farms about their calf management practices across Quebec, Canada. They found that 75 % of farms were feeding calves less than 6 L of milk

or milk replacer in the first week of life, and that the median of milk fed at the middle of the pre-weaning period was 5.5 L/d, with a maximum of 10 L/d (Vasseur *et al.*, 2010).

Much research has gone into whether feeding 10 % of the calf's body weight is the best method or if there can be improvements made to how dairy producers manage their replacements heifers. It has been found that the nutritional requirements of calves have been underestimated (Khan *et al.*, 2011). When calves are left with their dam, they will gain weight much faster than conventionally housed calves; in one study control calves were raised conventionally on 10% of BW/d while treatment calves were kept with the dam and allowed to suckle freely for two weeks (Flower and Weary, 2001). At the end of the two weeks, control calves had only gained 4.5 kg while treatment calves gained 16.5 kg (Flower and Weary, 2001). Calves do not need to be housed with their dam in order to reach a high weight gain, since providing a higher milk allowance can lead to weight gains similar to calves left on the dam (Jasper and Weary, 2002). Indeed, Jasper and Weary (2002) found that calves allowed ad libitum milk intake drank about twice (4.2 – 5.7 kg/d for restricted compared with 9.0-10.0 kg/d for ad libitum) the amount as their restricted counter parts. This in turn allowed for ad libitum calves to gain 10.5 kg more than restricted calves by the start of the weaning period. More recently, Miller-Cushon *et al.* (2013) compared restricted calves fed 5 L/d vs. ad libitum and also found that when given the opportunity, calves would drink 10 L/d, and have twice the average daily gain. Borderas *et al.* (2009) reported that calves are capable of consuming up to 13 to 14 kg of milk/d, which leads to a higher growth rate of 1.05 ± 0.05 kg/d for ad libitum fed calves in the first 21 days of life when compared to restricted fed calves at 0.48 ± 0.04 kg/d (Borderas *et al.*, 2009). During the second half of the milk feeding period prior to weaning the ad libitum calves gained less than the restricted fed calves, 0.62 ± 0.05 kg/d and 0.80 ± 0.04 kg/d respectively, most likely because the ad libitum calves had decreased starter intake compared with restricted calves (Borderas *et al.*, 2009). However, even though the restricted fed calves gained more during the second half of the milk feeding period, they still gained less overall than the ad libitum calves: 0.80 ± 0.05 kg/d for ad libitum calves while restricted fed calves gained 0.66 ± 0.04 kg/d (Borderas *et al.*, 2009). Jasper and Weary (2002) also found that the higher weight gains continued until past the weaning period and that early higher weight gains may lead to a decreased age at first calving. In addition, it was also found that while calves are able to grow very quickly during the first few

weeks of life, these high gains may not be possible later on in life if they are not allowed while the calf is still young (Jasper and Weary, 2002).

One problem seen with providing ad libitum or a high milk allowance is that calves prefer milk over calf starter and when weaning time comes, they are not adjusted to eating enough starter in order to maintain their growth levels (Khan *et al.*, 2011). However, Borderas *et al.* (2009) suggested that calves below the age of three weeks may not be able to increase their grain consumption in order to compensate for a lower milk feeding level. This can be remedied by feeding a high level of milk and weaning through a step down method, while increasing available starter at the same time (de Passillé *et al.*, 2011). This way the calves are being slowly weaned from milk and therefore are gradually increasing their starter intake until the milk is gone (Roth *et al.*, 2009; de Passillé *et al.*, 2011). Miller-Cushon *et al.* (2013) used the gradual weaning method; all calves were weaned during week 7 by gradually reducing the amount of milk fed by 25 % per day. Through weaning, it was noted that ad libitum calves plateaued while restricted calves continued to gain, mostly due to the restricted calves having a higher dry matter intake than ad libitum calves (Jasper and Weary, 2002; Miller-Cushon *et al.*, 2013). The ad libitum calves slowly increased their dry matter intake post-weaning to a higher intake level than the restricted calves and also consistently had a higher overall body weight (Miller-Cushon *et al.*, 2013).

Another concern with regards to higher milk allowance is that it may lead to diarrhea or an increased incidence of disease; however, Borderas *et al.* (2009) did not find any difference between high and low milk fed calves when looking at gastrointestinal tract infections and respiratory infections. It has been suggested that health problems when feeding a high milk allowance are more likely to result from poor sanitation, management and/or poor housing conditions as opposed to from a high milk allowance (Khan *et al.*, 2011). In contrast, it has even been suggested that feeding a low milk allowance can lead to nutritional deficiency, which could depress calves' immune function and potentially make them more susceptible to disease (Khan *et al.*, 2011).

1.2 Calf Behaviour

1.3.1 Lying and resting

Lying and time spent resting is very important to the calf's development and growth, as well as ensuring calf health (Siegel, 2005). It is also important for the calf's ability to regulate its temperature (Hanninen *et al.*, 2003). Jensen and Larsen (2014) found that calves spent 5.5 h of their day (24 h) upright, while Faerevik *et al.* (2008) found that calves spent an average of 66 % of daily time lying down and 1.2 % of time standing idle. When calves are lying, they can either be lying awake or lying asleep. It is important that calves are able to sleep enough to maintain their growth and performance. Hanninen *et al.* (2008) showed that a calf's lying posture can be a good indicator of sleep. They estimated the amount of time that a calf was spending in each NREM (non-rapid eye movement) sleep and REM (rapid eye movement) sleep and found that REM sleep composed 45 % of their total sleep time. REM sleep is important for brain activity and functioning and has been studied extensively in humans and other mammals (Horne, 2009), but has been difficult to determine in cattle (Hanninen *et al.*, 2008).

1.3.2 Sucking Behaviour

Calves have a natural instinct to suck in order to receive milk. In a natural environment calves would need to suckle their dam's teat in order to receive milk. When they are fed in a restricted milk feeding situation, there are incidents of nutritive and non-nutritive sucking (Haley *et al.*, 1998; de Passillé, 2001). Nutritive sucking occurs when the calf is allowed to suck for its milk (Veissier *et al.*, 2002), either by sucking on its dam for a short time during the day or by receiving milk or milk replacer from a bottle or bucket with a teat attached (de Passillé, 2001). However, only 17.7% of producers in Quebec, Canada use teats to feed their calves (Vasseur *et al.*, 2010) with 35 % of producers in Ontario, Canada using teats (CALF-ETERIA, 2012) and therefore most calves have no natural outlet for this behaviour. Non-nutritive sucking occurs when a calf sucks on something that does not provide milk, either from a non-nutritive teat or on part of the environment (Haley *et al.*, 1998; Veissier *et al.*, 2002). Calves that are fed from buckets will most likely spend the period after feeding sucking on a part of the pen or sucking on a conspecific, while calves fed by bottle will continue to suck on the teat after the milk is gone (Haley *et al.*, 1998). Haley *et al.* (1998) found that calves that suck milk through a teat with slow

flow will not suck the teat after the milk is gone as long as calves that were fed through a teat with fast flow (5 min of non-nutritive sucking compared with 2 min). This suggests that it is the actual performance of sucking behaviour that is important to the calf and not necessarily the sucking of milk. The motivation for a calf to suck has been studied by Rushen and de Passillé (1995), who used a syringe to place 10 mL of milk into a calf's mouth; this amount of milk was able to stimulate sucking on a non-nutritive teat, which shows that even ingesting a small amount of milk leads to non-nutritive sucking. However, the duration of milk feeding also plays a role (de Passillé, 2001). de Passillé and Rushen, (2006) later discovered that it is the lactose in milk that actually stimulates this behaviour.

One of the main reasons that producers house their calves individually is the fear that they will suck on each other, a behaviour called cross sucking, which is a variation of non-nutritive sucking (Haley *et al.*, 1998). Cross-sucking in calves is thought to lead to inter-sucking (when a cow or heifer sucks at the udder/teats of herd mates) and milk stealing (a cow or heifer sucking the teats of herd mates and ingesting milk) in cows and heifers after weaning (Kiel *et al.*, 2000). Cross sucking has been seen in many different group housing situations and has been studied to understand its mechanisms and impacts on welfare. Consistent cross sucking on specific calves can lead to inflammation of the area being sucked as well as hair loss over the calves' body (Haley *et al.*, 1998; Jensen, 2003). However, this is typically only seen when calves are being fed a low milk allowance from a bucket. Haley *et al.* (1998) found that providing calves fed low quantities of milk with hay reduced the amount of non-nutritive sucking seen (0.5 ± 0.15 min compared with 1.9 ± 0.04 min), and could be one way of managing the occurrence of cross sucking. However, providing calves with an outlet for their sucking motivation is considered the best way to manage the behaviour. Feeding calves through a teat attached to a bottle or bucket helps to relieve the sucking motivation and is a good way of encouraging this natural behaviour (Veissier *et al.*, 2002). Indeed, just attaching a dry teat to the wall of the pen allows the calf to suck on something other than a conspecific while being fed from a bucket (Veissier *et al.*, 2002).

1.3.3 Social Behaviour

Cattle are herd animals and social interactions are part of their behavioural repertoire; in an environment, calves will begin socializing with other calves after the first week of age before which, they mostly interact with their dam (Boe and Faerevik, 2003). It has been shown that

calves will work harder to have physical contact with another calf than to just have limited contact (Holm *et al.*, 2002). Holm *et al.* (2002) measured calf motivation to gain social contact with another calf by training them to press a panel in order to receive the reward, which was access to their companion for 3 minutes. With each consecutive test the workload calves had to perform increased (more panel presses to receive reward). Holm *et al.* (2002) also found that calves persisted through higher workloads in order to receive full social contact as opposed to just head contact, showing a motivation to be able to socially interact with their companion. This supports research that suggests that individually housed calves have reduced welfare (Holm *et al.*, 2002).

The social isolation that individual housing places on calves is believed to be stressful and may prevent the learning of social behaviours which adult cattle use during their production life (Duve and Jensen, 2011). Broom and Leaver (1978) conducted a study where they housed calves in visual isolation or in a group of 3 for 8 months. At the end of the 8 months the calves were all grouped in a field together. They found that calves housed in isolation initiated many competitive interactions on day 1 in the field but not many after that. They noted that the group reared calves appeared to stay closer to their group mates while the isolation reared calves also appeared to stay closer to the calves they were housed beside or spent time alone (Broom and Leaver, 1978). Duve and Jensen, (2011) found that calves who had been housed in pairs from birth showed preference for their companion when allowed to choose between their companion and a strange calf. They also measured the response from calves housed together from 3 weeks of age, and calves who were individually housed beside another calf with visual and auditory contact, and physical contact through the bars of the pen. They tested the calves in a novel environment with the companion present and absent. When the companion was present all calves took more steps (108.0 ± 6.25 compared with 82.3 ± 6.25) than when alone and this may suggest that there was a lower level of fear when calves were introduced to something new with a companion than without (Duve and Jensen, 2011). At one point they separated the companion calf from the test calf and measured the separation behaviour. Individually housed calves were more inactive during the separation test than other calves, while the paired calves had a higher heart rate during separation showing that individually housed calves were less stressed at separation. This suggests that calves housed together form a stronger bond than those housed beside each other (Duve and Jensen, 2011).

Jensen and Larsen, (2014) conducted an experiment where they tested different levels of social access housing by exposing calves to a novel calf in a test arena. They found that when presented with a novel calf in an open field, paired calves had the shorter latency to sniff the novel calf by 3.2 – 7.8 seconds compared with the other treatments of individual housing (isolated, visual access, or tactile access through bars). They also found that with increasing access to another calf the amount of time the subject calf spent sniffing or licking the muzzle of the novel calf increased, so that the paired calves spent the most amount of time sniffing and licking the muzzle and the isolated calves spent the least amount of time (Jensen and Larsen, 2014). During the novel environment test, the pair housed calves had a lower heart rate (139 ± 4.3 beats/min compared with: 143 ± 5.2 , 152 ± 5.5 , and 160 ± 5.3) than the calves who were individually housed, which suggests that they were less stressed (Jensen and Larson, 2014). Indeed, multiple studies have shown that socially housed calves will interact with another calf more readily than individually housed calves, and that once the interaction has been initiated, the individually housed calves will more forcefully push the other calf showing an impaired ability to regulate social interactions (Broom and Leaver, 1978; Duve and Jensen, 2011; De Paula Vieira *et al.*, 2012; Jensen and Larsen, 2014). Olsson and Westlund (2007) suggest that this increased aggression individually housed calves show can be considered as the product of limited social learning and few social skills.

Play behaviour is a natural social behaviour that many suggest can be linked with positive welfare (Krachun *et al.*, 2010; Mintline *et al.*, 2013). Juvenile animals are known to be motivated to play when their essential needs are met (Jensen *et al.*, 1998). This means that calves play when they have enough energy left once their physiological needs are taken care of (Krachun *et al.*, 2010; Duve *et al.*, 2012). Play has also been reported to decrease when calves have been subjected to a painful procedure. Mintline *et al.* (2013) disbudded calves using various pain mitigation techniques and found that in the three hours after disbudding the sham disbudded calves and the calves given a local anaesthetic or non-steroidal anti-inflammatory (NSAID) played more in a test arena than calves who were disbudded without any pain control at all. Rushen and de Passillé (2012) have also found that calves that were disbudded using a caustic paste played less in a test arena the day after disbudding, than calves that had not been disbudded.

Valnickova *et al.* (2015) compared calves that were left with the dam for four days after birth with those who were removed immediately and also looked at the level of play from single housed calves and calves housed in groups of three. They found that the calves who were kept with their dam played more (3.3 minutes compared with 1.8 minutes) in week 12 than calves that were immediately separated. They also found that while group calves played approximately twice as much as single calves during week 2 and 5, there was no difference at week 12 (Valnickova *et al.*, 2015). Duve *et al.* (2012) found effects of the type of social contact and milk allowance on the amount of play behaviour that calves performed. They measured the duration of play after provision of straw for 20 min, and found that calves housed under traditional conditions (low milk allowance and individual housing) played less (for week 3 of observations: 2.4 s [single housing, low milk allowance] compared with: 30.3 s [pair housing, high milk allowance], 32.2 s [pair housing, low milk allowance], 36.2 s [single housing, high milk allowance]) than conspecifics who were housed in groups or who had a higher milk allowance. Play peaked in week 3 and then decreased to low levels until the end of the trial in week 6. Similarly, Babu *et al.* (2004) observed a higher incidence of play in calves housed in groups, while they only saw one occurrence of play in individually housed calves. Krachun *et al.* (2010) also found that a higher milk allowance (12 L/d compared with 6 L/d) and later weaning (13 weeks compared with 7 weeks) increases play behaviour. Recently, Jensen *et al.* (2015) found that calves who are fed 5 L/d overall played less (140 s/24h compared with 202 s/24h) than calves who are fed 9 L/d. Higher intake calves played 200 s more than standard intake calves on d 15, but there was no difference between treatments on d 29 and d 43. Play was significantly higher on d 15 and d 29 compared with d 43 by approximately 190 s. Individually housed calves actually expressed more locomotor play than pair housed (119 s/24h vs. 67 s/24h), but were unable to express social play, which accounted for 69 s/24h, 115 s/24h, and 12 s/24h of the calves time budget on the three observation days (Jensen *et al.*, 2015). Individually housed calves in Jensen *et al.* (2015) study may have expressed more locomotor play because they were given twice the amount of space per calf as paired calves. As can be seen the duration of play over a full day is quite small; however, multiple authors have suggested that it can be an important indicator of welfare (Krachun *et al.*, 2010; Mintline *et al.*, 2013; Jensen *et al.*, 2015). While play behaviour has been studied in open field tests and novel object tests, it has not been

studied in a typical commercial setting, likely due to the small amount of time it occupies in a calf budget time or the lack of automated tool to monitor activity in commercial dairies.

Calves begin to play around the age of two weeks old, beginning with locomotor behaviours and play fighting, which then progresses to social licking around four weeks (Boe and Faerevik, 2003). By the second month they have begun play mounting each other and will begin to have aggressive interactions around four months of age (Boe and Faerevik, 2003). Most bovine play behaviour is either locomotor play or social play (Jensen *et al.*, 1998). Locomotor play includes kicking, bucking, and running (Jensen *et al.*, 1998). While these behaviours can be performed singularly, they are more commonly seen between multiple calves expressing locomotor play together (Jensen *et al.*, 1998). These behaviours, along with investigative behaviour decrease significantly around six months of age (Boe and Faerevik, 2003).

Social licking has not been studied in calves much, but in cows, social licking or allogrooming is thought to have an influence on social bonding (Sato *et al.*, 1993). Sato *et al.* (1993) found that allogrooming was expressed more in cattle that have been raised together and are closer in birth, which may be due to a stronger bond between cattle closer in birth than those further apart. Laister *et al.* (2011) showed that in adult dairy cattle the heart rate of receivers decreased (by 1.3 beats/min for study 1 and 1.1 beats/min for study 2) during grooming. Allogrooming itself has not been shown much in calves; however, Faerevik *et al.* (2008) measured it while looking at space allowance for resting in a group environment. While the number of social grooming occurrences was not found to change with the different sizes of resting area (small, medium, and large), it has been suggested as a measure of welfare for calves, similarly to play behaviour. In addition, Boe and Faerevik (2003) mentioned it as an indication of the social bonding between calves. More research would be needed in order to show that allogrooming or social grooming has a similar calming effect on calves as it does on adult cattle.

1.4 Calf Rearing Environment

Traditionally, calves have been housed in outdoor hutches or indoor calf pens that vary in size and number of solid walls (Lago *et al.*, 2006). This type of housing does not allow for a large space allowance if the calf is kept tethered to the hutch or with a small outdoor enclosure. The style of barn or arrangement of the calf pens inside a barn also varies (Kelly *et al.*, 1984).

More recently, group housing has become more popular and this can range from pair housing calves to large (> 10 calves) groups with an automated feeder (Chua *et al.*, 2002; Hammon *et al.*, 2002; de Passillé *et al.*, 2011; Pereira *et al.*, 2014). Automated feeders have also become more popular and this also allows for a group housing environment (Hammon *et al.*, 2002). These systems enable producers who are interested in feeding free-choice or ad libitum milk or milk replacer to do so, the high milk feeding can be accomplished with both acidified milk or automated feeders (de Passillé *et al.*, 2011; Pereira *et al.*, 2014). However, there are still many producers (especially in North America) who continue to house calves individually: 87.9 % of farms surveyed in Quebec, Canada, house calves individually (Vasseur *et al.*, 2010) and 67.9 % in the United States housed calves individually in pens or in hutches (USDA, 2008).

Waltner-Toews *et al.* (1986) surveyed 104 farms in southwestern Ontario, Canada and found that out of 104 farms studied, during the summer, 49.0 % housed calves indoors in individual calf pens, 22.1 % in group pens, 17.3 % in calf hutches outside, and the remaining in other types of housing not mentioned. The authors also surveyed the same farms in the winter, and found some differences: 55.8 % of farms housed calves indoors in individual pens, 24.0 % in group pens, and only 7.7 % in outdoor hutches, with the remaining 12.5 % in other unknown housing. Vasseur *et al.* (2010) surveyed farms across Quebec, Canada regarding their unweaned calves' management and found that most calves were still housed individually, only 12.1% of farms surveyed housed their calves in groups. They found that 7.4 % of calves were housed in hutches, while 45.9% were housed individually in pens with walls or barriers between them, while 27.0% are housed in metal or wood crates and 13.9% in tie-stalls. Vasseur *et al.* (2010) also found that 5.7% of farms actually tied calves to the wall in front of the cows' tie stall. A more recent survey of dairy calf management in California conducted by Love *et al.* (2016) found that 93.3 % of 134 surveyed farms housed some or all of their calves individually, and 92.8 % housed calves in hutches outside. They also found that 19.4 % of farms (n= 134) housed at least some of their calves in groups. The authors do note that outdoor housing is most common in California due to the climate.

Davis *et al.* (1954) were one of the first to introduce the outdoor calf hutches to the industry when they compared an outdoor portable pen made from metal roofing material to indoor calf pens with solid sides. Multiple different types of hutches have come into the industry since then and Macauley *et al.* (1995) conducted an experiment where they compared three

different types of calf hutches that were commonly in use: wooden hutches with an outdoor pen, enclosed molded polyethylene domes, and thermo-molded opaque polymer hutches with an outdoor pen. The authors did not come to any conclusions with regard to what type of hutch is best, however they stated that the decision can be made based on manager preferences on farm. They mentioned that the dome hutch was consistently at a higher temperature inside than the other two, and encouraged the use of the outdoor area that is available with the other two hutch types (Macauley *et al.*, 1995).

Lago *et al.* (2006) surveyed naturally ventilated calf barns from 13 different farms. They took note of the number of solid walls surrounding an individual calf pen and found that 9 of the 13 barns used solid walls between the calves while three used mesh walls. They found that solid dividers between pens decreased respiratory disease, while other solid panels (in the front, roof, or back of the pen) actually increased respiratory disease. They believe that the solid panels between calves decreased bacterial transfer between calves. They also found that barn area per calf varied greatly from 4.2 m² to 15.6 m², which show many different management techniques (Lago *et al.*, 2006). Hill *et al.* (2011) compared the use of outdoor polyethylene hutches to a more modern indoor nursery with individual pens with mesh walls. They found that calves housed in the nursery had a 6 % higher average daily gain than calves housed in the hutches, and that straw bedding lead to a higher average daily gain (9 to 13 % higher) than sand bedding.

There are many factors to consider when planning a calf rearing environment. The following sections will review space allowance, enrichment, bedding and ventilation, and temperature. Factors that are specific to group housing, such as re-grouping and group size will also be reviewed.

1.4.1 Space allowance

Much of the calf's time is spent resting and lying down, so a comfortable lying area is important (Hokkanen *et al.*, 2011). Faerevik *et al.* (2008) found that on average the calves were lying down 66 % of the time over a 24h observation period. Jensen and Larsen (2014) found that calves spent 5.5h of the day (24 h) standing with the remaining 18.5 h lying down. The lying area needs to be large enough for the calf to express natural lying behaviours, which include lying down with the legs stretched (Faerevik *et al.*, 2008). Lago *et al.* (2006) looked at 13 different calf barns and found a wide range in individual calf pen area: 2.3 m² to 4.1 m² with an

average pen area of 3 m². The Canadian Dairy Code of Practice does not actually state a recommended amount of space per calf; however they do state that calves must be able to “easily stand up, lie down, turn around, adopt normal resting postures and have visual contact with other calves” (NFACC, 2009); this would apply to both individually housed calves as well as group housed calves.

The European Union states that calves under 150 kg live weight should each be given 1.5 m² of lying space when in a group housed situation (Council Directive 97/2/EC). This value was based on space allowance research that suggests that providing less than this decreases group-housed calves possibility to perform natural lying behaviours (Tapki *et al.*, 2006). Faerevik *et al.* (2008) found that calves housed in groups with a space allowance of 0.75 m² per calf had less synchronous lying time than calves housed with larger allowances (20.15 ± 3.22 % lying simultaneous for the small pen compared with 28.60 ± 1.60 % for the medium pen and 31.25 ± 2.67 % for the large pen) per calf. They also saw that lying posture changed with more space allowance given, with calves in the large (1.75 m²) and medium (1.25 m²) lying areas found to be lying recumbent more often (4.32 ± 0.52 % for the medium pen and 3.67 ± 0.67 % for the large pen) than calves in the small space allowance pen (1.77 ± 0.52 % of observations for the small pen). These findings were consistent for both the 100 kg calves and 150 kg calves (Faerevik *et al.*, 2008).

1.4.2 Enriched housing

Environmental enrichment has been used to help prevent frustration and fulfill behavioural needs (Mandel *et al.*, 2016). Newberry (1995) defined enrichment as a modification in the housing environment that improves the biological functioning of confined animals. Regarding a group housing environment, Ninomiya and Sato (2009) conducted a study where they provided an enriched space to a group of 5 calves compared with an empty pen. The calves in the enriched treatment were given different lying areas, a grooming brush, and a feeding area. They found that providing the enriched environment increased the variety of behaviours seen in the calves, but did not affect weight gain. The enriched group did use the brush they were provided, but use decreased throughout the trial (10.1 ± 4.9 minutes on day 3 compared with 0.8 ± 0.6 minutes on day 51). Calves in the enriched environment slept with the head touching the flank almost twice as much (on day 21 and 51) as the control calves; Hanninen *et al.* (2008)

showed that REM sleep occurs during this posture. This sleeping behaviour is thought to be related to behavioural satisfaction from the calves' housing environment (Ninomiya and Sato, 2009).

1.4.3 Bedding and ventilation

Stull and Reynolds (2008) note that the most important aspects of the calf's lying area, next to the space given, is the dryness and cleanliness of the area. Bedding and ventilation play large roles in calf health by affecting the levels of bacteria in the calf environment (Wathes *et al.*, 1984; Panivivat *et al.*, 2004; Hill *et al.*, 2011). Different types of bedding have been studied to increase the calves' comfort but also to reduce bacterial growth thereby reducing possible bacterial infections (Hill *et al.*, 2011). Hill *et al.* (2011) found that the deeper the bedding the lower the occurrence of respiratory infection. There was a higher incidence of fluid feces and more treatments for scours on granite fines (1.61 ± 0.057 fecal fluidity score) and sand bedding (1.59 ± 0.057 fecal fluidity score) compared with wood shavings (1.38 ± 0.057 fecal fluidity score) and straw bedding (1.38 ± 0.057 fecal fluidity score); however fluid feces were more visible on granite fines and sand bedding, which may have affected the results (Panivivat *et al.*, 2004). Lago *et al.* (2006) noted that in a cold environment, deep straw bedding was important in reducing respiratory infections, most likely due to the insulating factors of deeply bedded straw. As well, calves bedded on straw were found to be more feed efficient and had faster growth when compared with calves bedded on wood shavings in cold weather conditions, possibly due to better insulation (Hill *et al.*, 2007).

Calves are susceptible to respiratory disease (Lorenz *et al.*, 2011) and different types of bedding can contribute to the prevention of respiratory disease. However, ventilation in the housing environment can be integral to this as well. Outdoor housing options generally provide good ventilation for calves (Earley *et al.*, 2004). However, when looking at calf hutches it is important to ensure they are placed in the proper position in order to encourage dryness and ventilation (Stull and Reynolds, 2008). Calf barns should be properly ventilated either naturally or artificially. Lago *et al.* (2006) found that out of 13 barns studied, wind was the main ventilation force in 8, thermal buoyancy in 4 barns, and 1 barn was essentially unventilated (ventilation rate of 0). Improperly ventilated calf barns show an increased incidence of respiratory disease when compared with outdoor housing (Wojcik *et al.*, 2013). Nordlund (2008)

looked at types of ventilation in calf barns and stated that due to the design of barns, it is sometimes difficult for ventilation to properly occur, and emphasized the contributing factors to decreasing respiratory disease in a calf barn, such as a solid panel between calves, providing sufficient bedding for calf comfort and warmth, and decreasing the number of airborne bacteria.

Some research has gone into trying to increase the potential ventilation of calf hutches. In summer, calves housed in hutches can be prone to heat stress depending on weather conditions. Moore *et al.* (2012) found that raising the back of the hutch with a concrete block led to lower respiratory rates (44 vs 58 breaths per min for not raised) for calves during the late evening observation time. It has also been found that elevating the back of the hutch led to a reduction in airborne bacterial counts (Hill *et al.* 2011). In contrast, Pezzanite *et al.* (2010) did not find that elevating the back of the hutch increased ventilation, which may be explained by temperature and humidity differences between studies.

1.4.4 Temperature

A calf's thermoneutral zone lies between the temperatures of 9°C (lower critical limit) and 29°C (upper critical limit) (Hepola *et al.*, 2006). If the calf is undergoing heat stress or cold stress, this will increase its body's demands in order to maintain its core body temperature. Body weight gain has been used in the past as an indirect measure of heat stress (Broucek *et al.*, 2007). Broucek *et al.* (2007) found that calves born in the summer gained significantly less than calves born in the fall. West (2003) also found that calves raised in a climate with an average of 27°C gained 8.61 kg less over three months than calves raised under an average temperature of 10°C. This suggests that calves are much better able to handle and adapt to cold conditions than to hot conditions.

Heat stress may be a problem for calves housed in hutches in the summer (Moore *et al.*, 2012). Friend *et al.* (2014) found that placing a reflective cover on the hutch lead to a decreased hutch temperature. However, this study was conducted on empty calf hutches and it has yet to be seen whether the covers would be able to affect the calf's body temperature while inside the hutches. Carter *et al.* (2014) measured the temperature inside calf hutches with an insulated reflective cover on them as well, and also measured calf ear canal temperature. They found that control hutches (no covers) had a lower interior temperature (16.5°C compared with 18.2°C) at lower ambient temperature (18°C) than insulated hutches, while at higher ambient temperatures

(35°C) control hutches had a higher interior temperature (35.0°C compared with 33.0°C) than insulated hutches. This shows that at higher ambient temperatures the interior temperature of the hutch was decreased by the insulated cover. When looking at ear canal temperature, calves in control hutches had a lower temperature (37.4°C compared with 37.8°C) at low temperature humidity index (THI) (63) values than calves in insulated hutches, and at higher THI (79) values, there was no difference between treatments (Carter *et al.*, 2014). While this suggests that the insulated hutches did not make much difference between treatments at high THI, the respiration rate was lower (57.4 compared with 63.9) for calves housed in insulated hutches at higher THI (79) (Carter *et al.*, 2014).

Heat stress is not the only ailment that can affect the health and well-being of dairy calves. In Canada and the northern United States, cold stress can also be a factor. Nonnecke *et al.* (2009) stated that in the northern United States, calves that are born during the winter and early spring can go through periods of sustained cold during their first weeks of life. This cold stress can lead to losses that are associated primarily with cold, wet and windy conditions (Nonnecke *et al.*, 2009). It has been shown that morbidity during the winter can be as high as 52 % compared with 13 % for calves born in the summer, while mortality during the winter can be around 21 % and mortality in the summer around 3 % (Godden *et al.*, 2005).

In order to properly maintain their body condition during periods of cold stress, calves must increase their caloric intake to maintain their body temperature (Nonnecke *et al.*, 2009). Extra energy is needed once the temperature decreases below 6-10°C for calves over two weeks old, and prior to this, extra energy is needed around 10-15°C for calves to maintain their core body temperature (Lorenz *et al.*, 2011). Nonnecke *et al.* (2009) calculated that a 45 kg calf would require 1,735 to 1,969 kcal of metabolizable energy (ME)/d at 15°C, while at 5°C that same calf would require 1,969 to 2,437 kcal of ME/d in order to maintain its body temperature. They conducted an experiment where calves were individually housed in either a cold or a warm indoor environment, and found that calves housed in the cold environment ate about 2 kg more calf starter per week than calves housed in the warm environment, but gained a similar amount of weight (Nonnecke *et al.*, 2009). This suggests that the extra intake was needed in order to maintain the calves' growth rate in the cold environment to comparable levels as those maintained by the calves in the warm environment. For this reason, a higher level of milk feeding is needed in a cold environment, in order to ensure calves are able to properly grow.

1.4.5 Re-grouping

Producers in Europe have started adapting different housing systems in order to comply with the current EU regulations banning individual housing from the age of 8 weeks (Council of the European Union, 1997). Some producers house calves individually until weaning at 8 weeks and then transfer them to a group housing environment, others only house them individually for two weeks before transfer to group housing, while others still house all calves in groups from birth (Marce *et al.*, 2010). These different systems all promote group housing in some way, but methods that encourage multiple groupings could lead to higher stress levels for calves, as observed by Wilcox *et al.* (2013). These authors mixed calves 5 times and then compared them to control calves that were not mixed; they found that mixed calves had higher cortisol levels than control calves; as well, mixed calves consumed more molasses than control calves. The authors state that the mixing induced anxiety not seen in cortisol levels could be seen in increased consumption of molasses. Raussi *et al.* (2005) also noted that 11 month old heifers did not habituate to weekly re-groupings over an 11 week study, and that re-grouping was consistently stressful for the heifers. Therefore re-groupings should be kept to a minimum in order to decrease the stress involved in re-grouping as shown by increased cortisol levels (Wilcox *et al.*, 2013) and more agonistic interactions between heifers (Raussi *et al.*, 2005). However, Veissier *et al.* (2001) found no difference in re-grouping of milk fed calves with regard to health and production; they also found very low levels of aggression. Veissier *et al.* (2001) used young milk fed bull calves while Raussi *et al.* (2005) used 11 month old heifers, which could have contributed to the difference in results.

1.4.5 Group Size

Automatic feeders have increased in popularity in recent years due to the ability of the feeder to feed large numbers of calves. According to one supplier (De Laval, 2000) automatic feeders can feed groups of up to 25-35 calves. However, Svensson and Liberg (2006) state that this increases the potential for disease transmission between calves and also can make it more difficult for producers to detect possible health issues. They studied groups of 8 and 16 calves being fed with automatic feeders and provided with the same area per calf. They found that calves housed in the large groups grew approximately 40 g/d less than the calves housed in small

groups. The small groups were also associated with a reduced risk of respiratory disease (Svensson and Liberg, 2006). Faerevik *et al.* (2007) conducted a study where they raised calves in groups of 8 with automatic feeders before weaning and then moved the calves to groups of 4, 8, and 16. Calves were kept in individual pens for the first ten days of life and then moved to groups of 8 until weaning. The mean number of displacements from the feed barrier was higher for the group of 4 (5.1 ± 0.9 observations of feed displacement) than for the group of 16 (1.4 ± 0.8 observations), which could be explained by less monopolisation of resources and the adoption of a non-aggressive strategy in large groups compared to small groups (Faerevik *et al.*, 2007).

Fujiwara *et al.* (2014) conducted a study where they examined the social behaviour of calves that had been previously housed individually, and housed in a group pen with automatic feeder from 5-6 d of age. There were no more than 9 calves in the group pen at any time. They then repeated the experiment by housing calves before grouping in pairs or singles. During the first trial, the authors found that 27% of calves voluntarily drank milk in the first 24 hours of grouping, and in the second trial there were no differences found between the pairs and single calves with regard to when they first voluntarily drank milk (Fujiwara *et al.*, 2014). Based on the results from the second experiment, the authors state that social housing in the first few days after birth may not make a significant difference in the performance or welfare of calves (Fujiwara *et al.*, 2014). Similarly, Duve and Jensen (2012) housed calves either individually or in pairs from d 1 of life to d 42 and then all calves were housed in groups of 6 until d 49. They studied three treatments, individual housing for the duration, pair housing for the duration, and individual housing for three weeks and then pair housing until grouping. Weight gain or health of the calves did not differ between treatments.

Cobb *et al.* (2014a) compared calves housed in individual hutches with calves housed in groups of three, in hutches twice the size as the individual ones. Each hutch had an outdoor pen attached to allow the calves an outdoor environment. Calves housed in groups consumed more calf starter after weaning than the individually housed calves (approximately 250 g DM more per day) and this resulted in a tendency for a higher average daily gain for the grouped calves ($P < 0.099$). No differences in health were found between treatments. In a later study, Cobb *et al.* (2014b) housed calves either individually, in pairs, or in triplets inside a barn in calf pens. The calves were all given 2.50 m² of space and the pens were evenly allocated around the barn. No

differences were found in average daily gain or in calf height and length, but the paired and tripled calves had greater calf starter intake at weaning. There were no differences between the treatments with regard to health.

Pair housing calves could be a compromise between group housing and individual housing. By housing calves in pairs they have the ability to socialize with another calf while limiting the interactions that allow for disease transmission. Indeed, a number of studies showed that pairing calves allows for social interactions that improve calf welfare when compared with individual housing, while not reducing calf performance or increasing disease prevalence (Chua *et al.*, 2002; de Paula Vieira *et al.*, 2010; Jensen and Larsen, 2014; Jensen *et al.*, 2015). This suggests that pairing calves can have similar benefits to group housing calves, while reducing the risk for disease transmission without compromising on performance.

1.5 Conclusions

Dairy calf housing is still a concern in the Canadian dairy industry. Even with much research showing the welfare improvements that group housing can bring, many producers are still housing their calves individually. There can be many reasons for this, and while group housing in a complex social environment with other calves and cows is the ideal, housing calves in pairs can be a close second. Pair housing results in similar feed intakes and growth when compared to individual housing (Chua *et al.*, 2002), and also provides other benefits, including social interaction that are similar to group housing (Gaillard *et al.*, 2014). Examining different ways to provide a paired housing system will enable producers to make an informed decision regarding the best housing system for themselves and their calves.

1.6 Thesis Objectives

The main objective of this thesis is to investigate an outdoor method of pair housing calves using calf hutches with enclosure. The specific objectives are:

1. Determine if the growth and feed intake of the pair housed calves and the single housed calves differed.
2. Determine how the calves use their environment in terms of time spent in each area and behaviours performed.

3. With regard to paired calves: document the interaction between paired calves, and the time they spend together.

It was hypothesized that paired calves would interact together and that there would be no differences between the growth and milk intake between the paired or single calves, and all calves would make use of the different areas of their environment (hutch, enclosure, feeding area).

CHAPTER 2: AN OUTDOOR METHOD OF HOUSING DAIRY CALVES IN PAIRS USING INDIVIDUAL CALF HUTCHES

2.1 INTRODUCTION

Producers routinely house their replacement dairy heifers individually either in hutches or in single pens (Chua *et al.*, 2002; De Paula Vieira *et al.*, 2010), and calves typically have visual contact with one another (Marce *et al.*, 2010). Housing calves in groups or pairs can help to satisfy their motivation for physical contact; calves have been reported to work harder for full physical access to another calf when compared to just head-to-head access, suggesting that they value physical access to another calf (Holm *et al.*, 2002). Group-housed calves have not only been shown to have increased or similar weight gains compared to individually-housed calves (Chua *et al.*, 2002), but they have also been shown to have the ability to interact socially and perform natural behaviours such as social licking and play behaviour (Sato *et al.*, 1993; Faerevik *et al.*, 2007; Jensen *et al.*, 2008). Social licking or allogrooming is thought to influence social bonding; calves that are raised together from an early age expressed more allogrooming than those grouped together later in life (Sato *et al.*, 1993).

The social isolation that occurs with individual housing is thought to be stressful for calves and can prevent the learning of social behaviours (Duve and Jensen, 2011). Some studies have shown that individually-housed calves have an impaired ability to socialize with other calves; when presented with a novel calf, individually-housed calves will react more aggressively than calves that have been socially housed (de Paula Vieira *et al.*, 2010; Jensen and Larsen, 2014). The increased social interaction found in paired housing can be beneficial to the calf with respect to learning social cues as well as adapting to future changes in feeding system or environment (Costa *et al.*, 2014).

One reason that producers have shied away from group housing in the past is because of the possibility that cross sucking and competition at the feeder can occur. Cross sucking is a non-nutritive sucking behaviour (Rushen and de Passillé, 1995) that can lead to hair loss and inflammation of the sucked area (Sambraus, 1980)). However, when calves are allowed to suck for their milk or are able to redirect their sucking motivation to a dry teat on the wall, then cross sucking can be decreased (Veissier *et al.*, 2002). Providing calves with an ad libitum or high milk allowance can also contribute to a decreased occurrence of cross sucking, as Rushen and de

Passillé (1995) found that calves that were fed less milk had a higher occurrence of cross sucking. Displacements at the teat can also be a problem with group housing, but this can be managed by providing more teats (von Keyserlingk *et al.*, 2004). Some authors have looked at whether pair housing can yield similar improvements to calf welfare as group housing does, and found similar weight gains and milk intakes as in group housing (Cobb *et al.*, 2014b) and individual housing (Chua *et al.*, 2002). As well, calves housed in pairs can still benefit from the social contact provided by a companion, as shown by Meagher *et al.* (2015).

Calves housed in hutches are typically tethered or enclosed in a small pen (Davis *et al.*, 1954; Macauley *et al.*, 1995); raising them loose in a larger outdoor pen could provide them with spatial or physical enrichments. Enrichments can be considered as anything that helps prevent frustration in the animal or to fulfill the animal's needs (Mandel *et al.*, 2016). This outdoor area would allow calves to run more when paired together and provide multiple areas for the animals (inside the hutch or outside), and the choice to have physical contact (Ninomiya and Sato, 2009). Much research has looked at the effect of hutch housing in the summer, and how the hutches can contribute to heat stress (Moore *et al.*, 2012; Friend *et al.*, 2014; Carter *et al.*, 2014). However there is little research regarding outdoor hutch housing in the winter. Krohn *et al.* (1992) reported that cows reduced their time spent outside during extreme adverse weather conditions and preferred to stay indoors when the temperature dropped below zero. However E. Shepley (University of Guelph, Alfred, Ontario, Canada, personal communication) showed that dairy cows used to year-long outdoor access will choose to spend a minimum of one hour per day during Eastern Canadian winter conditions, even with cold temperatures and snow coverage.

In this experiment, we compared single and paired calves housed in hutches with an outdoor enclosure. The objectives were to determine if the growth and feed intake of the pair-housed calves and the single-housed calves differed, and to characterise the paired calves' interactions. Both a summer and winter trial were conducted to see if the housing method was successful under Canadian extremes.

2.2 MATERIALS AND METHODS

The experiment was conducted at the University of Guelph's Alfred Campus (Alfred, Ontario, Canada) and was approved by the University of Guelph's Animal Care Committee, which adheres to the Canadian Council on Animal Care (CCAC) guidelines (CCAC, 2009). A Summer trial was conducted during the months of June to August of 2014, while a Winter trial was conducted during the months of February to April of 2015.

2.2.1 Animals, Housing, and Management

For each trial, 18 Holstein heifer calves were purchased from external sources prior to the start of the trial. The calves were randomly assigned to 2 treatments: housed either as singles ($n = 6$ for each season) or pairs ($n = 6$ for each season i.e. 6 pairs; 12 calves). Single calves had access to a 6.9 m² outdoor pen and one plastic hutch (2.4 m² of indoor space). Indoor and outdoor area was exactly doubled for paired calves with 13.7 m² of outdoor space and 4.8 m² of indoor space (2 hutches). No shade was provided besides the sun protection offered by the hutches. Each pen was constructed using wire cattle fencing, on a 15 cm deep compacted sand base. Straw bedding was added at a minimum of 20 cm for each hutch. Manure was removed four days per week and straw added three days per week or as needed to ensure a dry indoor and outdoor environment. Additional straw was provided outdoors after precipitation, when calf pens were wet.

Calves were brought to the farm at an average (\pm SE) of 7.5 d (\pm 1.6) (age of calves on arrival to farm was estimated, as no records of birth were transferred) and after a period of adaptation (minimum of 12 d), were approximately 24.0 d (\pm 4.3) when the trial began. The adaptation period was used to adjust calves to the high milk allowance and the milk feeding method. Calf general condition (i.e. health and vigour) were evaluated visually upon arrival and navels were dipped in iodine (7 % Iodine solution) to prevent bacterial infection. Calves were given 1 mL of tulathromycin (Draxxin; Pfizer Animal Health, Kirkland, QC, Canada) and 1 mL of selenium (Dystosel; Pfizer Animal Health, Kirkland, QC, Canada) as prevention and to decrease incidence of illness (Miller-Cushon *et al.*, 2013). Calves were also given 2 mL of a bovine rhinotracheitis-parainfluenza-respiratory-syncytial virus vaccine (modified live virus) (Inforce 3; Zoetis Canada, Kirkland, QC, Canada) as prevention against respiratory disease and

influenza. During the summer trial two calves were treated by the vet, one calf for coccidiosis and ulcers that was removed from the trial for 7 days and 1 calf that was treated for a navel infection but was kept enrolled in the trial. During the winter, no calves required medical treatment once the trial began.

2.2.2 Milk and Grain Feeding

Acidified milk replacer was delivered 2 \times /d in high quantities (between 12 and 16 L/d/calf) using an artificial teat attached to the fence with a rubber tube running from the artificial teat (Peach Teats; Skellerup Industries Ltd., Woolston, New Zealand) to a bucket placed on the ground outside the pen. Shur-Gain Optivia High Performance milk replacer (22 % CP and 18 % fat) (Nutreco Canada Inc., Guelph, ON, Canada) was mixed at 150 g powder to 1 L of water and was acidified using 9.8 % dilute formic acid (The Acidified Milk Solution; NOD Apiary Products Ltd., Frankford, ON, Canada) following OMAFRA protocol (Anderson, 2012). A one-way valve was attached to the end of the tube inside the bucket to prevent backflow of milk. Buckets were thoroughly cleaned and sanitized twice per day, while teats and tubes were cleaned and sanitized thoroughly once per day and rinsed a second time.

Feeding method was adapted for the winter trial to prevent milk freezing and to allow for high milk intake. Milk replacer was available for 30 min to 1 hour per feeding or as long as the calf had continued interest in the teat. Non-acidified milk replacer was fed 3 \times /d by attaching an artificial teat to the side of a bucket. The bucket was then attached to the pen wall at an appropriate height allowing calves to drink. Buckets and teats were thoroughly cleaned and sanitized three times per day immediately following the feeding period.

Calves had access to calf starter (Rooney 20 % Calf Starter Grower Medicated, Iroquois, Ontario, Canada) from d 1 of trial and starter was gradually increased to 2 kg/d at the start of weaning, and increased up to 2.5 kg/d by the end of weaning. Hay and water were provided ad libitum. Provision of hay, water, and grain was done using a bucket for each calf to limit competition in the paired pens (3 buckets per calf). Calves were weaned gradually at 49 d (41 d for winter) of trial by gradually decreasing milk allowance by 10 % of initial milk intake for 10 days (de Passillé, *et al.*, 2010).

2.2.3 Measures

Feed intake

Milk intake was measured daily based on difference in weight of offered and refused milk replacer. Grain refusals were recorded daily 3 wk prior to the start of weaning, once intake increased.

Growth

Calves were weighed 1 ×/wk on a scale (Brecknell PS-2000 Scale; Brecknell Canada, Pointe-Claire, QC, CA) that was calibrated weekly, prior to each weighing to ensure accurate readings.

Lying and standing behaviour

Throughout the duration of each trial the posture of each calf (lying or standing) was recorded continuously over seven days with one recording per minute in order to monitor resting behaviour and ensure that the housing method allowed calves to rest enough. Activity loggers (Hobo Pendant G Acceleration Data Logger, Onset Computer Corp., Bourne, MA, US) were placed every week (Winter) or every 2 weeks (Summer) on alternating (each seven day period) hind legs, located on the lateral aspect of the leg along the metatarsus bone, following the procedure of Bonk *et al.* (2013).

Space usage, social interactions and redirected behaviour

Live behavioural observations were done 1x/wk for 7 non-consecutive hours (5 periods) in Summer (between 7:30 A.M. to 8:30 P.M.) and 6 non-consecutive hours (4 periods) in Winter (between 7:30 A.M. to 6:00 P.M.) by two trained observers (3 different observers in total) (Period 1: 7:30-9:30 A.M.; Period 2: 11:00 A.M.-12:00 P.M.; Period 3: 1:30-2:30 P.M. Period 4: 4:00-6:00 P.M. and Period 5: 7:30-8:30 P.M.) over the 7 (Summer) or 6 weeks (Winter) of the trial. Observers recorded behaviour of different calves at the same time, each positioned (between 2 to 4 m away from calf pens) to view 6 groups of calves (3 pairs and 3 singles each) with minimal movement. From their position observers could see inside the hutch to determine posture inside the hutch. Observers took position 5 min before the observation period began to

allow habituation and did not consciously attract the attention of the calves during the observation period. Observers switched position each recording day to prevent bias.

Inter-observer reliability was verified twice during each trial (>97 % for all behaviours). Observers sat in the same spot and recorded behaviour from the same 6 pens at the same time for at least 3 h at the beginning and end of each trial. Data from observations was compiled for each observer, observations were compared between the two observers and a percentage was given for related observations. Space usage (inside or outside the hutch), as well as the posture (lying and standing) of the calf in the pen for paired and single housed calves and proximity of the paired calves to each other were recorded twice per minute for 20 min each hour of observation. This was then calculated as a percent of observed time for each week of observations. Space usage was measured to see how often calves used their hutches and whether this amount changed as they grew. Proximity of paired calves to each other was assessed visually by approximation of the distance (one calf's length [distance was adjusted as the calves grew]) between the calves. This was recorded qualitatively as whether calves were together as part of the space usage observations. During feeding, synchronicity was recorded as when calves were feeding at the same time. Social interactions for paired calves, such as the number of allogrooming, cross sucking, and displacement events that occurred were recorded for both calves over 2-min continuous sampling for a total of 20 periods so 40 min per h. Descriptions of all behaviours observed can be found in Table 1.

Weather conditions

Temperature (maximum, average and minimum) and precipitation (in mm, either of rain or snow) were taken from the St-Albert (Ontario) weather station (approximately 33 km from the Alfred research dairy farm), collected from the Weather Canada website, and reported for each observation day in Table 2.

2.2.4 Statistics

Because of large differences in climatic conditions, summer and winter trials could not be considered as replicates, and were therefore analysed separately. Space usage data from each observation period were collated in percent of observed time. Space usage, milk intake, and weight gain data were analysed at the pen level, and for the paired calves, were obtained by

taking the mean value of the two calves. All data were tested for normality using the UNIVARIATE procedure in SAS (version 9.3, SAS Institute Inc., Cary, NC) or by plotting the residuals. Data found to be normal (weight gain and milk intake) were analysed using the MIXED procedure while data found not to be normal were transformed using an arcsine transformation (space usage, and activities performed) or a square root transformation (lying time) in SAS (version 9.3, SAS Institute Inc., Cary, NC). All data presented in the manuscript are back-transformed.

The effect of treatments (single vs. pair), week, and their interaction on weight gain, milk intake, lying time, space usage, and activities performed were tested using the MIXED procedure. Interactions are presented when significant; otherwise, main effects are presented. Starting body weight was included as a covariate for weight gain and milk intake. The variance components structure was used as the variance-covariance matrix structure for weight gain, space usage, activities and lying time while the autoregressive structure was used for the milk intake data. All covariance structures were selected based on the best fit according to Schwarz' Bayesian information criteria. For the pair and single comparison the Group option was also used to state a heterogeneous variance of error. Treatment and treatment by week interaction were included in the model as fixed effects, pen was included as random effect, and week was included as a repeated measure. Descriptive statistics were calculated on the percentage of time spent in close proximity. However, no statistical analysis was conducted on these data. Statistical significance was declared at $P < 0.05$.

Social interactions for paired calves i.e. displacements at the teat, cross sucking, and allogrooming, were collated for each pair of calves ($n=6$), each period of observation ($n=4$ in winter, $n=5$ in summer) and each week ($n=6$ in winter, $n=7$ in summer) as average number of bouts / 2 min observation, and then reported as average number of bouts / h of observation. Average difference in displacement at the teat, cross sucking, and allogrooming between weeks and between periods were tested using Cochran-Mantel-Haenszel (CMH; FREQ procedure) statistics adjusting for pairs of calves. As a Post Hoc test, differences between individual periods were compared using a Wilcoxon signed-rank test (UNIVARIATE procedure), with familywise error rate adjusting for multiple comparisons (new pairwise $\alpha_B = 0.04$).

2.3 RESULTS

2.3.1 Summer

2.3.1.1 Growth and milk intake

There were no differences in growth rate between treatments with paired and single calves gradually gaining weight over time ($P_{week} < 0.01$) with an average (\pm SE) daily gain of 1.1 ± 0.14 kg/d for both treatments, with the exception of a drop in average daily gain for paired calves on week 4 (average daily gain week 4 for pairs: 0.9 ± 0.09 ; $P_{trt \times week} < 0.1$). Final weights for paired and single calves averaged 106.4 ± 4.53 kg. Average daily milk intake was 11.1 ± 0.29 kg/d/calf for both treatments and all calves increased their milk intake throughout the trial ($P_{week} < 0.05$). In week 1, paired calves drank 2.0 kg/d more than single calves ($P_{trt \times week} < 0.01$). Average daily gain and milk intake for each treatment across weeks are reported in Figure 1.

2.3.1.2 Lying behaviour

Except for week 1, there was no difference in lying time between treatments with all calves lying on average 16.9 ± 0.16 h/d. A bout frequency of 25.1 ± 0.39 bouts/d was found for both treatments across all weeks except for week 3, and mean bout duration was 41.1 ± 0.76 min for both treatments across the whole trial. Lying time was different between treatments on week 1, when single calves lay 0.81 h longer ($P_{trt \times week} < 0.05$), and had 1.2x more lying bouts ($P_{trt \times week} < 0.05$) than pairs. In week 3, single calves had 1.2x more lying bouts than paired calves ($P_{trt \times week} < 0.01$) but did not differ in daily duration of lying or mean bout duration.

2.3.1.3 Space usage

Percentages of observed time spent inside and outside the hutch across weeks of the trial are presented in Figure 2. When calves were observed outside the hutch, they spent 38.5 % of time standing 33.3 % to 47.4 % of time lying down and approximately 15.3 % standing and feeding across weeks for both treatments. Of the time paired calves were inside the hutch, they spent over 80.0 % in the same hutch. Percent of time spent inside and outside the hutch, and doing activities in each location are reported for each treatment in Table 3. Paired calves lay 1.8x, 1.4x, 2.6x, and 4.7x more inside the hutch than single calves on weeks 2, 3, 6, and 7 respectively ($P_{trt \times week} < 0.05$; Figure 2). Single calves stood outside 1.3x more than paired calves

on week 1 ($P_{trt \times week} < 0.05$), but stood outside 1.4x less and lay outside 1.7x more than paired calves on week 7 ($P_{trt \times week} < 0.05$).

2.3.1.4 Feeding behaviour

All calves spent approximately 9.0 % of their observed time across weeks of the trial feeding. More specifically, they spent 4.0 % drinking milk, 3.4 % eating hay, 1.6 % eating grain, and 0.5 % drinking water. Paired calves drank milk and ate hay synchronously for 63.8 % and 29.0 % of the observed feeding times, respectively. Negligible amounts of time spent eating grain or drinking water synchronously were found. Single calves spent 1.4x and 1.7x more time drinking milk than paired calves in week 3 and 5, respectively ($P_{trt \times week} < 0.05$). Paired calves spent 2.1x more time eating grain than single calves in week 4 ($P_{trt \times week} < 0.05$), and 1.7x more time eating hay than single calves in week 7 ($P_{trt \times week} < 0.05$). Time spent drinking water did not differ between treatments or weeks, and there was no interaction between treatment and week.

2.3.1.5 Social interactions and redirected behaviour for paired calves

Social interactions did not differ between weeks ($P_{week} > 0.1$), averaging 1.8, 0.4, and 1.4 bouts / h of observations per pen across weeks for allogrooming, cross sucking and displacements at the teat, respectively. However, all three were affected by period of the day ($P_{period} < 0.01$ for allogrooming, cross sucking, and displacements at the teat, respectively; Figure 3). Allogrooming was observed more often in period 5 than in any other periods ($P_{pairwise} < 0.04$). Cross-sucking was observed mainly in period 1 (0.6 bouts/h) and 5 (1.3 bouts/h) and was almost non-existent in periods 2, 3 and 4 ($P_{pairwise} < 0.04$). Displacements at the teat was observed mainly in period 1 (2.7 bouts/h) and 4 (3.2 bouts/h) and was almost non-existent in the remaining periods 2, 3 and 5 ($P_{pairwise} < 0.04$).

2.3.2 Winter

2.3.2.1 Growth and milk intake

Average daily gain for both paired and single calves was 1.2 ± 0.10 kg/d across the whole trial. Single calves gained 0.3 kg/d more in week 4 than paired calves ($P_{trt \times week} < 0.05$; Figure 1). There were no effects of treatment or week on daily milk intake, which averaged 13.7 ± 0.42

kg/d across the trial for both treatments. Final average weight for paired and single calves was 115.6 ± 3.18 kg.

2.3.2.2 Lying behaviour

The average daily duration of lying for all calves was 17.1 ± 0.07 h, with a bout frequency of 20.5 ± 0.81 bouts/d and mean bout duration of 55.2 ± 1.07 min for all calves across the whole trial. Daily duration of lying peaked in week 3 and 4 and then decreased to lower levels in week 6 ($P_{week} < 0.01$). Bout frequency followed a similar pattern peaking in week 4 ($P_{week} < 0.01$) while mean bout duration followed an opposite pattern, peaking in week 1 and then decreasing in week 4 before increasing slightly in week 6 ($P_{week} < 0.01$). Differences between weeks for daily duration of lying, bout frequency, and the mean bout duration can be found in Table 4.

2.3.2.3 Space usage

Percentages of observed time spent inside and outside the hutch and activities performed in each area of the pen are presented in Table 3. Calves in both treatments used the hutch approximately 55.0 % of the time, and of the time paired calves spent inside the hutch, they spent over 80.0 % of observed time in the same hutch across the whole trial. All calves spent 1.3x and 1.4x more time inside the hutch in week 5 ($P_{week(1-5)} < 0.05$) and 6 ($P_{week(1-6)} < 0.01$) respectively, than in week 1. Percentage of observed time that all calves spent lying outside across all weeks is presented in Figure 4.

2.3.2.4 Feeding behaviour

All calves spent approximately 14.3 % of observed time feeding over the whole trial; approximately 5.0% drinking milk, 6.5 % eating hay, 1.1 % eating grain, and 1.5 % drinking water. Paired calves spent 75.9 % of time drinking milk synchronously, 38.6 % eating hay synchronously, and negligible amounts of time spent eating grain or drinking water synchronously. In week 1, paired calves spent 1.4x more time drinking milk than single calves ($P_{trt \times week} < 0.01$).

2.3.2.5 Social interactions and redirected behaviour for paired calves

Social interactions did not differ between weeks ($P_{\text{week}} > 0.1$), averaging 2.4, 0.1, and 0.8 bouts/h of observation per pen across weeks for allogrooming, cross sucking and displacement at the teat, respectively. However, cross sucking and displacements at the teat were both affected by period of the day ($P_{\text{period}} < 0.05$; Figure 3). Displacement at the teat was observed more often in period 1 and 4 than in period 3 ($P_{\text{pairwise}} < 0.04$).

2.4 DISCUSSION

2.4.1 Growth and milk intake

Calves grew within the range of 1.0 (Chua *et al.*, 2002; Borderas *et al.*, 2009) to 1.2 kg/d (Miller-Cushon *et al.*, 2013) previously reported for calves fed ad libitum. Throughout both trials there were no differences in growth rate between treatments except for one week in the summer trial for which no explanation could be provided (i.e. unknown weather conditions). Even though a lack of difference between treatments could be attributed to the small sample size, our results are supported by other studies looking at paired and single calves fed a high milk allowance, and reporting similar growth rates (Chua *et al.*, 2002; De Paula Vieira *et al.*, 2010; Duve and Jensen, 2012). In contrast, Jensen *et al.* (2015) found that paired calves consumed more concentrate and grew more than single calves when fed 9 L of milk per day; presumably, this reflects a lower milk allowance than in our current study resulting in calves being hungry and consuming more concentrate since milk was not available.

Milk intake in both seasons was also within the range of 11.4 L/d to 16.1 L/d reported in other studies where calves were fed ad libitum or a high milk allowance of fresh or acidified milk replacer (Miller-Cushon *et al.*, 2013; von Keyserlingk *et al.*, 2004). On average, calves did not reach the high level of 16.1 L/d reported by Miller-Cushon *et al.* (2013), but some individuals did towards 8 wks of age. The only difference seen in milk intake between treatments was during the first week of the summer trial, where paired calves drank on average 2.0 kg liquid milk replacer/d more than single calves. A higher overall milk intake in paired calves compared to single calves was also observed by Hepola *et al.* (2006), (0.79 kg DM/d milk replacer [5.3 L/d] for paired calves compared with 0.74 kg DM/d of milk replacer [4.9 L/d] for single calves). Paired calves may have drank more in the first week because of social learning; social

facilitation can contribute to how calves adjust to a new environment and to the social learning of new feeding methods (Nicol, 1995).

2.4.2 Feeding behaviour

Overall, single and paired calves ate for approximately the same amount of time (9.0 % in summer and 14.3 % in winter). During the summer in week 3 and 5, single calves spent more time drinking milk than paired calves. Considering that milk intakes were similar across the whole trial, it is possible that the single calves spent more time sucking the milk nipple even when there was no milk available; or if calves finished the milk given in the teat bucket then the taste of the milk on the teat could stimulate a period of sucking (de Passillé *et al.*, 1992; Rushen and de Passillé, 1995). Alternatively, because the paired calves had the option for social interaction, the single calves may have had to find other ways of occupying their time. Jensen and Larsen (2014) reported that the single housed calves in their study sniffed and licked the fixtures inside the pen more than paired calves; however, it should be noted that these authors restricted calves to 9 L/d. Paired calves were able to socialise and lick each other, while single calves were unable to perform those activities. Paired calves drank milk simultaneously for 63.8 % of their total time spent drinking milk. Behavioural synchrony is when animals are performing behaviours together or at the same time (Asher and Collins, 2012). Miller-Cushon *et al.* (2014) also measured milk feeding synchrony and found that across weeks, synchrony ranged from 41.3 % to 79.9 %, which includes the percentage found in this trial. However, it is documented that most milk feeding occurs around milk delivery time (Appleby *et al.*, 2001; Miller-Cushon *et al.*, 2013), which would contribute to the behavioural synchrony.

2.4.3 Lying time and space usage behaviour

Through both summer and winter trials there was no difference between treatments with regard to daily duration of lying. All calves spent approximately 17.0 hours of their day lying down, which falls between the ranges of 16.8 h to 18.5 h previously reported (Chua *et al.*, 2002; Jensen and Larsen, 2014). Both Jensen and Larsen (2014) and Chua *et al.* (2002) found no differences between individually and pair housed calves with regard to the amount of time spent lying. There were differences between the weeks of the winter trial in lying time, bout frequency and duration, which may have been due to weather variations.

The winter trial had an average maximum daily temperature of $-1.7\text{ }^{\circ}\text{C}$ and an average minimum daily temperature of $-10.7\text{ }^{\circ}\text{C}$. The differences between the weeks of the winter trial in lying time, bout frequency and duration, are difficult to explain. Steers have been reported to lie down more at lower temperatures (Redbo *et al.*, 1996; Tripon *et al.*, 2014), while calves have laid the same amount across four different ambient temperatures in controlled indoor environments (5, 9, 13, and $18\text{ }^{\circ}\text{C}$) (Schrama *et al.*, 1993). The average minimum temperature during the outdoor winter trial for Tripon *et al.* (2014) though was $3\text{ }^{\circ}\text{C}$. However, the ambient temperatures experienced by calves in the winter trial here were lower than the lowest temperature considered by Schrama *et al.* (1993) and the calves used by Schrama *et al.* (1993) were very young, approximately 6-11 d. Even though wide variations in daily temperature were observed throughout this study, peaks in lying did not correspond to lower temperatures. It should be noted however that we did not measure the temperature inside the hutch. Hutches were insulated with snow around the outside and deeply bedded with straw, which permits calf nesting behaviour and contributes to warmth. Snow cover on the ground may have affected where calves decided to lie down. Beef cows and heifers (Graunke *et al.*, 2011) as well as dairy cows (Schütz *et al.*, 2010) reduced their outdoor lying time with increased snow coverage which could have affected our calves in the winter.

No differences were found between treatments with regard to where calves preferred to lay, either inside or outside of the hutch, during the winter. All calves gradually increased the amount of time spent lying outside as the trial progressed, possibly due to the seasonal increase in temperature (temperature highs increased from -5.5 to $7.5\text{ }^{\circ}\text{C}$) over the course of the experiment, but also possibly due to improved thermoregulation by the calves as they grew (Hepola *et al.*, 2006) or because of spatial restriction inside the hutch. Paired calves may have spent more time outside as the trial progressed because as they grew, the individual hutches could have become uncomfortable for both calves at the same time. Tapki *et al.* (2006) found that calves up to 9 weeks of age housed individually in larger pens (4.0 m^2 compared with 1.5 m^2 and 2.3 m^2) rested longer and spent less time standing than calves in smaller pens. The hutch area (2.4 m^2) most closely compares with the medium sized pen (2.3 m^2), which could be why calves preferred to lay outside towards the end of the trial. The lower critical temperature of calves decreases as they age (Hänninen *et al.* 2003), which could influence their behaviour depending on the severity of weather. Conducted under the same climatic conditions as the present

experiment, E. Shepley (University of Guelph, Alfred, Ontario, Canada, personal communication) showed that dairy cows with year-long outdoor exposure would choose to be outside for at least one hour per day during the winter when given the option. However Krohn *et al.* (1992) found that cows preferred to be inside when the outdoor temperature was below 0 °C. During the summer trial, it was noted that paired calves spent more time lying inside the hutch than single calves (40 % compared with 24 %). This difference could be due to the single calves wanting to spend more time outside in order to have visual contact with another calf, as preference tests have shown that calves will work for physical contact with another calf (Holm *et al.*, 2002). While it is unknown whether calves will work for visual access, it has been shown to be beneficial to calf's social abilities. Jensen and Larsen (2014) compared individually housed calves with calves having either auditory or visual access, and found that calves with visual access to another calf had a decreased latency to approach a novel calf when compared with calves with auditory access only, suggesting that having visual access makes a calf less reluctant to interact socially with another calf. The difference between single and paired calves in the time spent inside the hutch was not seen during winter, and this could be the result of the colder weather in the winter forcing single calves into the hutch for warmth.

It was also noted that when paired calves were lying inside the hutch, they were more often (approximately 80 % of time lying inside the hutch) seen lying together in the same hutch. Calves may have been motivated to maintain physical contact with each other, as shown previously by Holm *et al.* (2002), or to keep warm in the winter (Boe and Havrevoll, 1993). Single calves spent the same amount of time inside the hutch as paired calves during week 1 and 4 in the summer trial; during week 1, this coincided with 9 mm of precipitation, but no similar weather occurred during week 4. Single calves spent more time inside the hutch during week 1 of summer trial when it rained, so presumably the calves used the hutch for shelter from precipitation as well as shade from the sun. More research is needed to determine which conditions (climatic, physical enrichment, etc.) will optimize calf utilization of resources in a mix indoor and outdoor environment, i.e. spending time both inside and outside the hutch, engaging in play behaviour (Jensen *et al.*, 2015) and other exercise opportunities. The point at which the hutch becomes too hot for the calves to stay inside in summer, or when the outdoor temperature becomes too cold for calves to stay outside in the winter needs to be determined.

2.4.4 Social interactions and redirected behaviour for paired calves

Calves' needs for social contact with conspecifics (reviewed by Mandel *et al.*, 2016) have been documented from the first week of age (Wood-Gush *et al.*, 1984), and fulfilling their needs for social contacts, e.g. by paired housing, has been shown to help development of their cognitive skills (de Paula Vieira *et al.*, 2010) and their ability to cope with environmental stressors (de Paula Veira *et al.*, 2012). Allogrooming is considered a positive interaction between calves and an indication of social bonding (Boe and Faerevik, 2003). Bouts of allogrooming in this study showed that calves bonded socially together (Sato *et al.*, 1993). During the summer trial, allogrooming was observed to be higher in period 5, corresponding to the evening period (which was not observed during the winter trial). Faerevik *et al.* (2008) found that the number of allogrooming events ranged from 2.87 – 4.90 bouts per combined 5 h observation (0.57- 0.98 bouts / h). The calves used in Faerevik *et al.* (2008) were slightly older and heavier than our calves, weighing between 89.7 kg and 128.5 kg. The number of allogrooming bouts per hour reported by Faerevik *et al.* (2008) was lower than those found in the present summer and winter trials, but their observations were done only in the morning (9:00-11:30 A.M.) and evening (5:00-7:30 P.M.) rather than throughout the day such as in the present study. Sato *et al.* (1991) conducted a study using steers and heifers over the age of 12 months and found 4.8 bouts/h. They also found that social licking was influenced by different aspects of the environment: it decreased on rainy days to half that seen on clear days and it tended to increase when the housing environment was dirty (Sato *et al.*, 1991). In contrast, our results did not show any differences between weeks and the pens and hutches were maintained to provide a clean and dry environment, probably showing that the housing environment provided to calves favoured positive interactions between calves.

Negative interactions will also occur when a social companion is provided. Overall the level of cross sucking was low across both the summer and winter trials, and at the lower end of the range of previous studies (e.g., 0.33 – 1.80 cross sucking events/d; Margerison *et al.* 2003). Cross sucking was higher during period 1 and 5 in the summer trial with minimal cross sucking being seen in other periods. It is unknown why cross sucking was higher in period 5 but period 1 was a milk delivery time, which would explain why there was a higher occurrence level. Rushen and de Passillé (1995) found that milk stimulates sucking behaviour and that drinking milk can lead to non-nutritive sucking. Cattle are more active in the morning and in the evening, near

sunrise and sunset (crepuscular activity pattern) (Shabi *et al.*, 2005), this could be one reason for the increase in cross sucking in period 5 during the summer. The summer trial averaged 2.8 bouts/d per pen, which was one occurrence higher than what was found by Margerison *et al.* (2003) in calves that were allowed to suckle for their milk, but had restricted access to the cow and therefore ingested less milk (approximately 1-2 kg/d). However, no detrimental effects, such as hair loss and sores developing in the sucked areas (Haley *et al.*, 1998) were observed in our study, suggesting that occurrence of cross sucking was not detrimental to the calves.

In both seasons, there were low numbers of displacements at the teat with the majority of displacements observed in periods 1 and 4, which are the periods when fresh milk was delivered. Displacements are generally seen when calves are competing over feed, either teats or bunk space (Miller-Cushon *et al.*, 2014). Miller-Cushon *et al.* (2014) found a decreased number (2.2-3.7/d compared with 10.7-11.3/d) of displacements when paired calves were offered 2 teats as opposed to 1 teat per pair when fed ad libitum. In the present trial there was one teat available per calf (therefore two teats available per pair); von Keyserlingk *et al.* (2004) recorded 18 displacements/d when a group of 3 calves was provided with 4 milk teats, and 30 displacements/d when 3 calves were provided with 3 milk teats, suggesting that more teats could decrease competition between calves that were fed ad libitum. In this study, teats were placed at opposite ends of the pen to limit competition over feeding resources. Jensen *et al.* (2008) limit fed (6 L/d) calves housed in pairs and found that the number of displacement at the teat events between pairs decreased when separated by a long barrier (100 cm) (1/30 min) compared with a short barrier (46 cm) (14/30 min) and no barrier (13/30 min). The displacements found in the summer and winter trials fall below the range presented by Miller-Cushon *et al.*'s (2014) treatment with 1 teat, but is higher than the treatment with 2 teats. It could be that calves preferred to stand together to drink, and because the teats in the present study were at opposite sides of the pen, this lead to the higher amount of displacements compared with Miller-Cushon *et al.* (2014) treatment with 2 teats, where the teats were place beside each other on the same side of the pen. The occurrence of displacements in our trials were similar to Jensen *et al.* (2008)'s long barrier results; therefore, separating the teats on either side of the pen could be an alternative to physical feeding barriers to limit competition between calves.

2.5 CONCLUSIONS

Paired and single calves had similar growth rates and milk intakes, which were consistent with previously reported results for high-fed calves. They showed good performance in both the summer and winter trials. All calves also had similar lying times, suggesting that calves were getting enough rest to grow similarly. All calves altered their behaviour in some way to accommodate companions; paired calves were seen interacting and spending time together (i.e. lying in the same hutch) and single calves spent more time lying outside presumably to have visual access with other calves. Physical social interactions between paired calves were seen in both the summer and the winter trials; no detriments were seen from cross sucking and displacements at the teat, while the presence of allogrooming can suggest positive interactions between the paired calves in a clean environment. The doubling of all resources and the strategy to provide milk and other feeds at opposite ends of the outdoor area allowed for a non-competitive environment shown by the low number of displacements at the teat compared with other studies. The solution of mixed indoor and outdoor housing environments tested as part of this study showed that calves make use of all resources provided to them, in winter and in summer conditions, while maintaining good performance. Pairing calves outdoors in hutches is a good alternative to housing calves individually, however more research is needed to assess the practicality of this method on farm, and determine how environmental conditions affect calf behaviour in order to provide a more welfare-friendly environment to dairy calves on farm.

Table 1. Ethogram of observed behaviours

Behaviour	Description	Adapted from:
Cross sucking	One calf has its head and nose under the belly of a second calf, or one calf sucking on ear or sucking on vulva - bout recorded as when calf stops and turns head away	de Passille et al. (2010); Chua et al. (2002)
Allogrooming (Social grooming)	Calves groom/lick each other/ one calf may groom or lick another calf- bout recorded as finished when calf stops and turns head away.	Boe, K.E and Faerevik, G. (2003)
Displacement	One calf displaces another at the nipple- calf then puts mouth completely on the nipple	von Keyserlingk et al. (2004)
Drinking milk	Calf is standing in front of nipple and has its head directly in front of or has its mouth on the nipple	Chua et al. (2002); Miller-Cushon et al. (2013); Hammel et al. (1988) ; Appleby (2001)
Drinking water	Calf has its head inside the bucket or is standing with head facing bucket	Hepola et al. (2008)
Eating calf starter	Calf has its head in bucket and is standing with head facing the bucket.	Miller-Cushon et al. (2013)
Space used	Posture (lying or standing) and location (inside hutch or outside hutch) of calf were recorded	Faerevik et al. (2008)

Table 2. Maximum, average, and minimum temperature¹ and precipitation¹ for each observation day for the summer and winter trial.

Trial	Week	Max Temp	Average Temp	Low Temp	Precipitation (mm)
Summer					
	1	22.5	17.0	11.5	9.0 ²
	2	23.5	17.3	11.0	0.0
	3	27.0	22.3	17.5	0.0
	4	22.0	19.8	17.5	0.0
	5	23.0	17.3	11.5	0.0
	6	23.5	17.8	12.0	0.0
	7	26.0	20.0	14.0	0.0
Winter					
	1	-8.8	-12.9	-16.8	0.6 ³
	2	-7.5	-13.7	-19.8	2.0 ³
	3	0.0	-6.4	-12.8	1.3 ³
	4	0.5	-5.5	-11.5	1.3 ³
	5	1.5	-1.7	-4.8	0.0
	6	-1.3	-5.9	-10.9	0.0

¹Information taken from the St. Albert weather station and collected from the Weather Canada website

²Indicates rain as precipitate.

³Indicates snow as precipitate.

Table 3. Percentage of observed time paired (P) and single (S) calves spent inside and outside the hutch, and performing activities in each location for Summer and Winter trials along with *P*-value for the effects of treatment (trt), week, and their interaction (trt x week). Least means square and standard error of means (SEM) are presented.

	Treatment			trt	<i>P</i> -value ²		
	P	S	SEM		week	trt x week	
SUMMER							
Inside hutch	40.6	24.3	4.63	0.0882	<0.0001	0.0003	
Standing	39.6	41.6	3.08	NS	<0.0001	NS	
Lying	53.3	33.7	4.77	0.0313	<0.0001	<0.0001	
Outside hutch	58.7	75.7	4.67	0.0448	<0.0001	<0.0001	
Standing ¹	40.9	36.2	2.33	NS	0.0001	0.0041	
Lying	33.3	47.4	4.04	0.0967	<0.0001	0.0044	
Standing feeding ¹	17.4	13.1	1.57	NS	<0.0001	0.498	
WINTER							
Inside hutch	51.7	51.2	4.42	NS	0.0004	NS	
Standing	57.9	62.3	5.77	NS	NS	NS	
Lying	33.7	24.6	2.56	0.0587	NS	NS	
Outside hutch	47.5	48.7	4.49	NS	0.0378	NS	
Standing ¹	41.5	46.8	3.14	NS	0.0030	NS	
Lying	19.9	15.5	2.57	NS	<0.0001	NS	
Standing feeding ¹	33.1	34.6	2.68	NS	0.0241	NS	

¹Standing includes only when the calf is standing idle and not engaged in other activities. Standing feeding includes all feeding activities while standing, or drinking milk or water, which were always performed in standing position.

²NS shows *P* > 0.1

Table 4. Daily duration of lying, bout frequency, and mean bout duration (L.S.M. \pm S.E.) for all calves

	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6
Daily duration of lying (h/d)	16.8 \pm 0.12 ^c	16.9 \pm 0.10 ^{bc}	17.3 \pm 0.13 ^a	17.3 \pm 0.14 ^{ab}	17.2 \pm 0.11 ^{abc}	16.8 \pm 0.12 ^{bc}
Bout frequency (bout/d)	15.8 \pm 0.98 ^c	17.3 \pm 0.43 ^c	21.6 \pm 0.57 ^{ab}	23.5 \pm 0.54 ^a	22.9 \pm 0.53 ^a	19.9 \pm 0.50 ^b
Mean bout duration (min/bout)	66.6 \pm 1.79 ^a	58.6 \pm 1.64 ^b	49.4 \pm 1.38 ^{cd}	45.9 \pm 0.97 ^d	46.3 \pm 1.09 ^{cd}	53.1 \pm 1.51 ^{bc}

(paired and single treatments) at each week of the winter trial¹.

¹Different letters shows difference between individual weeks at $P_{week} < 0.05$

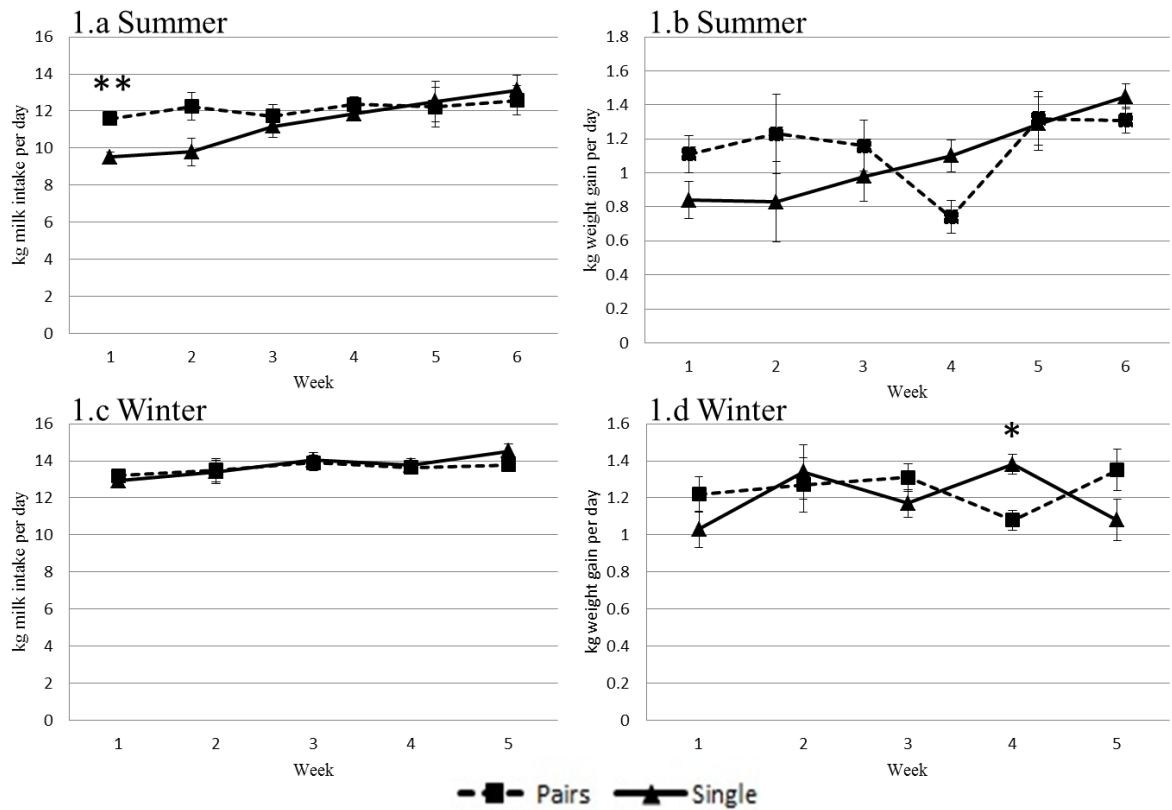
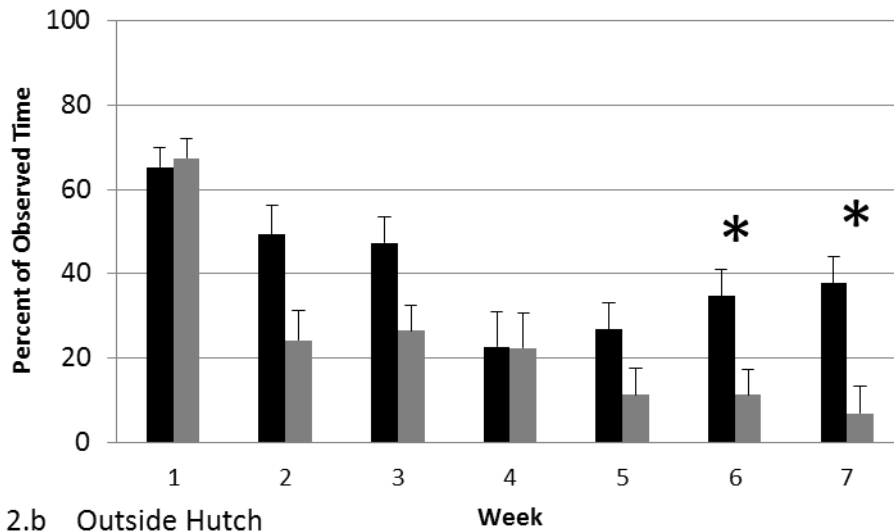


Figure 1. Average daily milk intake (1.a and 1.c) and average daily gain (1.b and 1.d) for Summer and Winter across the weeks of each trial with standard error bars for both paired and single calves. ** $P_{Trt} < 0.01$ and * $P_{Trt} < 0.05$.

2.a Inside Hutch



2.b Outside Hutch

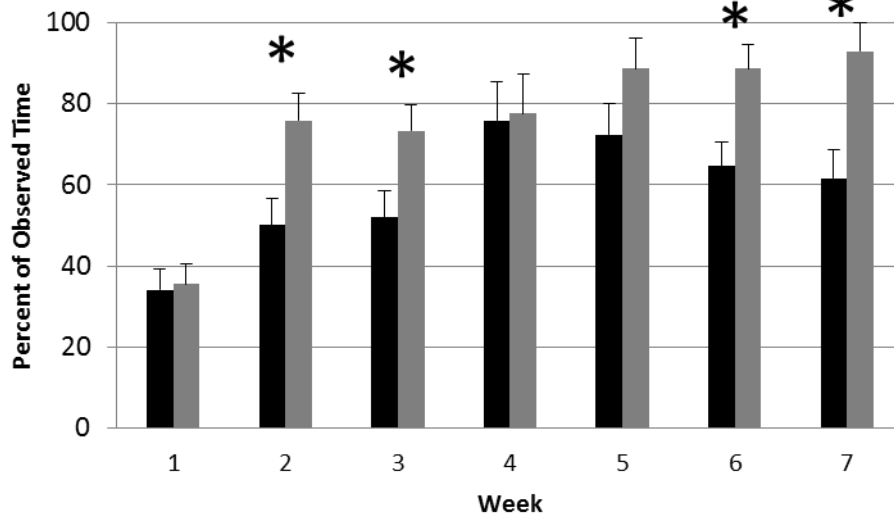


Figure 2. Percent of observed time that paired (black) and single (grey) calves were seen inside the hutch and outside during the Summer trial. * $P_{trt} < 0.05$

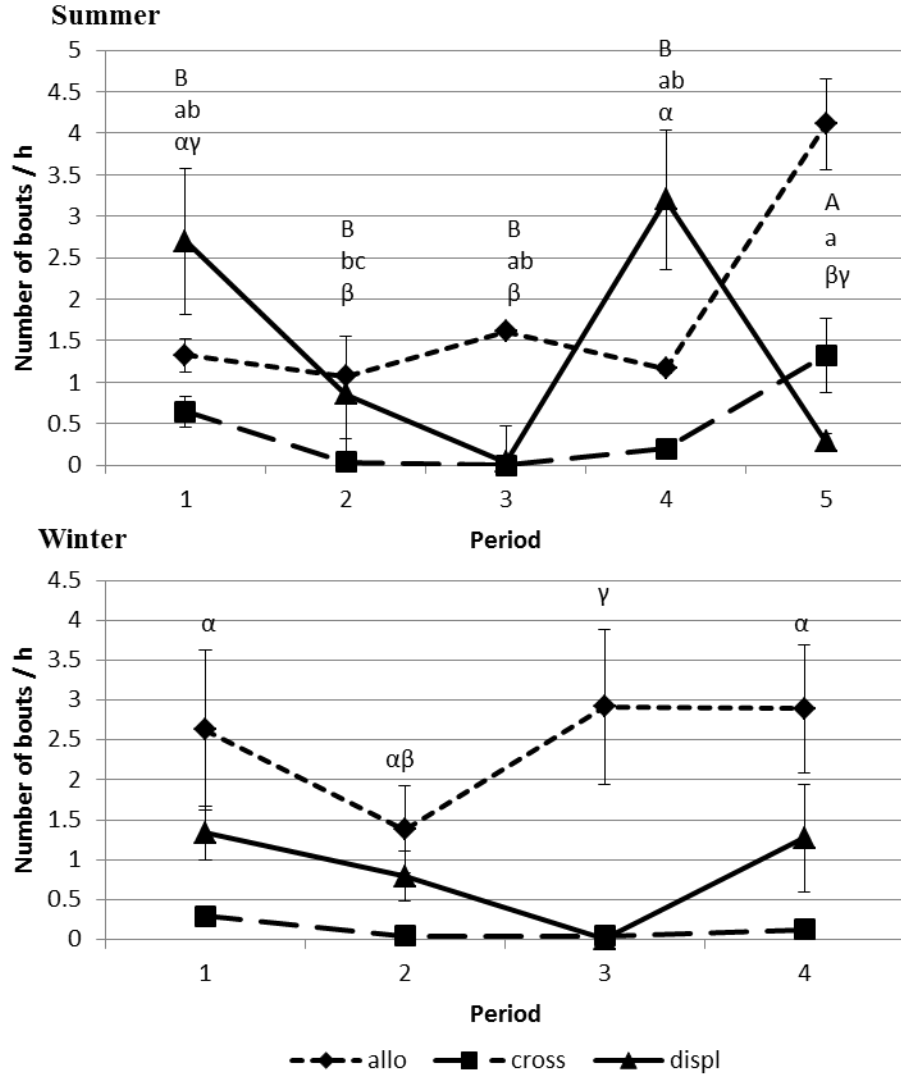


Figure 3. Average number of bouts of allogrooming (allo), cross sucking (cross), and displacements (displ) for each period of the day, for summer and winter trial. Different upper case Latin letters signify differences between periods for allogrooming, different lower case Latin letters signify differences between periods for cross sucking while different Greek letters signify differences between periods for displacements ($P_{pairwise} < 0.04$).

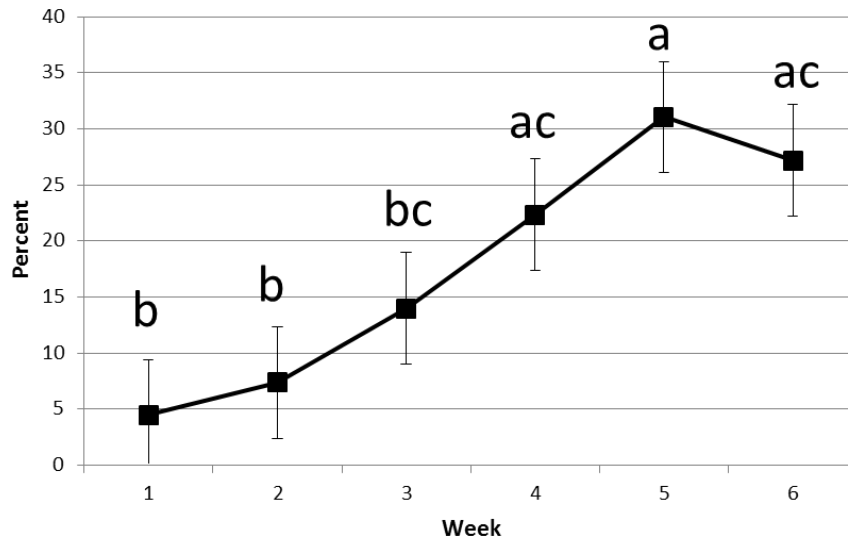


Figure 4. Percent of observed time spent lying outside for all calves across weeks for the winter trial. Different letters represent differences between weeks at $P_{week} < 0.05$

CHAPTER 3: GENERAL DISCUSSION

The purpose of this thesis was to examine whether pair housing calves outdoors in hutches would be feasible and result in milk intake and growth similar to those of individual housing. Multiple studies have found that when calves are fed a high (over 8 L/d) milk allowance, there is no difference in growth and milk intake between group housing and single housing (Hanninen *et al.*, 2003; Cobb *et al.*, 2014); this has also been shown by studies comparing paired housing and single housing (Chua *et al.*, 2002; Borderas *et al.*, 2009). Pair housing has been shown to allow for social interactions between calves, which would allow for social learning. Vasseur *et al.* (2010) found that 87.9 % of farms surveyed housed pre-weaned calves individually, with 7.4 % of producers in Quebec housing calves in hutches. In Ontario, 29.0 % of producers house pre-weaned calves in hutches (CALF-ETERIA Project, 2012). We wanted to examine whether it would be possible for producers to use either existing hutches, or purchase hutches as an alternative to remodelling their calf barn. Group-housing of calves has been found to be beneficial to the calves' social development (Jensen and Larsen, 2014), and cognitive abilities (Gaillard *et al.*, 2014; Meagher *et al.*, 2015). Studies have already shown that pairing calves can have the same social benefits (such as an improved ability to learn) as raising calves in complex social groups (Meagher *et al.*, 2015), and other research has compared the levels of social contact (Duve and Jensen, 2011). Duve and Jensen (2011) found that calves raised together in pairs from an early age preferred their companion over a novel calf, and that calves that were pair-housed together showed a stronger bond than calves who were individually housed beside each other. However, few studies have compared single and paired housing of calves using hutches in an outdoor environment.

3.1 Overview of results

As previously found in the literature, no differences in growth rate and milk intake were found between paired and single calves in either the summer or winter trial. Paired calves exhibited social behaviours, including allogrooming, as well as low levels of cross sucking and displacements at the teat. According to previous research, allogrooming can contribute to the social bonding between calves (Sato *et al.*, 1993). Few cross sucking bouts were seen and calves

exhibited no injuries (hair loss or sores) in sucked areas, which lead to the understanding that the levels of cross sucking seen in these trials are low and did not affect the calves' welfare.

Paired calves were also seen to be lying together inside and outside the hutch, actively spending time together. Single calves lay outside more in the summer than paired calves, perhaps because they wanted to maintain visual contact to other calves, while the paired calves would lie inside the hutch. In both the summer and winter, calves used the hutch for shelter from precipitation as well as shade from the sun. Calves used all the space that was available to them (both indoor and outdoor), while competition was limited and weight gain was not affected. Therefore, this housing option seems to be a suitable environment to raise calves.

3.2 Study limitations

In these trials we did not study the calves over the weaning period, which leaves open the questions of how the paired calves would have coped over weaning. De Paula Vieira *et al.* (2010) reported that paired calves consumed more calf starter through weaning as well as showed signs of social buffering through weaning. They suggest that paired calves were less distressed through the weaning period because of their companion (De Paula Vieira *et al.*, 2010). De Paula Vieira *et al.* (2010) found that calves housed individually vocalised 3 times more than calves housed in pairs, which they suggest shows a higher level of distress by the individually-housed calves. Whether or not this difference between the pairs and singles would be seen using outdoor hutch housing is unknown.

The amount of grain that calves ingested was recorded but the method of grain feeding lead to an abundance of missing data. Calves were fed grain in buckets, and during the summer, buckets were clipped to the fencing outside. However, calves were still able to move the buckets and spill the grain during the winter; buckets were also moved around and tipped over consistently. This and the losses related to the weather (both rain in the summer, and snow and rain in the winter) lead to a small amount of usable data, which could not be analysed. We also did not take measurements on the temperature inside and outside the hutch. Being able to record daily temperature inside and outside the hutch as well as daily humidity would have been beneficial in potentially aiding in the explanation of the variation in behaviours.

In addition, only one trial per season was conducted and each trial had a small sample size ($n = 6$ per treatment), being able to conduct a replicate of both the summer and winter trial would solidify findings and allow for more understanding of the seasonal variation.

3.3 Implications

Pair housing calves using outdoor calf hutches could provide a method of social housing for calves on farms that are unable to house calves in larger groups. The number of calves that producers house at any given time can also contribute to the amount of time involved in caring for calves. This method of social housing may work better for producers with smaller herds and lower numbers of calves, compared with 18 calves at a given time as tested in this study, which would limit the amount of labour needed to maintain the calves' environment. Producers who have between 6-10 calves at a time would most likely be able to optimize this housing method while limiting the amount of labour involved.

Paired calves and single-housed calves all had similar milk intake and average daily gains. However paired calves spent considerable amounts of time together and interacted socially, which suggests an improved behavioural welfare when compared with single-housed calves. Pairing calves currently housed in hutches on farm could improve their welfare and improve their social development. Minimal research has been conducted in the potential of housing calves in groups or pairs using hutches. Cobb *et al.* (2014) conducted a trial using large group hutches to house three calves together, but they did not attempt to use traditional hutches for multiple calves. Housing calves in pairs using traditional single calf hutches could offer a new way to use existing hutches to provide a more welfare-friendly approach to outdoor calf housing. The outdoor enclosure in this housing method may require materials not owned by the producer, but they are relatively inexpensive. Calf hutches could also be used as shelter in a large outdoor group housing method.

While this housing method showed good growth and milk intake, which would indicate it would be beneficial for producers to adapt in order to provide a more social housing environment to their calves, the labour involved was more than expected. The calf pens required cleaning out multiple times per week and straw had to be added whenever this happened or the weather required. Mixing and distributing the milk at each feeding also took longer than expected. However, on farms feeding acidified milk, this would most likely be done once per day while we

fed calves twice per day in the summer and cleaned and sanitized buckets both times. In the winter, because of the possibility of milk freezing, we were unable to leave milk outside, and therefore fed three times per day in order to provide a high milk allowance. Producers could get around this by purchasing heated buckets and thus enabling them to feed once per day. It is unknown whether the time and labour required to care for calves in pairs would be comparable to what producers who are housing their calves individually in hutches currently expend, but this would be something to take into consideration in the future. Cleaning the calf pens could be reduced by using different bedding substrates and different drainage options.

3.4 Future research

This housing system would need to be adapted in order to determine whether the time and labour involved can be decreased with different feeding methods or other types of bedding substrates. More research would be needed to determine whether more than two calves could be housed together in an outdoor pen using multiple hutches as shelter; however the optimal number of hutches per number of calves would need to be determined. On this note, paired calves in our study primarily lay down in the same hutch; future research could test whether paired calves actually require two hutches, or if pairs would lay the same amount with similar indoor/outdoor patterns with one hutch available instead of two. This could decrease the number of hutches needed for outdoor housing of calves, and would decrease the labour required for cleaning pens/hutches.

More research is also needed to determine whether this housing method would yield similar results through weaning as other pair housing trials. We did not monitor calves through weaning in this trial and so more research would be beneficial to find whether all calves had consistent weight gains through weaning, or if any growth checks were seen. Determining how the outdoor temperature affects the indoor temperature of the hutch, as well as how the outdoor temperature affects the indoor temperature of the hutch when occupied by one or two calves could help to explain why the calves use the hutch when they do and possibly under what conditions calves are most likely to use hutches. Examining how the outdoor temperature and humidity, along with other climatic data (sun exposure, snow cover, precipitation) affects the behaviour of the calves would allow for further understanding of how outdoor housing is affected by the weather and how this can affect calf behaviour and welfare.

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Annex 1. Summer trial: Percentage of observed time paired (P) and single (S) calves spent inside the hutch (engaged in the following activities: standing and lying) and outside the hutch (engaged in the following activities: standing, lying, and feeding) as well as feeding behaviours (milk, hay, grain, water) along with *P*-value for difference between treatments for each week of the trial¹ Least square means (L.S.M.) and standard error of the means (S.E.M.) are presented.

Activity	Trt	Week 1			Week 2			Week 3			Week 4		
		L.S.M.	SEM	<i>P</i> ²	L.S.M.	S.E.M.	<i>P</i> ²	L.S.M.	S.E.M.	<i>P</i> ²	L.S.M.	S.E.M.	<i>P</i> ²
Space Usage													
Inside Hutch	P	65.2	4.61	NS	49.3	7.08	0.0832	47.4	5.98	0.0777	22.8	8.36	NS
	S	67.4			24.2			26.6			22.4		
Standing	P	23.6	2.83	NS	33.2	6.82	NS	37.1	8.36	NS	56.9	9.86	NS
	S	17.6			33.6			44.9			42.6		
Lying	P	76.4	4.81	NS	60.6 ^a	6.82	0.0022	59.2 ^a	6.90	0.0428	29.7	14.45	NS
	S	75.7			33.1 ^b			41.8 ^b			37.4		
Outside Hutch	P	34.1	5.08	NS	50.1 ^a	6.64	0.0245	52.0 ^a	6.47	0.0285	75.8	9.63	NS
	S	35.6			75.8 ^b			73.4 ^b			77.6		
Standing ³	P	42.5 ^a	6.13	0.0311	39.3	4.18	0.0904	42.7	6.80	NS	44.0	7.96	NS
	S	55.8 ^b			25.7			40.4			41.7		
Lying	P	7.3	5.64	NS	27.5	8.36	0.0557	30.9	8.27	NS	41.1	9.77	NS
	S	9.8			54.3			43.9			44.8		
Standing feeding ³	P	30.3	4.89	NS	17.4	2.52	NS	16.8	2.62	NS	15.8	2.75	NS
	S	21.6			13.3			12.3			13.5		
Feeding													
Milk	P	4.5	0.95	NS	3.7	0.89	NS	3.2 ^a	0.83	0.0379	3.4	0.86	NS
	S	3.0			4.3			4.6 ^b			4.7		
Hay	P	4.5	0.81	NS	4.0	0.84	NS	3.0	0.76	NS	5.5	1.23	NS
	S	3.0			3.5			2.9			4.7		
Grain	P	0.0	0.04	NS	0.6	0.23	NS	0.9	0.23	NS	1.5 ^a	0.31	0.0472
	S	0.0			0.6			0.5			0.7 ^b		
Water	P	0.3	0.12	NS	0.6	0.19	NS	0.8	0.22	NS	0.4	0.15	NS
	S	0.2			0.1			0.6			0.2		

¹Different Latin letters (a b) indicate significance between treatments at $P < 0.05$. ²NS: $P > 0.1$; ³Standing includes only when the calf is standing idle and not engaged in other activities. Standing feeding includes all feeding activities of eating hay and grain while standing or drinking milk or water always performed in standing position.

Annex 1. Summer trial: Percentage of observed time paired (P) and single (S) calves spent inside the hutch (engaged in the following activities: standing and lying) and outside the hutch (engaged in the following activities: standing (idle), lying, and feeding) as well as feeding behaviours (milk, hay, grain, water) along with *P*-value for difference between treatments for each week of the trial¹ Least square means (L.S.M.) and standard error of the means (S.E.M.) are presented.

Activity	Trt	Week 5			Week 6			Week 7		
		L.S.M	S.E.M	<i>P</i> ²	L.S.M.	S.E.M	<i>P</i> ²	L.S.M.	S.E.M	<i>P</i> ²
Space Usage										
Inside	P	26.8	6.24	NS	34.8 ^a	6.20	0.0343	37.8 ^a	6.38	0.0262
Hutch	S	11.3			11.3 ^b			7.0 ^b		
Standing	P	46.9	7.50	NS	36.9	7.72	NS	42.5	7.89	NS
	S	53.1			42.7			56.6		
Lying	P	46.4	8.41	NS	53.1 ^a	9.00	0.0484	47.5 ^a	4.77	0.0214
	S	16.9			20.6 ^b			10.1 ^b		
Outside	P	72.4	7.57	NS	64.7 ^a	5.88	0.0211	61.6 ^a	7.08	0.0286
Hutch	S	88.6			88.7 ^b			92.9 ^b		
Standing ³	P	33.4	5.20	NS	47.8	5.53	NS	36.5 ^a	3.92	0.0413
	S	31.9			32.7			25.3 ^b		
Lying	P	52.3	6.84	NS	36.3	6.71	0.0917	37.4 ^a	5.85	0.0223
	S	58.1			57.3			63.7 ^b		
Standing	P	11.5	2.11	NS	12.7	1.95	NS	17.3	2.82	NS
	S									
Feeding ³	P	9.9			10.0			10.9		
	S									
Milk	P	3.1 ^a	1.00	0.0215	3.8	0.94	NS	3.7	1.00	NS
	S	5.4 ^b			4.1			5.1		
Hay	P	3.1	0.89	NS	2.4	0.67	NS	3.5 ^a	0.70	0.0121
	S	2.4			2.7			2.1 ^b		
Grain	P	1.0	0.41	NS	2.0	0.50	NS	2.4	0.56	NS
	S	0.8			1.5			2.2		
Water	P	1.0	0.29	NS	0.7	0.17	NS	0.7	0.24	NS
	S	0.6			0.3			0.8		

¹Different Latin letters (a b) indicate significance between treatments at $P < 0.05$. ²NS: $P > 0.1$; ³Standing includes only when the calf is standing idle and not engaged in other activities. Standing feeding includes all feeding activities of eating hay and grain while standing or drinking milk or water always performed in standing position.

Annexe 2. Winter trial: Percentage of observed time paired (P) and single (S) calves spent inside the hutch (engaged in the following activities: standing and lying) and outside the hutch (engaged in the following activities: standing (idle), lying, and feeding) as well as feeding behaviours (milk, hay, grain, water) along with *P*-value for difference between treatments for each week of the trial¹ Least square means (L.S.M.) and standard error of the means (S.E.M.) are presented.

Activity	Trt	Week 1			Week 2			Week 3		
		L.S.M.	S.E.M	<i>P</i> ²	L.S.M.	S.E.M	<i>P</i> ²	L.S.M	S.E.M	<i>P</i> ²
Space Usage										
Inside	P	66.4	7.39	NS	58.8	5.27	NS	54.5	7.67	NS
Hutch	S	54.3			55.2			51.9		
Standing	P	34.4	6.82	NS	40.7	6.85	NS	28.7	8.39	NS
	S	29.9			32.8			29.6		
Lying	P	61.5	7.31	NS	51.2	8.00	NS	62.9	13.09	NS
	S	53.4			58.8			66.2		
Outside	P	32.8	7.47	NS	40.8	5.25	NS	45.0	7.75	NS
Hutch	S	45.6			44.9			48.1		
Standing ³	P	49.4	7.28	NS	40.0	9.30	NS	48.6	5.03	NS
	S	52.6			45.1			57.0		
Lying	P	2.0	3.04	NS	6.2	5.36	NS	18.9	6.40	NS
	S	6.9			8.5			9.0		
Standing	P	36.9	4.72	NS	37.3	5.42	NS	32.9	6.20	NS
Feeding ³	S	31.1			41.2			34.0		
Feeding										
Milk	P	4.5 ^a	0.98	0.0038	4.8	0.97	NS	5.4	0.94	NS
	S	3.3 ^b			5.2			5.7		
Hay	P	6.4	2.34	NS	6.9	2.22	NS	5.6	1.75	NS
	S	5.5			7.3			7.3		
Grain	P	1.5	0.68	NS	1.5	0.57	NS	0.7	0.46	NS
	S	1.5			1.3			1.5		
Water	P	1.9	0.81	NS	1.8	0.74	NS	1.5	0.57	NS
	S	2.1			2.1			1.5		

¹Different Latin letters (a b) indicate significance between treatments at $P < 0.05$. ²NS: $P > 0.1$; ³Standing includes only when the calf is standing idle and not engaged in other activities. Standing feeding includes all feeding activities of eating hay and grain while standing or drinking milk or water always performed in standing position.

Annexe 2. Winter trial: Percentage of observed time paired (P) and single (S) calves spent inside the hutch (engaged in the following activities: standing and lying) and outside the hutch (engaged in the following activities: standing (idle), lying, and feeding) as well as feeding behaviours (milk, hay, grain, water) along with *P*-value for difference between treatments for each week of the trial¹ Least square means (L.S.M.) and standard error of the means (S.E.M.) are presented.

Activity	Trt	Week 4			Week 5			Week 6		
		L.S.M.	S.E.M	<i>P</i> ²	L.S.M	SE.M	<i>P</i> ²	L.S.M.	S.E.M	<i>P</i> ²
Space Usage										
Inside	P	49.2	7.59	NS	43.0	10.55	NS	38.4	10.27	NS
Hutch	S	47.9			48.0			50.0		
Standing	P	33.9	5.65	NS	33.8	5.94	NS	31.2	7.58	0.0589
	S	16.9			19.8			18.5		
Lying	P	66.1	8.97	NS	53.7	8.16	NS	52.2	10.36	0.0578
	S	66.4			63.6			69.0		
Outside	P	49.6	7.70	NS	56.2	10.78	NS	60.6	10.56	NS
Hutch	S	52.1			51.7			50.0		
Standing ³	P	36.5	4.43	NS	40.7	6.12	NS	33.8	4.10	0.0610
	S	42.8			34.4			48.3		
Lying	P	23.3	8.52	NS	34.6	11.15	NS	34.3	10.32	0.0808
	S	21.3			27.5			19.9		
Standing	P	41.7	5.37	NS	21.3	7.35	NS	28.7	3.76	NS
Feeding ³	S	35.8			33.9			31.8		
Feeding										
Milk	P	6.3	0.96	NS	4.0	0.82	NS	4.8	0.80	NS
	S	5.7			5.3			5.8		
Hay	P	7.2	1.71	NS	5.4	2.13	NS	7.9	1.54	NS
	S	5.8			8.0			5.6		
Grain	P	0.9	0.37	NS	0.8	0.53	NS	1.0	0.60	NS
	S	0.6			0.7			1.4		
Water	P	1.1	0.59	NS	0.7	0.45	NS	1.1	0.55	NS
	S	1.6			1.1			1.5		

¹Different Latin letters (a b) indicate significance between treatments at $P < 0.05$. ²NS: $P > 0.1$; ³Standing includes only when the calf is standing idle and not engaged in other activities. Standing feeding includes all feeding activities of eating hay and grain while standing or drinking milk or water always performed in standing position