UNDERSTANDING THE WELFARE OF DAIRY ANIMALS DURING THE
TRANSITION BETWEEN LACTATIONS

by

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Abstract

The cessation of milking, or dry off, is a regular management practice in dairy animals. This practice initiates a non lactating, or dry, period. Milking begins again after parturition. Provision of a dry period is done largely to improve milk production in the subsequent lactation, but also to address udder health issues (intramammary infections); therefore, the majority of literature focuses on these areas, and little consideration is given to the welfare of the individual animal. The goals of this thesis were to develop a better understanding of how common dry off methods, and the dry period itself, affect three components of animal welfare: biological functioning, affective states and natural behaviour in dairy cows and dairy goats. The first study in this dissertation explored how high producing dairy cows experience abrupt cessation of milking, a commonly utilized procedure. The results suggested that cows remain motivated to leave the pen around milking time, and that these cows leak milk, a risk factor for intramammary infections. Since dry off methodology is not well understood in dairy goats, the second study shifted towards describing dry off management used by goat producers. Although similarities to cow management exist, goat producers show more flexibility in decision making around dry off, sometimes opting to give high producing goats shorter, or even no, dry periods. Within this work, concerns were also identified regarding metabolic issues in goats (pregnancy toxemia and ketosis). Therefore, the final studies combined to explore the early identification of these issues in goats. The third study validated the use of data loggers on goats, allowing for automatic recording of lying behaviour. The fourth study applied these loggers to monitor the lying behaviour of goats during the dry period, and searched for links to pregnancy toxemia and ketosis. The results showed that at-risk goats increase their lying time and decrease their activity, making lying behaviour a promising indicator of metabolic issues. Finally, three key areas are discussed for future research, namely continued work in evaluating affective states in dairy animals, benchmarking of on-farm research results, and exploring the possibilities of deviating from standard annual lactation cycles.
Preface

The study described in Chapter 2 included animals cared for according to a protocol approved by the University of British Columbia’s Animal Care Committee (A10-0163). The remaining Chapters describe work where animals were cared for according to the University of British Columbia’s Animal Care Committee (A12-0249) and the University of Guelph (AUP1636). Human participation was approved by the University of British Columbia Behavioural Research Ethics Board (H12-02311) and the University of Guelph Research Ethics Board (12NV014).

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The first pages of these chapters have similar information in the footnotes.
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1 Introduction

1.1 Background

Female ruminants, including cows and does, initiate lactation immediately following birth. Under natural conditions, offspring will be nursed for 5 to 9 months, depending on the species. Milk production increases rapidly, peaks and then slowly declines until the offspring become nutritionally independent. At this point, milk production ceases, and new offspring begin the cycle again. Conversely, in most commercial dairy systems, the offspring are separated from the mother within hours of birth, and milk is redirected for collection and human consumption. The resulting lactation cycle is different from what would occur in a natural setting; dams are encouraged to produce large amounts of milk, then milk production is abruptly ceased for a short period prior to the birth of new offspring.

The benefit of a rest from lactation, or ‘dry period’, has been acknowledged since the early 1800s (reviewed by Dix Arnold and Becker, 1936). A dry period is now standard on most dairy farms. In the case of the cow, most farmers aim for one calf per cow per year, allowing for approximately 305 days of lactation and 60 days when she is not lactating (dry). Much research has focused on the physiological impacts of the dry period. Progress has been made in understanding mammary physiology at the cellular level (e.g., Wilde et al., 1999), and how this ties to milk production during the next lactation (e.g., Bachman and Schairer, 2003). Also, the effects of dry period management on intramammary infections (IMIs) have received a great deal of attention (e.g., Dufour et al., 2011). Even though knowledge of dry period mammary health has expanded, our knowledge of how the individual animal is affected by the way we manage the dry period remains minimal.

Few working in the dairy industry today would disagree with the fact that poor health and reproduction are bad for the animal and the farm’s economic status; however, a health-only focus is not sufficient. Concerns regarding animal welfare go beyond health, with proponents arguing that assurances for good welfare are only achieved when there is a balance between 3 key components: 1) the biological functioning (including health) of the animal, 2) the affective states the animal is experiencing, and 3) the naturalness of its life (Fraser et al., 1997). It follows that when seeking to understand how a dairy animal’s welfare may be affected by cessation of lactation, it is vital to identify how the associated management practices impact productivity and health, prevent states such as pain and hunger, and impact the animal’s natural adaptations.
The first part of this review summarizes the abundance of research that has focused on ensuring good health status, with a specific focus on cellular processes, dry period length effects on milk production and metabolic status, and the control of udder health issues (intramammary infections). Next, an argument is presented that this narrow focus on biological functioning has largely ignored the consequences on animal affect (e.g., pain, hunger). Lastly, a brief overview is given of the dairy industry’s deviation from a natural lactation cycle, and how exploring its potential impact on dairy animals could provide insight into the continuing welfare issues seen in the dairy industry. Given the available literature, the majority of this review focuses on the dairy cow; however, where applicable, evidence from other mammalian species, in particular the dairy goat, is discussed.

1.2 Biological functioning and health

1.2.1 Mammary involution and apoptosis

A major area of research in dry off literature has focused on the cellular processes occurring at dry off. Mammary involution, or the process where a gland moves from a lactating state to a non-lactating state, occurs in all lactating mammals, and can be categorized into three main types.

Gradual involution occurs early in lactation, and results in the slow milk production decline of a natural lactation cycle (Wilde et al., 1999). The point at which gradual involution occurs is dependent on peak milk yield, and is therefore highly species specific (e.g., rats – 12 d: DeSantiago et al., 1998; human – 40 d: Butte et al., 2002; cows – 45 to 90 d: Stanton et al., 1992; Khorshidie et al., 2012; goats – 50 to 124 d: (Gipson and Grossman, 1990).

Senile involution refers to an age-related decline in the mammary gland’s ability to produce milk. The high culling rate (or turnover rate of individual animals within a herd) frequently observed in many intensive commercial milk production systems (Oltenacu and Algers, 2005), has resulted in a reduced average age at removal from the herd, and generally little focus on this aspect of involution. Thus, senile involution is largely only considered in human literature (Neville, 1983; Silanikove, 2014).

Acute involution occurs when milk removal from the mammary gland is ceased. This can occur naturally (e.g., death of an offspring) or, as is common in the modern dairy industry, when lactation is abruptly halted in preparation for the dry period prior to the birth of the offspring. When milking is ceased abruptly, the udder’s cisternal ducts and alveoli
become engorged, raising intramammary pressure (Oliver and Sordillo, 1989). This local physical change triggers the involution process (Wilde et al., 1997). Rodent work has shown that apoptosis has a negative relationship with the presence of galactopoietic hormones (i.e., hormones which stimulate milk production; e.g., prolactin) (Wilde et al., 1997). When milk is no longer removed from the gland, prolactin is not produced, triggering apoptosis. Apoptosis, or programmed cell death, occurs with all three types of involution, but the highest rate of apoptosis is associated with acute involution. A major difference between apoptosis and trauma-related cell death (i.e., necrosis) is that the former does not elicit an immune response; no inflammation is triggered by apoptosis itself (Wilde et al., 1997). Therefore, since the abrupt cessation of milking has begun receiving increasing criticism (e.g., Bertulat et al., 2013), it has been suggested that monitoring for an inflammatory response could be a useful indicator of any tissue damage caused by excessive engorgement associated with acute involution. This hypothesis was recently given merit via work that showed that although mammary glands with low engorgement do exhibit some inflammatory response (likely due to a backlog of clearing of dead cells) the cell types involved in the inflammatory response are different when engorgement is high (Silanikove et al., 2013).

The level of net cell death due to apoptosis of milk epithelial cells (MECs), and regression of surrounding mammary tissue, is species dependent. Rodents appear to have the most significant losses of MECs (Paape and Tucker, 1969) and collapse of alveoli (Li et al., 1999). Conversely, much less tissue degeneration occurs in cows (Capuco et al., 1997) and goats (Sordillo et al., 1984). It has been shown that the alveoli decrease in size corresponding to the reduced milk secretory activities within them, but the surrounding stromal (i.e., connective) cells increase in size, resulting in many of the alveoli staying intact (cows: Li et al., 1999; sheep: Tatarczuch et al., 1997). Although a rudimentary indicator of potential changes in alveoli structure, Fowler et al. (1991) did note that lactating and non-lactating glands on the same animal remained similar in size.

It follows that with such species contrasts in tissue degeneration and apoptosis during involution, the necessity of the dry period across species would also be questioned. Omitting the dry period entirely does not result in a net loss of MECs (Capuco et al., 1997), therefore, it makes sense for milk production to not be negatively impacted, yet it is (reviewed by Bachman and Schairer, 2003). Involution is believed to promote the removal of senescent (i.e., older, non-dividing) cells, and the production of new MECs (Capuco et al., 1997). Since MECs must differentiate to develop lactational capacity, the level of
differentiation is indicative of cell age. The level of cell turnover can be estimated by the presence (or absence) of highly differentiated cells; cell turnover is highest when various stages of differentiation are observed. Older MECs are known to have decreased milk secretory abilities due to their tendency towards dedifferentiation as they age (Wilde et al., 1997; Capuco and Akers, 1999). Therefore, it would appear that promoting the turnover of MECs, thus ensuring that MECs differentiate near parturition, would be advantageous for optimal milk production in the new lactation. This hypothesis works well for explaining the importance of involution in cows, but the evidence is less clear for goats.

In one goat study, although an omitted dry period decreased cell turnover, the increased number of differentiated MECs did not appear to correspond to a decrease in milk production in the next lactation (Safayi et al., 2010). Indeed, of the three studies examining the omission of a dry period in dairy goats (Fowler et al., 1991; Caja et al., 2006; Safayi et al., 2010), only Caja et al. (2006) suggested that milk production was negatively impacted. Unfortunately, due to goats spontaneously drying up, the sample sizes were small and uneven between study groups, making it difficult to draw substantive conclusions. Further, neither this, nor the other two studies, controlled for peak milk production, production persistence and number of kids, all of which are known to influence next lactation milk production (Gipson and Grossman, 1990; León et al., 2012). So from existing work, it is not possible to conclude whether increased number of differentiated MECs (indicating low cell turnover) actually corresponds to a decrease in milk production in goats, as observed in cows. Goats may simply have longer MEC survivability compared to cows, allowing older MECs to sustain milk production for longer. More studies are needed to determine the difference in MEC proliferation rates between the two species.

1.2.2 Dry period length and omission: Impact on milk production

Complimenting the cellular level research that suggests omitting a dry period is not advantageous in terms of milk production in cows, another large body of literature has focused on understanding the ideal dry period length. Early retrospective reviews of milk production records suggested that dry periods of 30 d or less had negative impacts on milk production in subsequent lactations of dairy cows (e.g., Klein and Woodward, 1942; Wilton et al., 1967). However, with the potential financial gains of shorter dry periods (e.g., Santschi et al., 2011b) being considered, research in this area has continued, collectively demonstrating the complexity of choosing the correct dry period length. For instance, 30 day dry periods were successfully implemented without impacting milk production in a
number of controlled trials (e.g., Bachman, 2002; Gulay et al., 2003), while others have shown the opposite impact (Bernier-Dodier et al., 2011; Steeneveld et al., 2013). Furthermore, it has been suggested that short dry periods (e.g., 28 d: Pezeshki et al., 2007; 35 d: Santschi et al., 2011a) appear to only negatively impact the milk yield of primiparous cows, and if the dry period is extended slightly (40 to 45 d: Kuhn et al., 2006) these effects could be negated.

In goats, dry period length can be considered a function of lactational persistence (Knight and Wilde, 1988; Caja et al., 2006). Persistence can be partially explained by how MEC numbers are regulated throughout lactation. Although the number of MECs decline after peak lactation, these cells stay highly differentiated towards secretory activity in goats (Wilde et al., 1997). Thereby, lactation is continued, even in animals that are pregnant (Knight and Wilde, 1988). Yet, it is not clear why some animals are more persistent than others. In a half-udder experiment where one gland was dried off 9 weeks prior to parturition, and the other gland was continuously milked, Safayi et al. (2010) found that only 6 out of the 13 glands that were kept milking actually continued producing milk until parturition. However, because this was a half-udder study, it is difficult to differentiate between true persistence and the potential impact decreased galactopoietic hormone levels, initiated by the dry gland, might have had on the lactating gland. Caja et al. (2006) aimed to compare continuously milked goats to those on a 56-day dry period. Of the 8 goats assigned to the continuous milking group, only 3 goats continued lactating through to kidding. However, it should be noted that those that dried up spontaneously (and therefore had a shortened dry period between 23 – 31 d) had no difference in milk production compared to goats with the 56 d dry period. Some evidence in sheep indicates that dry periods shorter than 30 d are detrimental to milk production in the next lactation (Hernandez et al., 2012). Nonetheless, the variation demonstrated to date in goats responding to the lack of a dry period suggests the need for more research.

1.2.3 Dry period length and omission: Impact on negative energy balance

The complexity of achieving an ideal dry period length is furthered by its contradictory impact on milk production and metabolic status. Negative energy balance is a common occurrence after parturition in cows due to the metabolic demands of milk production (Butler and Smith, 1989). In goats, the condition more frequently occurs prior to parturition as a consequence of growing foetal energy requirements (Marteniuk and Herdt., 1988; Edmondson and Pugh, 2004). Many animals are able to cope by metabolizing body
fat reserves into non-esterified fatty acids (NEFAs) and glycerol; yet if too much of this occurs, hepatic lipidosis can result as the liver becomes overwhelmed with NEFAs (Van Saun, 2000; Mulligan and Doherty, 2008). The outcome is typically an excessive release of ketone bodies (Harmeyer and Schlumbohm, 2006). When left untreated, the conditions (e.g., pregnancy toxemia prior to parturition; ketosis after parturition) can be fatal. Although the primary focus of the dry period in dairy animals has been to achieve the best possible milk production and udder health in the next lactation, research in cows has also considered the effects of the dry period on metabolic status.

Shortened and skipped dry periods shift a portion of the milk production to the pre-partum period and reduce milk production in the next lactation (Bachman and Schairer; 2003, Collier et al., 2004). From a milk production standpoint, this is largely considered a negative outcome. However, a number of studies have identified a more positive outcome; keeping the animal physiologically adapted to lactation for a longer period maintains feed intake, and therefore results in improved energy balance (Rastani et al., 2005; Pezeshki et al., 2007; de Feu et al., 2009; Jolicoeur et al., 2014). Of course, not all studies have shown improvements (e.g., Gulay et al., 2003). Given that much of the previous work has used relatively small sample sizes, a recent review extends a cautionary approach towards dry period length alterations and metabolic impacts (van Knegsel et al., 2013).

Further, although there is now a substantive body of work available on the effects of dry period length on dairy cows, research is minimal in small ruminants. A 5-year longitudinal examination of 6762 lactations on one farm resulted in a broad recommendation of a 30-60 day dry period being appropriate for sheep (Hernandez et al., 2012). This dry period length was recommended based on milk yield and conception rate, but did not consider impact on metabolic states. Interestingly, although no published research has examined this topic in goats, some producers appear to have a different perspective on the importance of the dry period, and place emphasis on avoiding negative energy balance. Anecdotal reports indicate that some producers believe that forcing their persistent goats to dry off is detrimental to energy balance and overall goat longevity, and therefore elect to keep these animals milking. These concerns echo the work of Salama et al. (2005) who suggest that since pregnancy naturally reduces milk production, an alternative approach to managing goats would be to not breed as often, and focus on optimizing extended lactations, particularly in terms of improving goat longevity.
1.2.4 The dry period and intramammary health

The final, and largest, body of work in the dry off literature centres on the prevention and treatment of intramammary infections (IMIs), caused by a variety of contagious and environmental pathogens. Milk losses, treatment costs, and early culling, result in immense financial loss for dairy cow industries (e.g., Petrovski et al. 2006; Halasa et al., 2007; Huijps et al., 2008). However, in goats, financial losses are not well established, debate about the feasibility of treatment exists (Contreras et al., 2003; Sanchez et al., 1999; Koop et al., 2010; McDougall et al., 2010), and milk production losses are not definitive (Leitner et al., 2004; Koop et al., 2010).

While IMIs can occur at any point in lactation, a collection of studies have demonstrated that cows are at highest risk around the dry period (see reviews by Dingwell et al., 2003; Bradley and Green, 2004). While not well studied, goats appear to follow a similar pattern (Leitner et al., 2007b). New IMIs are most likely to occur at either one of two time periods during the dry period. The first of these is during the first stage of dry off, as the mammary gland begins moving from a lactational state to a non-lactational state (i.e., involution). A fully involuted mammary gland is unlikely to develop an IMI (Bradley and Green, 2004). As involution occurs, the mammary environment changes in a way that helps prevent IMIs. First, increasing lactoferrin activity inhibits bacterial growth, since this protein binds with the iron some pathogens would otherwise use (Sordillo et al., 1997). Second, lactoferrin acts in conjunction with the increasing levels of immunoglobulins (IgG) against major gram-negative bacteria (Bushe and Oliver, 1987). Third, as fat globulins and casein concentrations decrease, leukocyte concentration and activity increases, which improves the mammary gland’s ability to resist infection. Interestingly, recent evidence suggests milk production level affects leukocyte populations. For example, cows which entered the dry period producing less than 14 kg/d produced higher numbers of lymphocytes and macrophages, giving the mammary glands a more effective antibacterial response when compared to cows producing more than 25 kg/d (Silanikove et al., 2013). Clearly, the beginning of the dry period is a high risk time for IMIs, but this risk can be decreased by reducing milk production prior to dry off.

The second period of bacterial sensitivity in the dry period is when the mammary gland begins shifting from a non-lactating to lactating state late in gestation (i.e., during colostrogenesis). This period begins approximately one to two weeks before parturition (Oliver and Mitchell, 1983), as the gland’s main protective barriers against bacteria disappear (Bradley and Green, 2004). The teat cisterns begin to dilate and the keratin
plugs break down, providing a potential infection route for pathogens (Oldham et al., 1991). Furthermore, increases in MEC secretory activity results in a dilution and activity of lactoferrin, IgG and leukocytes (Sordillo and Nickerson, 1988).

The economic implications, coupled with the high risk for IMIs during this time, have fuelled dozens of studies examining the dry period’s link to new and persistent IMIs. Research has focused on a variety of subjects, including classification of the pathogens causing dry period IMIs (e.g., Bradley, 2002; Contreras et al., 2003; Barkema et al., 2009) and the development of efficient and cost effective monitoring and identification methodologies, such as somatic cell count (SCC) (Dohoo and Leslie, 1991), California Mastitis Test (CMT) (Sanford et al., 2006; Bhutto et al., 2012) and on-farm bacteriological testing (Cameron et al., 2013; Cameron et al., 2014). This type of research is minimal in goats, likely because identification has not been as easy in goats as it has been in cows, particularly in regards to SCC. Measuring SCC is problematic in goats, because in addition to indicating presence of bacteria (Koop et al., 2012), SCC is also sensitive to age and stage of lactation (Luengo et al., 2004; Paape et al., 2007; Persson et al., 2014). Identification issues (resulting in potentially underestimated prevalence in dairy goats), coupled with low animal replacement costs, are likely culprits for the bulk of dry period IMI prevention research being focused on dairy cows.

In addition to work exploring pathogen types and identification of infection, a huge amount of research has focused on prevention. Vaccines have received some attention (reviewed by Middleton et al., 2009); however, the largest focus has been on ‘dry cow therapy’ (for the purpose of this review, this will be referred to as ‘dry off therapy’ in order to include goats). Adoption of this practice has soared in cows since its introduction into even the earliest of mastitis prevention protocols (e.g., Neave et al., 1969). Dry off therapy includes long-acting intramammary antibiotics, which have been widely acclaimed for their prevention of new, and treatment of existing, dry period IMIs caused by contagious, gram-positive bacteria (e.g., Bradley and Green, 2004; Halasa et al., 2009; Dufour et al., 2011). Despite dry period antibiotics having been tested and encouraged in goats (Plommet and Bézard, 1974; Fox et al., 1992; Poutrel et al., 1997; McDougall and Anniss, 2005), they are rarely used. A likely determinant of this situation is the contradictory evidence for treatment efficacy, and necessity, in goats. Some authors have suggested that applying dry period antibiotics may not be worth the investment, due to the propensity of goats to self cure IMIs (Paape et al., 2001; Bergonier et al., 2003). Others support the use of dry period antibiotics either selectively (e.g., only administered to infected animals: Fox et al., 1992; McDougall
and Anniss, 2005) or via blanket use (e.g., administered to all animals: Poutrel et al., 1997). Interestingly, although useful for curing existing IMIs, there is no evidence supporting the use of dry period antibiotics for the prevention of new IMIs in goats (Paape et al., 2001).

Despite their proven efficacy and widespread use in cows, dry period antibiotics do have limitations. First, the efficacy of the antibiotic decreases over time, becoming non-effective at the end of the dry period (Oliver et al., 1990; Pinedo et al., 2012). Thus, the udder resumes a state where it will once again be susceptible to gram-positive bacteria that can also be found in the environment. Second, animals remain vulnerable to the environmental, gram-negative bacteria for which the majority of dry period antibiotics have limited effect. Indeed, due to the immense success of dry period antibiotics, environmental bacteria are now the most common causes of new IMIs during the dry period (Bradley and Green, 2004). While products aimed at addressing these bacteria are now entering the market, their efficacy is still being determined (e.g., Arruda et al., 2013).

In addition to antibiotics, internal teat sealers and external sealants have been added to dry off therapy, with the purpose of keeping pathogens out of the teat canal (reviewed by Rabiee and Lean, 2013). While a keratin plug is supposed to form after involution occurs, teat canals may stay open throughout the dry period in some animals (Dingwell et al., 2003). The use of teat sealers and sealants has been extensively examined in cows, and treatment and prevention efficacy has been proven with (Godden et al., 2003), and in some cases without (Huxley et al., 2002; Bhutto et al., 2011), the combination of antibiotics. Of particular interest is the study by Huxley et al. (2002) who reported finding that teat sealers were especially useful for preventing environmental pathogens, a growing area of concern as contagious pathogens are being controlled by dry period antibiotics. To date, no research has reported on the efficacy of these products in goats.

As a final point, in line with the intended purpose of the aforementioned teat sealers and sealants, early dry period IMI prevention research focused on using reduced milk production to prevent intramammary infections (Bushe and Oliver, 1987). With the advent of dry period antibiotics, as well as teat sealers and sealants, the importance of reduced milk production was largely ignored for decades. However, the topic of reducing milk production prior to dry off has recently received renewed attention. Cows entering the dry period with high milk production are more likely to develop IMIs (Rajala-Schultz et al., 2005); furthermore, these cows experience more milk leakage, delayed teat canal plug
formation as well as display differences in mammary gland response to infection (Bertulat et al., 2013; Silanikove et al., 2013). All this occurs in spite of widespread dry off therapy use. Perhaps rather than concentrating future research on developing means of treating and preventing the still problematic IMIs caused by environmental pathogens, it may be advantageous to identify the factors at the beginning of dry off that affect susceptibility through to parturition. Perhaps abrupt dry off coupled with dry off therapy is simply not appropriate for high production cows, and alternatives need to be explored. This may become increasingly important, particularly as blanket application of antibiotics becomes more of a public concern (Bos et al., 2013), and an interest grows in the implementation of selective dry off therapy (Scherpenzeel et al., 2014).

As has been demonstrated by the numerous reviews and original research cited, the biological aspects and health implications of the dry period have received significant attention in the literature. On the contrary, only a small fraction of dry period research has examined the impact of dry off on the affective states of the individual dairy animal. Regardless if they receive dry off therapy, all dairy animals enter the dry period after a series of routine changes in management practice; some of these changes have been suggested to cause negative affective states such as hunger, pain and frustration.

1.3 Affective states

The ultimate goal of dry off is to stop milk production. Prior to the widespread adoption of dry off therapy regimes, dry off was achieved by reducing milking frequency (Natzke et al., 1975) and providing a lower energy diet, thereby reducing milk production and ensuring the lowest possible IMI risk (Bushe and Oliver, 1987). The incorporation of dry off therapy into recommended dry off protocols (e.g., National Mastitis Council Recommended Mastitis Control Program; NMC, 2006) has resulted in a move to milking being stopped abruptly, with little consideration placed on how this practice may impact the animal's affective state. However, as concern for animal welfare grows in the dairy industry (e.g., von Keyserlingk et al., 2009), identifying and addressing the potential negative consequences of dry off management practices is being given more consideration in the literature (Bertulat et al., 2013; Silanikove et al., 2013; Chapinal et al., 2014). One reason for this interest is that the production level of the modern cow has greatly increased. In 1975, a cow in the US was producing an average of 15 kg/d in a standard 305-day lactation (USDA, 2012) and it was common for cows to be below 9 kg/d at the end of their lactation (Natzke et al., 1975). Almost 4 decades later, the average 305-day lactation has
more than doubled (USDA, 2012), and with that has come higher milk production at the end of lactation (e.g., 24 kg/d, Chapinal et al., 2014), and even higher in cows treated with bovine somatotropin (bST) (e.g., 26-30 kg/d, Annen et al., 2004). Given such high end-of-lactation milk production levels, some researchers have questioned the appropriateness of abrupt cessation of milking (Bertulat et al., 2013; Silanikove et al., 2013), arguing that pain may result if milk production is not first reduced. Interestingly, the act of reducing milk production (e.g., by reducing or withholding feed), may itself be detrimental to the welfare of the animal, by causing hunger (Valizaheh et al., 2008).

1.3.1 Hunger caused by dietary changes

Decades of nutritional research have resulted in the formulation of diets that promote high milk production in cows (Stefanon et al., 2002). These diets are beneficial to the annual milk yield of the cow (and arguably the profitability of the farm), but this also makes cessation of lactation more difficult. A similar trend is likely for the growing commercial dairy goat industry; milk production is increasing with improvements in diet formulations (e.g., Monzón-Gil et al., 2010; Goetsch et al., 2011), and many goats already have a tendency for production persistency (Gipson and Grossman, 1990). Given these changes, it is not surprising that there has been increased interest in determining how changes in feeding management can facilitate dry off. The impact of a reduced energy diet on decreasing milk production in cows at, or shortly prior to, dry off is well established (e.g., Bushe and Oliver, 1987; Tucker et al., 2009; Ollier et al., 2014). However, minimal work has examined how these dietary changes impact hunger at this time.

Reduced energy intake can be achieved by formulating a total mixed ration (TMR) with less energy dense feedstuffs (e.g., reduced concentrate levels), increased levels of less palatable forage, or by feeding only forage. The difficulty with dietary changes is achieving the end goal (reduced milk production) without compromising the animal metabolically (Odensten et al., 2007b) and without inducing hunger (Valizaheh et al., 2008). Hunger is a negative affective state experienced by an animal that is not able to reach satiety (D’Eath et al., 2009). In the case of dairy animals at dry off, the effects of hunger are likely to be short term, but still may have a negative impact on welfare. Behavioural observations are typically used to identify hunger (reviewed by D’Eath et al., 2009). In adult cows, vocalizations can be linked to periods of distress for the cow, including social isolation, pain and hunger (Watts and Stookey, 2000). With the latter state in mind, Valizaheh et al. (2008) found that when cows were provided free access to diets
comprised largely of low energy hay, the cows offered the less palatable of the two hay types vocalized more. Both diets were successful at reducing milk production, but the increase in vocalizations left the authors concluding that cows were hungry. An alternative technique to reduce milk production at dry off is to provide readily palatable feed, but in restricted amounts. Using this approach, Tucker et al. (2009) reduced IMI risk factors such as milk leakage, but noted an increase in vocalizations in the cows receiving only 50% of the grass pasture and supplemented silage diet. Unfortunately, the authors failed to describe the proximity of the two treatment groups to one another, so it is possible that the continued feeding behaviour by animals within the treatment groups offered 100% of the diet instigated the vocal response in the restricted dietary treatment groups.

It is evident that drastic reduction in feed or changes in the energy level of feed may be problematic from an animal welfare perspective. Both the potential of metabolic issues (e.g., compromised physical state) and hunger (e.g., presence of a negative affective state) demonstrate the potential impact that changes in diet at dry off can have on the welfare of the animals. Attention should be given to the amount of energy reduction that is necessary and the most appropriate feed components for both cows and goats, with special focus on managing high production animals.

1.3.2 Pain due to abrupt cessation of milking

Pain and discomfort are terms frequently used in conjunction with one another. The International Association for the Study of Pain defines pain as, “an unpleasant sensory and emotional experience associated with actual or potential tissue damage” (IASP, 1994). The term discomfort has not been as clearly defined. Thus, although the minimal research available that examines affective states around dry off often uses pain and discomfort interchangeably, within this review, the word pain will be utilized.

Considering the above definition, there is potential for abrupt cessation of milking to cause pain. After milking is ceased, mammary tissue becomes engorged with milk, causing intramammary pressure (Peaker, 1980). This pressure can lead to tissue damage, thereby resulting in pain (Bertulat et al., 2013; Silanikove et al., 2013). In humans, abrupt cessation of milking is not recommended due to its propensity to cause milk leakage, engorgement and pain (Betzold, 2007; Lawrence and Lawrence, 2011). The cisternal structure of the udder in cows (Davis et al., 1998) and in goats (Salama et al., 2004) allows for a much larger storage capacity potential than the cistern-lacking human breast (Ramsay et al.,
2005). Nonetheless, if storage capacity reaches its threshold, which may be the case in high production cows and goats, tissue damage and associated pain are possible.

Challenges inherent with measuring pain directly have resulted in researchers using indirect measures. Silanikove et al. (2013) suggested that increased vocalizations were indicative of udder engorgement-related pain when milking was ceased abruptly in cows producing more than 25 kg/d; since all cows received the same change in diet, it is unlikely that these vocalizations were caused by hunger. Other researchers have focused on lying behaviour changes. In lactating cows, decreased lying time has been attributed to milk accumulation and the resulting udder pressure caused by omitted milkings (O'Driscoll et al., 2011) and by reduced milking frequencies (Österman and Redbo, 2001). At dry off, lying behaviour responses to cessation of milking are less conclusive. Tucker et al. (2009) found no impact on lying time when cows were abruptly dried off, but average milk production was below 10 kg/d, and udder firmness increased minimally. Chapinal et al. (2014) noted a change in lying behaviour only in primiparous cows ending their first lactation. Conversely, Leitner et al. (2007a) demonstrated that cows producing 25 kg/d at dry off and treated with intramammary casein hydrolyzate, which reduces intramammary pressure and engorgement by accelerating the involution process, spent more time lying down than non-treated cows. Udder firmness in untreated cows increased for the first 4 d, while it immediately decreased in the treated cows. Therefore, it is suggested that future work evaluating lying behaviour as an indicator of potential pain consider milk production at dry off.

1.3.3 Frustration due to abrupt cessation of milking

As with the measurement of pain, measuring frustration must also be done indirectly. It has been suggested that frustration could result if animals are not allowed to perform a behaviour or activity that they are highly motivated to perform (Munksgaard and Simonsen, 1996). With this in mind, abruptly stopping milking, and the entire milking routine, could result in a state of frustration for dairy animals at dry off. A small number of studies have explored this topic, using standing behaviour as an indicator. For instance, Stefanowska et al. (2000) increased standing at the pen’s exit gate was associated with missed milkings in lactating cows. Conversely, Tucker et al. (2007), transitioned cows from twice to once a day milking and found no increase in standing at the gate. It is clear that cows are responding to changes in management associated with dry off, however, research is needed to determine what level of change minimizes negative affective states,
such as frustration. Studies utilizing methods intended to evaluate motivation for access to a resource, such as the distance a cow will walk for access to pasture (Charlton et al., 2013) and food (Schütz et al., 2006), could be applied to assessing how motivated a cow is to be milked as well.

1.4 Natural living

In most mammals, the natural tendency is for the dam to produce enough milk for her offspring. As dependency on the dam decreases, offspring nurse less. This has been noted in feral cattle (Vitale et al., 1986) as well as managed Zebu populations, where calves are given partial access to milk (Das et al., 2000). When the demand for milk declines, milk production naturally diminishes due to gradual involution (Wilde et al., 1997). Milk production ebbs further if the cow (Olori et al., 1997) or goat (Knight and Wilde, 1988) is pregnant. Conversely, although a certain amount of gradual involution does occur after lactation peaks, in the modern dairy industry milk production often remains high even late into gestation, particularly in cows. Furthermore, the removal of milk from the udder is typically ceased abruptly. This involves the mammary gland going through acute involution, a process that in nature would be relatively rare. With the exception of a loss of offspring in nature, the amount of acute involution experienced by modern cows, and perhaps goats, is entirely a construct of the modern dairy industry. Acute involution is discouraged in humans; pain is a major concern, and more recently serious health outcomes have been suggested (e.g., increased risk of breast cancer; Silanikove, 2014). Regardless, virtually nothing is known about how cows actually experience this unnatural lactation cycle.

In decades past, there was a focus on reducing milk production prior to dry off. As dry off therapy antibiotics and sealants became widely used, reducing milk production was no longer a priority. Current dry off practices are almost entirely focused on fitting the cow into the standard 305-d lactation, and rarely consider production level. Milking is now ceased when a cow is producing what a cow in 1975 would have produced at peak lactation (Figure 1.1).
Figure 1.1. Example dairy cow lactation curves for 1975 and 2012

Vertical black dashed line denotes dry off according to standard 305-d lactation management. Estimated milk production at dry off presented for 1975 (A) and for 2012 (B). Vertical gray dotted line denotes the estimated number of days in milk (C) required for a cow to reach the milk production at dry off achieved in 1975. Lactation curve for 1975 estimated according to Natzke et al. (1975) and USDA (2012). Lactation curve for 2012 adapted from Cole et al. (2011).

Indeed, models predict that it may take over 700 d after parturition for a modern cow to reach milk production levels that were once considered appropriate for drying off (Cole et al., 2011). With this information in mind, perhaps the 305-d lactation cycle simply does not apply to the modern cow, and that longer lactations would be beneficial. In goats, there is tendency for persistent milk production in some animals (Safayi et al., 2010); this may result in more variable lactation cycles (García-Peniche et al., 2012) than that of cows. As previously mentioned, the minimal work examining dry off and dry periods in goats suggests that extended lactations, with and without dry periods, are a possibility (Fowler et al., 1991; Safayi et al., 2010). Overall, a clear need exists for research examining how deviating from the natural milk production cycle impacts dairy cows at the end of lactation, particularly since the modern lactation cycle has retarded the gradual involution process;
this work could be aided by examining the differences between goats and cows in their response to set lactation lengths.

Differences in physiological responses to forced acute involution between low producing and high producing cows have been shown (Silanikove et al., 2013), with reasoning that the former animals are already undergoing a more natural state of gradual involution. Interestingly, with scientific interest having been largely focused on improved milk production, the animals which have steeper lactation cycles, and that approach dry off with lower milk production, have not been the focus of much research. Arguably, these animals are following a more natural lactation cycle. Perhaps the findings of Silanikove et al. (2013) hold the answers to some problems that continue to plague the dairy industry, in particular, the high incidence of disease that occurs during the transition between lactations (e.g., Mulligan and Doherty, 2008; Grummer, 2008) and the reproductive issues that occur in high milk production cows (e.g., Pryce et al., 2004; Moore and Thatcher, 2006).

Although there is minimal evidence, some research exploring the effects of natural behaviour has shown a positive impact on mammary health. Walsh (1974) found a dramatic difference in IMI incidence between cows that were suckled (2%) versus milked (29%) in the first 8 weeks. Similarly, Fröberg et al. (2008) found an initial tendency for decreased SCC when cows were milked normally but were also suckled by their calf. Unfortunately, both studies only focused on an added ‘naturalness’ component early in lactation. Although neither of these studies followed the cows through to the dry period, it is unlikely that this early suckling of calves impacted involution at the end of lactation. Future research should investigate the potential benefits of encouraging a more natural lactation cycle on cow metabolic and intramammary health.

1.5 Summary of gaps in the literature

Dry off research in dairy cows began decades ago and has resulted in an immense amount of literature; however, the vast majority of this is focused primarily on aspects of biological functioning. The lack of literature in other areas has illustrated two clear gaps in our knowledge in regards to dry off and the dry period.

First, a few studies have examined affective states such as pain, hunger and frustration caused by dry off related management, yet little has been solidified about how animals experience the dietary and milking routine changes. Current management of cows was established decades ago and is likely outdated for present day cows’ production.
levels. In goats, there is simply a dearth of research describing management practices of any kind, let alone exploring how dry off impacts affective states.

Second, we have deviated drastically from natural lactation patterns, decidedly forcing an annual lactation cycle, including set dry periods, onto modern dairy animals. Quantifying how this deviation impacts the animal’s welfare is quite difficult, but some work looking at indirect measures, such as the metabolic health outcomes of set dry period lengths in cows, has pointed towards detrimental welfare effects of current management. Work is needed in both cows and goats to assess the potential benefits of working more within the animals’ natural lactation tendencies.

1.6 Thesis research questions

With the literature gaps in mind, the following broad thesis goals developed: 1) to better understand how milking cessation methods and dry period management impact welfare, 2) to clarify these dry off and dry period methodologies in goats, and 3) to assess the usefulness of certain behavioural measures for measuring welfare. The hypothesis of this dissertation is that dry off and the dry period have the potential to negatively affect the welfare of dairy goats and cows, and that these effects can be assessed using behaviour. In cows, this hypothesis was investigated with one study focusing on an established dry off practice (Chapter 2). In goats, a lack of background research required that some foundation work (Chapters 3 and 4) first be completed before the impact of the dry period could be assessed. The following specific research questions were asked:

1. **Chapter 2**: Does the common dry off practice of abrupt cessation of milking cause pain and frustration in dairy cows as assessed by behavioural responses?
2. **Chapter 3**: What are the common dry off practices used by dairy goat producers?
3. **Chapter 4**: Can data loggers used for monitoring lying behaviour in dairy cows also be used in dairy goats?
4. **Chapter 5**: Can dry period length and lying behaviour be used to identify dairy goats at-risk of developing pregnancy toxemia and ketosis?
2  Gradual Cessation of Milking Reduces Milk Leakage and Motivation to be Milked in Dairy Cows at Dry-Off

2.1  Introduction

To promote udder health, calf development, and production in the subsequent lactation in dairy cows, milking typically ends approximately 40 to 60 d before calving (Kuhn et al., 2006). Earlier work suggested that gradual reduction in milking frequency at dry-off resulted in fewer new intramammary infections at calving (Natzke et al., 1975). However, as blanket dry cow antibiotic therapies have become common, abrupt cessation of milking is now frequently recommended for achieving dry-off (e.g., Blowey and Edmondson, 2010). It has been reported that cows may still be producing 25–30 kg/d of milk at the time of abrupt dry-off (Stefanon et al., 2002; Annen et al., 2004). Early in the involution process milk continues to be produced, creating cisternal, duct and alveoli engorgement (Oliver and Sordillo, 1989). The continued milk production creates increased intramammary pressure in cows with skipped milking frequency (O’Driscoll et al., 2011) and when milking is completely ceased (Cousins et al., 1980; Oliver and Sordillo, 1989). It has been suggested that increases in udder pressure may result in udder discomfort (O’Driscoll et al., 2011). An indirect way of identifying discomfort due to increased udder pressure is to measure changes in lying and standing time (Medrano-Galarza et al., 2012). A cow may opt to stand for longer and have more changes between standing and lying when her udder is full and distended (Österman and Redbo, 2001). Reduction in lying time has been noted when milkings are skipped (Stefanowska et al., 2000). The merit of lying behaviour as an indicator of discomfort is supported by work using an intramammary treatment of casein hydrolyzate at dry-off on udder pressure. Cows treated with the hydrolyzate had decreased udder pressure and spent more time lying down compared to cows that did not receive the treatment (Leitner et al., 2007a).

Preventing highly motivated behaviour by cows may result in frustration and displacement activities (Munksgaard and Simonsen, 1996). High producing cows (i.e., > 25 kg milk production/d) stand more when milking frequency is reduced, displaying increased restlessness and standing at the gate, presumably in anticipation of milking (Pomiès et al., 2007). Rathore (1982) suggested being milked is pleasant for high producing cows, as

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evidenced by their entering the milking parlour earlier than lower producing cows. Furthermore, it has been suggested that *incontinentia lactis* (e.g., non-stimulated milk let down) can be triggered before entering the milking parlour (Rovai et al., 2007); cows that are highly motivated to leave the pen for milking may be more likely to experience this milk leakage.

The risk of increased intramammary infection (IMI) in the next lactation is greatest for high producing cows (Rajala-Schultz et al., 2005). Cows dried off while producing in excess of 21 kg/d are 1.8 times as likely to experience delayed teat canal closure (Dingwell et al., 2004). As milk leakage is a risk factor for increased intramammary infection (Klaas et al., 2005) the use of dry-off methods that limit milk leakage may be advantageous.

The aim of this study was to assess the effects of abrupt versus gradual cessation of milking on lying behaviour, standing at the gate and milk leakage in dairy cows.

### 2.2 Materials and methods

#### 2.2.1 Animals, housing and diet

This experiment was conducted at the University of British Columbia’s Dairy Education and Research Centre (Agassiz, BC, Canada) from May 2011 to July 2011. Cows were cared for according to the guidelines set by the Canadian Council on Animal Care (CCAC, 2009). Twenty-four Holstein cows (mean ± SD: parity = 2.3 ± 1.8; milk production = 24 ± 5 kg/d; DIM = 319 ± 35 d) were used in this experiment (6 cows per replicate, with 4 replicates over time). All replicates were housed in the same pen. Cows were housed at 50% stocking density, with 12 deep sand bedded stalls and 12 headlocks as a feed barrier. Cows were moved into the pen on d-4 relative to dry-off and fed TMR (DM: 48%, CP: 14.2% DM, ADF: 27.5% DM, NDF: 41.0% DM). On d0, the diet was switched to *ad libitum* oat straw (DM: 93%, CP: 6.7% DM, ADF: 46.7% DM, NDF: 68.7% DM) and approximately 10 kg tall fescue grass hay (DM: 93%, CP: 16.4% DM, ADF: 29.7% DM, NDF: 49.1% DM) per cow. Cows had *ad libitum* access to clean water from an automatic water trough.

#### 2.2.2 Experimental design and behavioural measurements

Within each replicate of 6 animals, cows were assigned to pairs (matched for 305d milk production and parity), with one cow from each pair randomly assigned to one of two experimental treatments: 1) ABRUPT cessation of milking or 2) GRADUAL cessation of milking consisting of a series of single-missed and double-missed milkings (d0 to d2 = AM milking only, d3 = PM milking only, d4 = no milking, d5 = AM milking and dry-off). Cows
were milked twice daily at 0500 and 1500 before dry-off. On d0, ABRUPT cows were milked and then completely dried-off; GRADUAL cows were dried-off on d5. Dry cow antibiotic (CEFA-DRI®, Boehringer-Ingelheim) and internal teat sealer (Orbseal®, Pfizer Inc.) therapy were administered at dry-off. All teats were also sealed externally (Gladiator Super Dry®, BouMatic).

Behaviour and milk leakage were observed from d-3 until d8 relative to the first skipped milking. Behavioural data were categorized for three periods: P0 (baseline; d-3 to d-2), P1 (ABRUPT cows dry, GRADUAL cows milking; d0 to d4) and P2 (all cows dry; d5 to d8).

Data loggers (HOBO Pendant® G, Onset, Cape Cod, MA) were attached to the rear right hind leg and recorded leg position (i.e., lying or standing) every minute. Data were summarized to calculate daily lying time, lying bouts and lying duration per cow according to the methods outlined by Ledgerwood et al. (2010).

Video captured by a Panasonic WV-CW504SP camera (Panasonic, Taiwan) fixed above the pen was continuously recorded by a GeoVision 1480 digital recorder (USA Vision Systems, CA, USA). Motivation to be milked (i.e., standing at the gate) was defined as the cow standing in the raised area (2.8 x 3.3 m) directly in front of the pen’s rear exit gate, which cows would typically use to go to and from milking. Cows rarely visited this area, bordered on three sides by the gate, the neighboring pen and a concrete divider from the lying stalls, unless they were leaving the pen. Cows had to have at least two front legs in this area to be scored as standing at the gate. As the gate faced away from the milking parlor, cows could be oriented in any direction on the raised area. We first watched the video continuously for 3 d, and then 5-min scan samples from the same 3 d. As the scan samples correctly estimated 95% of the time spent standing at the gate, they were used to determine this time during the 3 h periods after milking activities in the barn had ceased (0800–1000 and 1800–2000). Feeding behaviour was anticipated to change in relation to the change in feed offered at dry-off, and was assessed by means of the 5-min video scan samples (Endres et al., 2005). Cows were coded as feeding if their heads were through the headlock feed barrier.

Milk leakage was monitored every 20 min for 2 h periods beginning at the onset of each milking time (0500 and 1500). The teat ends of each cow were observed for 5 sec and scored as leaking if any teat was seen to be leaking or streaming milk. Cows lying down during this period were not disturbed and therefore these data were excluded from the total number of observations (mean number of observations excluded per cow 39 ±
14%). A percent of the number of leaking observations out of the total number of observations was calculated for each cow. Overall leakage incidence was summarized as either: 0 (no milk leakage observed during all 4 d) or 1 (milk leakage observed at some point over the 4 d).

Composite milk samples were taken on d-1 (GRADUAL and ABRUPT), d0 (ABRUPT), d5 (GRADUAL), and first colostrum, 1 d and 7–10 d after calving (GRADUAL and ABRUPT). Milk samples were analyzed for somatic cell count (SCC) and bacteria by Maritime Quality Milk (Atlantic Veterinary College, Prince Edward Island, Canada). A logarithm transformation (SCS = log2 (SCC/100,000) + 3) was used to convert SCC to somatic cell score (SCS). To determine a baseline pre-dry-off SCS for each treatment, the d-1 sample was compared to each group’s last milking. As an increase had been noted from d-1 to d5 in the GRADUAL group, treatments were tested separately over time.

2.2.3 Statistical analysis

For all behaviour data, d0 and d4 – 6 in replicate 3 were removed from the final dataset owing to management changes. Experimental d was corrected to start at the afternoon milking, as this is when cows would notice a change in their routine.

2.2.3.1 Milk production

Daily milk production data were collected for d-4 to d0 (for ABRUPT) and d-4 to d5 (for GRADUAL) from the computerized milking and management software system, Dairy Comp 305 (Valley Agricultural Software, Tulare, CA).

2.2.3.2 Milk leakage

One cow was removed from the dataset owing to leakage during the baseline period. For testing the effect of treatment, overall leakage incidence (either leaking or not leaking) was tested with a two-tailed Fisher’s exact test.

2.2.3.3 Lying and feeding behaviour and SCS

The effect of treatment on lying time, lying bouts, feeding time and SCS was tested with mixed model ANOVA in SAS (PROC MIXED). Period was used as a repeated measure, with milk production at dry-off, DIM, parity (primiparous and multiparous) and weight as covariates and replicate and replicate*treatment as random effects. The residual term of the model was cow (replicate*treatment) and the error term to test the effect of experimental group was replicate*treatment. The covariance structure selected for all models was an auto-regressive type 1 based on the lowest Aikake’s Information Criterion.
Residuals were examined for all models to verify normality and homogeneity of variances and to detect possible outliers and influential observations.

2.2.3.4 **Standing at the gate**

The number of times a cow was seen standing at the gate was summarized per cow per period, and then converted to a percent (time standing at the gate out of total observation time). The first replicate was not included because of a difference in pen exit gates compared to subsequent replicates. A logit-transformation with a bias correction factor of 0.25 (Cox and Snell., 1970) was applied to the proportion of times cows were by the gate out of the total observation time, to meet the assumptions of normality and homogeneity of variance and to ensure the estimates and CI were calculated correctly. Data were analyzed using mixed models in SAS (PROC GLIMMIX) that included period as a repeated measure over cow, treatment and parity (primiparous or multiparous) as fixed effects, biologically plausible 2-way interactions between fixed effects, milk production at dry-off as a covariate and replicate and replicate*treatment as random effects. The residual term of the model was cow (replicate*experimental group) and the error term to test the effect of experimental group was replicate*experimental group. An auto-regressive type 1 covariance structure was selected based on the smallest Aikake’s Information Criterion. Dunnett’s 2-tailed test was used as a post-hoc test of differences between baseline and subsequent days. Residuals were examined to verify normality and homogeneity of variances, and to detect possible outliers and influential points. Coefficients were back-transformed and results presented as odds ratio (OR) and confidence interval (CI). The OR expresses how much higher the odds of displaying a behaviour are during a period as compared to the baseline period.

2.3 **Results**

2.3.1 **Milk production**

No decrease in milk production was noted for either treatment in the 4 d before dry-off ($P > 0.1$). Milk production did not differ between treatments on the day before dry-off, averaging 24.2 kg/d and 23.8 kg/d in the ABRUPT and GRADUAL treatments, respectively (SED = 1.3, not significant). During the 5 d of skipped milkings in the GRADUAL treatment, milk production declined (on average 0.6 kg/d; $P < 0.0001$). Production for the GRADUAL cows averaged 10.9 kg at final milking before complete dry-off compared to 14.1 kg for ABRUPT cows (SED = 1.2; $P < 0.02$).
2.3.2 Behaviour

Lying time, frequency of lying bouts, lying bout duration and feeding time changed with period. After dry-off, lying time decreased from 14.1 vs. 13.2 h/d (SED = 0.2; \( P < 0.0001 \)). Lying bouts decreased from 10.7 to 8.3 (SED = 0.2; \( P < 0.0001 \)). Lying bout duration increased from 1.4 vs. 1.7 h/bout (SED = 0.03; \( P < 0.0001 \)) and feeding time increased from 5.0 vs. 5.9 h/d (SED = 0.2; \( P < 0.0001 \)). However, treatment did not have an effect on these behaviours (\( P \) for treatment and treatment*period > 0.05). Cows that produced more milk before dry-off spent less time lying down after dry-off (coefficient estimate = -7.8 ± 3.6 min/d; \( P = 0.04 \)). Heavier cows had longer bout duration after dry-off (coefficient estimate = 8.9 ± 3.8 min/d for each 100 kg increase in BW; \( P = 0.04 \)). Cows producing more milk had increased feeding time (coefficient estimate = 4.4 ± 1.5 min/d; \( P = 0.01 \)). Heavier cows spent less time eating (coefficient estimate = -0.3 ± 0.1 min/d for every 100 kg increase in BW; \( P = 0.01 \)) compared to lighter cows.

2.3.3 Milk leakage and SCS

Over the course of the 4 observation days following complete cessation of milking, more ABRUPT cows (9 cows out of 12) leaked compared to GRADUAL cows (3 cows out of 11) (Fisher’s exact test, \( P = 0.04 \)). ABRUPT cows began leaking 1 d after dry-off, and leaking continued for the next 2 d of observation. GRADUAL cows were observed leaking milk only on d3. Of the cows that leaked after dry-off, ABRUPT cows leaked for a higher percentage of the total observations. Milk production before dry-off did not differ between cows that later leaked or did not leak milk (Table 2.1).

Table 2.1. Cows leaking milk after abrupt and gradual milk cessation

Percent of total observations in which cows were leaking for ABRUPT and GRADUAL treatments, as well as milk production of both leaking and non-leaking cows (mean, SD and range).

<table>
<thead>
<tr>
<th></th>
<th>ABRUPT (n = 12)</th>
<th></th>
<th>GRADUAL (n = 11)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Range</td>
<td>Mean</td>
</tr>
<tr>
<td>Percent of total</td>
<td>36</td>
<td>16</td>
<td>8 – 62</td>
<td>10</td>
</tr>
<tr>
<td>observations in which</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>cows were leaking, %</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Last milking milk</td>
<td>13.6</td>
<td>3.0</td>
<td>10.5 – 18.0</td>
<td>13.7</td>
</tr>
<tr>
<td>production (cows which</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>leaked)(^a), kg/d</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Last milking milk</td>
<td>15.7</td>
<td>3.6</td>
<td>11.5 – 18.0</td>
<td>9.5</td>
</tr>
<tr>
<td>production (cows which</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>did not leak)(^a), kg/d</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\(^a\)Last milking day dependent on experimental group (ABRUPT = d0; GRADUAL = d5)
Treatment did not have an effect on SCS ($P$ for treatment and treatment*sample > 0.05). There was no difference between d-1 and final milking (d0) SCS for ABRupt cows. However, after removal of one outlier, which was having undue influence on SCS prior to dry-off, the GRADUAL treatment’s SCS increased between d-1 and final milking (d5) (2.3 vs. 3.7; SED = 0.6; $P = 0.04$). Therefore, changes in SCS from baseline to after calving were tested separately for each treatment. Both treatments returned to below pre-dry-off levels within 7 – 10 d after calving (Table 2.2). DIM, milk production at final milking and parity had no effect on SCS in either model.

Three cows developed clinical mastitis after calving: 1 (GRADUAL) - *Staphylococcus* spp. (CNS) + *E. coli, Enterobacter* spp., 2 (GRADUAL) - *Staphylococcus* spp. (CNS), and 3 (ABRUPT) - *Corynebacterium* spp.

### Table 2.2. Somatic cell score (SCS) changes
Changes in somatic cell score (SCS) after calving compared to baseline samples taken for each treatment on the last day of milking (ABRUPT = d0, GRADUAL = d5).

<table>
<thead>
<tr>
<th>Sample</th>
<th>ABRUPT$^a$ (n = 12)</th>
<th>GRADUAL$^b$ (n = 10)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Estimate</td>
<td>SED</td>
</tr>
<tr>
<td>Colostrum</td>
<td>2.7</td>
<td>0.5</td>
</tr>
<tr>
<td>24h after calving</td>
<td>1.6</td>
<td>0.5</td>
</tr>
<tr>
<td>7 – 10 d after calving</td>
<td>-0.6</td>
<td>0.5</td>
</tr>
</tbody>
</table>

$^a$ABRUPT baseline SCS (mean ± SD; 2.3 ± 1.4)

$^b$GRADUAL baseline SCS (mean ± SD; 3.7 ± 1.3)

### 2.3.4 Standing at the gate
The percent of time spent standing at the gate was highly variable among cows, but standing time at the gate was low for both treatments during the baseline period (mean ± SD: 0.5 ± 0.8% of total observation time). There was an interaction effect between period and treatment ($P < 0.001$). The GRADUAL treatment showed no increase in standing at the gate from baseline to P1 and P2. The odds of cows in the ABRupt treatment standing at the gate were greater by a factor of 6.2 in P1 and 5.2 in P2 compared to the baseline period (Table 2.3).
Table 2.3. Standing at the gate behaviour after dry off

Changes in the logit-transformed proportion of times cows (n = 18) were observed standing at the gate during the 3 h periods following cessation of all milking activities in the barn (0800 – 1000 and 1800 – 2000) for Period 1 (ABRUPT treatment dried off, GRADUAL treatment still milking intermittently) and Period 2 (both treatments dry) as compared to baseline.

<table>
<thead>
<tr>
<th>Standing at Gate</th>
<th>Parameter Estimate</th>
<th>SE</th>
<th>OR</th>
<th>95% CI</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Period 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ABRUPT</td>
<td>1.8</td>
<td>0.4</td>
<td>6.2</td>
<td>2.7 - 14.4</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>GRADUAL</td>
<td>-0.3</td>
<td>0.4</td>
<td>0.7</td>
<td>0.3 - 1.7</td>
<td>0.56</td>
</tr>
<tr>
<td>Period 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ABRUPT</td>
<td>1.6</td>
<td>0.5</td>
<td>5.2</td>
<td>1.8 - 14.6</td>
<td>0.002</td>
</tr>
<tr>
<td>GRADUAL</td>
<td>0.8</td>
<td>0.5</td>
<td>2.2</td>
<td>0.8 - 6.1</td>
<td>0.16</td>
</tr>
</tbody>
</table>

2.4 Discussion

Many cows are able to maintain high levels of milk production even at the end of their lactation (Dingwell et al., 2001; Stefanon et al., 2002) may pose risks for udder health (e.g., increased IMI due to delayed teat-canal plug formation and milk leakage; Schukken et al., 1993; Dingwell et al., 2004) and cow welfare (e.g., hunger due to the need to reduce milk production through dramatic diet changes; Valizaheh et al., 2008; Tucker et al., 2009) when subjected to common dry-off procedures. Reducing milk production can also be achieved by skipping milkings (Bushe and Oliver, 1987; Davis et al., 1998) as increased milk stasis induces mammary apoptosis (programmed cell death) (Wilde et al., 1997). In humans, a gradual reduction in milking frequency reduces milk production, milk leakage and discomfort (Betzold, 2007; Lawrence and Lawrence, 2011). Human and bovine mammary systems are anatomically different, probably resulting in different interpretations of mammary pressure by humans and cows. For instance, in the cow, milk is transported through primary ducts to the cisterns. These cisterns have been shown to have great milk storage capacity even after 24 h of milk cessation, only reaching full capacity after 40 h (Davis et al., 1998). Conversely, in humans, milk is transported through lactiferous ducts, and although they widen into areas once considered to be lactiferous sinuses, the structure of sinuses is lacking; hence the human breast has less capacity for milk storage (Ramsay et al., 2005) compared to the cow udder. Therefore, it is possible that the storage capacity of the bovine udder allows for a much larger milk fill proportionally compared to the human before discomfort is felt. Nonetheless, in high production cows that are abruptly dried-off, it is possible that cisternal pressure may reach a threshold at which the cows do feel
discomfort. There is evidence that in some instances cows do alter their lying behaviour in a way indicative of udder pressure avoidance (e.g., Österman and Redbo, 2001). Thus, it was hypothesised that high producing cows would experience milk leakage and discomfort when milking was ceased abruptly, and that the discomfort could be indirectly assessed through changes in lying behaviour and motivation to be milked.

Previous work demonstrated that omitted milkings (O’Driscoll et al., 2011) and reduced milking frequencies (Österman and Redbo, 2001) resulted in decreased lying time that was attributed to milk accumulation and the resulting udder pressure. Furthermore, Leitner et al. (2007a) demonstrated that when udder fill was minimized with casein hydrolyzate, cows lay for longer periods of time. In the present study, cows in both treatments showed a reduction in lying time and frequency of lying bouts, and increased bout duration. These changes in lying behaviour may be explained in part by the change in feeding management that was implemented as part of the dry-off routine. The change in feed from a highly palatable, high energy TMR, to a low energy combination of grass hay and ad libitum straw resulted in a 19% increase in daily feeding time. In previous work examining feed management changes similar to those used in the present study similar increases in feeding time were observed (Valizaheh et al., 2008). Since DMI was not measured in the current study, increased feeding time as a consequence of increased udder discomfort could not be disentangled from increased time required to consume the lower energy diet. Further work should separate these factors, as well as incorporate an evaluation of udder firmness as a secondary measure of the identifying the discomfort cows experience from udder fill.

The late stage of lactation may have also affected the lying behaviour of the cows used in the present study. O’Driscoll et al. (2011) found changes in lying behaviour when milkings were skipped, but this finding was for cows at about 90 DIM. Similarly, Österman and Redbo (2001) found changes in lying behaviour when milking frequencies were altered, but these authors used cows producing 38 to 40 ± 5 kg/d, approximately 15 kg/d greater than the cows in the current trial. Cows at lower milk production may plausibly experience less discomfort due to udder fill, muting the effects of dry-off method on changes in lying behaviour. Consistent with this suggestion, Tucker et al. (2007) failed to observe changes in lying time when milking frequencies were altered in cows producing 16.5 ± 4.1 kg/d.

In addition to potential discomfort, udder pressure increases the chances of milk leakage (Rovai et al., 2007). Schukken et al. (1993) reported that cows that leaked at dry-
off tended to develop clinical mastitis during the dry period. Protection of the udder against IMIs during the dry-period is helped by ensuring that each teat canal has a fully formed keratin plug. In one study, 97% of the quarters that were diagnosed with clinical mastitis had no keratin plug (Williamson et al., 1995). Therefore, practices that promote teat-canal keratin plug formation, such as lowering milk production at dry-off (Dingwell et al., 2004), should be encouraged. Cows in the current study were all treated with an intramammary antibiotic, as well as both an internal teat sealer and an external teat sealant. A number of studies have shown the efficacy of the internal sealer for preventing new cases of clinical mastitis, even when used without an antibiotic (Berry and Hillerton, 2002; Huxley et al., 2002; Bhutto et al., 2011). However, these trials targeted IMI incidence; detailed monitoring of leakage for a period after dry-off was not a focus. Also, the efficacy and adherence of external teat sealants has been documented, but not evaluated for prevention of leaking (Lim et al., 2007). The current study was not designed to identify treatment effects on SCS and IMIs, but some discussion is warranted.

First, SCS was found to increase between the start of the gradual milking frequency and the final milking. Numerous studies show that reduced milking frequency increases somatic cell count, however, this increase does not correspond to increases in mastitis-causing pathogens (for review see Stelwagen et al., 2013). When considering a reduction in milking frequency as part of dry-off, early work demonstrated that all the cows, regardless of dry-off technique, had increased somatic cell counts (Bushe and Oliver, 1987). This work also suggested that in cows where milking was gradually reduced and paired with a reduced energy diet, as in this trial, mammary secretions were actually more inhibitory to certain bacterial growths than were those of cows which had their milking ceased abruptly. The current trial did not measure somatic cell in cows beyond their last milking, but it is possible that the SCS increase seen over the 5 d of gradually reduced milking frequency could have occurred in the abruptly dried-off cows as well. It is important to note that Bushe and Oliver (1987) started their study using cows with milk production substantially lower than that in the current trial (approx. 13 kg/d). Further study is therefore needed to examine abrupt versus gradual milking cessation on SCS in cows with milk production more representative of current industry values (e.g., > 20kg), without the use of intramammary antibiotics.

Second, the descriptive results of IMI incidence may also be of interest. Of the 3 cows that developed clinical mastitis after calving, 2 were leaking at dry-off and at calving. Dingwell et al. (2004) found that almost a quarter of teats remained open 6 weeks after dry-
off, and it is possible that some cows develop IMIs even when teat sealants are used. From the current findings it is suggested that leakage remains an issue, even with the use of internal teat sealers and/or external sealants.

Regardless of experimental treatment applied during dry-off, the teat sealer and sealant appeared to have a short-term benefit in that leakage was first observed approximately 24 h after dry-off. After this initial period, the overall leakage incidence was 52%. This rate may be partially a function of milk production. Drying-off higher producing cows (e.g., above 21 kg/d, similar to those in this study) delays teat canal closure (Dingwell et al., 2004). Tucker et al. (2009) showed that when feed changes were not initiated to drop milk production, even cows producing 10 kg/d at abrupt dry-off had leakage rates of over 40%.

Both treatments had similar milk production; with no differences noted in milk production prior to dry-off. However, the GRADUAL cows’ milk production was reduced by d5. This reduction is probably at least in part due to the switch to a lower energy diet on d0. Indeed, Bushe and Oliver (1987) demonstrated the effectiveness of this management practice prior to dry-off on reducing milk production. In the case of the present study pairing a reduction in milking frequency with a change to a lower energy diet prior to dry-off achieved a substantial decrease in milk production at actual dry-off (Oliver and Sordillo, 1989). Nonetheless, actual milk production at final milking was similar in the leaky cows of both experimental treatments. Further work is needed to tease out whether other factors, such as the switch to a series of intermittent milkings prior to complete milk cessation, may also impact leakage. It should be noted that even cows dried off at much lower milk production (e.g., aim of < 5 kg/d at dry-off) sometimes leak (Schukken et al., 1993), indicating that leakage is variable among cows. As a variety of factors contribute to milk leakage, including energy in the diet at dry-off (Tucker et al., 2009), as well as high peak milk flow rate, short teats, teat canal protrusion and inverted teat ends (Klaas et al., 2005), these factors should be considered in future work.

A contributing factor to leakage in the current study may have been the location of the pen. Although not in direct sight of the milking parlour, the pen was within 50 m of it, meaning that cows were likely aware of the milking activities. Munksgaard and Simonsen (1996) suggest that preventing animals from participating in an activity to which they are accustomed could cause frustration. Since milking frequency reduction triggers an increase in standing at the gate around normal milking time (Pomies et al., 2007), it was not surprising that in the current trial an increase in standing at the gate was noticed for up to 3
h after milking had ceased. However, standing at the gate only increased in the abruptly dried-off cows; the cows that were gradually reduced in milking frequency did not display increased standing behaviour at the gate. Although it is not possible to discern whether the cows were motivated to stand at the gate simply owing to routine or whether they were feeling discomfort from udder fill, these cows did leak more often and for a longer period of time compared to cows that spent less time standing at the gate. This result agrees with that of Stefanowska et al. (2000), who showed that missed milkings triggered both increased standing and milk leakage. Because milk let down is triggered by auditory, visual, and other cues (e.g., presence of a calf; Pollock and Hurnik, 1978), increased standing at the gate in response to missed milking could have triggered milk leakage. The involution process does not begin immediately after milking is ceased (Capuco and Akers, 1999); udder pressure has been shown to increase markedly for at least the first 4 d following abrupt dry-off (Leitner et al., 2007a). Relieving some of this pressure by intermittent milking in the gradually dried-off cows likely reduced the number of cows that leaked.

2.5 Conclusions

At dry-off, all cows responded with reduced lying times. Abruptly dried-off cows were more likely to stand at the gate following regular milking hours, during the entire 8 d observation period following dry-off, indicating that these cows were motivated to be milked. A gradual reduction in milking frequency reduced the amount and length of milk leakage, especially when milk production was high at dry-off. Gradual cessation of milking should be considered as a method of dry-off, especially for high producing cows.
3 Dry Off Practices on Dairy Goat Farms

3.1 Introduction

It is a standard practice for dairy cows and goats to be pregnant late into their lactation cycle. Before parturition, a non-lactating, or ‘dry’, period is commonly provided. In cows, this dry period is helpful in achieving high milk production in the next lactation (reviewed by Bachman and Schairer, 2003). The dry period is also used as a key time to address intramammary infections (IMIs) (reviewed by Bradley and Green, 2004; Barkema et al., 2009). Some dry off practices may be detrimental to animal welfare. Previous studies, limited primarily to cows, have found that milk cessation methodologies can cause pain (Bertulat et al., 2013; Silanikove et al., 2013), frustration (Zobel et al., 2013) and hunger (Valizaheh et al., 2008).

Dry off and dry period management are different in goats compared to cows. While these differences have not been quantified, there is evidence that extended lactations are occasionally utilized. For instance, Salama et al. (2005) examined the merit of milking does for longer than a standard annual lactation length. Furthermore, it has been suggested that omitting dry periods may be a viable option in goats, and hence work has examined the effects of not providing a dry period on milk production (Fowler et al., 1991; Caja et al., 2006; Safayi et al., 2010) and metabolic status (Zobel et al., submitted). However, little is known about what factors dairy goat producers use when selecting does to dry off, how they achieve cessation of milking, if dry off therapies such as intramammary antibiotics and teat sealants are used, if extended lactations are common and if dry periods are actually even provided. Therefore, the aims of this study were 1) to describe the practices employed by dairy goat producers to manage does between lactations, and 2) to explore whether these management practices affect dry period length.

3.2 Materials and methods

Approval for this study was granted from the Behavioural Research Ethics Board at the University of British Columbia (H12-02311) and the University of Guelph’s Research Ethics Board (12NV014).

3.2.1 Survey

The survey began with questions about farm characteristics (e.g., herd size, years as a licensed producer, average bulk tank shipment, ability to monitor individual milk
production). Producers were then asked about how they managed their milking herd at the end of lactation, including the average length of lactation, the length of the dry period and methods used to decrease milk production (e.g., milking frequency changes, feed restriction, water restriction). Producers were also asked to indicate their top priority when drying off does and to quantify their level of concern for diseases common to the dry period (e.g., IMIs, pregnancy toxemia and ketosis). Producers were encouraged to provide open-ended comments after each set of questions. Where applicable these comments are presented in conjunction with the quantitative responses.

### 3.2.2 Survey dissemination

The survey was disseminated in January of 2013 as a paper-based booklet via post to all the licensed dairy goat milk producers (n = 229) in Ontario, Canada. Follow-up postcards reminding and encouraging producer participation were mailed in mid-February and again at the beginning of April. Producers were given the option to complete the survey over the telephone as well as online via Fluid Surveys (http://fluidsurveys.com).

### 3.2.3 Statistical analysis

Daily milk production per doe per farm was estimated using the equation: mean bulk tank shipment weight/number of milking does/number of days between bulk tank pickups. Descriptive statistics were calculated using PROC UNIVARIATE (SAS 9.2) for daily measures (e.g., farm characteristics, dry period length, length of lactation and number of days in which milking frequency was changed at dry off) and PROC SUMMARY for frequencies (e.g., milking ceased abruptly or by using reduced milking frequency, restriction of water, restriction of feed, top priorities when drying off, concern towards possible health issues). Descriptive results are presented as means and SD.

Mixed models (PROC MIXED) were used to evaluate the effects of a number of factors on both the reported minimum and the maximum dry period length. The effects of the following factors were tested: 1) producers always drying off versus sometimes continuing to milk, 2) abrupt cessation of milking versus reduced milking frequency, 3) feed restriction, 4) concern for IMIs, pregnancy toxemia and ketosis, and 5) top priorities for drying off (number of days until kidding versus milk production). With the exception of health concerns, which were kept as a 5-point scale, all other factors were converted to be a binary variable (e.g., top priority when drying off is either “milk production – 1” or “other – 0” or “number of kids – 1” or “other – 0”). Each factor was tested in its own model and was
included as the fixed effect. Correlation between the fixed effect and the number of does being milked was tested prior to inclusion of the latter as a covariate in each model. The results are presented as means and SED, and line equations. Residuals were used to check for normality, homogeneity of variances and outliers. Outliers were defined as points that were 3 or more times the inter-quartile range away from the first and third quartile; no outliers were noted in these models.

### 3.3 Results

Of the 229 surveys sent, 101 were returned (44% response rate). Table 3.1 reports milking herd size, milk production per doe and the number of years each farm had been licensed to ship milk, as well as the number of producers that answered each of these questions. Almost 50% of farms reported having been licensed for 5 years or less. Plans for expansion in the next 5 years were reported by 53% of the farms, while 39% indicated a desire to stay the same size. The remaining 8% reported that the market would dictate their 5-year plan, or that they may cease raising dairy goats completely.

**Table 3.1. Characteristics of goat farms responding to dry off management survey**

Survey returned by 101 respondents, but sample size varies as not all producers responded to every question.

<table>
<thead>
<tr>
<th></th>
<th>Mean ± SD</th>
<th>Range</th>
<th>Producers (n)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of milking does</td>
<td>210 ± 164</td>
<td>30 – 1100</td>
<td>100</td>
</tr>
<tr>
<td>Mean milk production$^1$ (kg/d/doe)</td>
<td>2.5 ± 0.6</td>
<td>1.4 – 4.2</td>
<td>80</td>
</tr>
<tr>
<td>Years licensed (yr)</td>
<td>8 ± 5</td>
<td>1 – 33</td>
<td>96</td>
</tr>
</tbody>
</table>

$^1$Calculated using mean bulk tank shipment divided by mean number of does milking divided by bulk tank pick up frequency

#### 3.3.1 Dry off management practices

The majority of producers indicated they always aimed to dry off their goats before kidding, but one third of respondents stated that they kept does milking (Table 3.2) when milk production was persistent, and in cases where there was a need for milk or a concern of IMIs. Interestingly, 47% of the producers that indicated that they always aimed to dry off their does commented that continued high milk production was a reason they occasionally did not dry off animals.
Table 3.2. Dry off related management as reported by producers

Survey returned by 101 respondents, but sample size varies as not all producers responded to every question.

<table>
<thead>
<tr>
<th>Method</th>
<th>Yes (%)</th>
<th>Sometimes (%)</th>
<th>No (%)</th>
<th>Producers (n)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Goats are dried off</td>
<td>67</td>
<td>32</td>
<td>1</td>
<td>101</td>
</tr>
<tr>
<td>Reduced milking frequency</td>
<td>51</td>
<td>6</td>
<td>43</td>
<td>83</td>
</tr>
<tr>
<td>employed before dry off</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water restriction</td>
<td>1</td>
<td>4</td>
<td>95</td>
<td>92</td>
</tr>
<tr>
<td>Feed restriction¹</td>
<td>43</td>
<td>-</td>
<td>57</td>
<td>93</td>
</tr>
<tr>
<td>Teat dip</td>
<td>55</td>
<td>-</td>
<td>45</td>
<td>89</td>
</tr>
<tr>
<td>Intramammary antibiotic</td>
<td>-</td>
<td>14</td>
<td>86</td>
<td>84</td>
</tr>
<tr>
<td>Internal/external teat sealants</td>
<td>-</td>
<td>1</td>
<td>99</td>
<td>84</td>
</tr>
</tbody>
</table>

¹The majority of producers that restricted feed did so by reducing quality of feed and amount of concentrate; only 3 producers indicated they withheld feed.

The definition of “high milk production” varied greatly between producers, ranging from a visual assessment to between 0.5 – 4.0 kg/doe/d. Some producers also commented that forcing a high production doe to dry off, particularly close to kidding, was detrimental to the health of the doe and kids. For instance, one producer stated, “In my opinion, these two questions [regarding using water and feed restriction to reduce milk production] are some of the worst things you can do to the doe if you expect healthy and full grown kids. The last few weeks are most important to get healthy kids and best milk production. If a doe's milk production stays up, then I keep milking her”.

To reduce milk production before dry off, over 40% of producers employed some sort of feed restriction (Table 3.2). Often this meant reduced or eliminated concentrate or switching to low quality forage; however, 3 farms indicated they withheld feed or switched does to straw only for up to 5 d. Just 5% of producers reported restricting the water available in order to dry off high production does.

Over half of the producers indicated that they altered milking frequency to encourage does to produce less milk (Table 3.2). Yet, the number of days (Table 3.3) and the pattern of skipped milkings varied between producers. Some producers described elaborate skipped milking routines, including increased intervals for a set number of days. Others took a less formal approach, stating for example, that they “[milk] once a day for awhile, then every other day for awhile, until dry enough”. For the 6% of producers that use both abrupt milking cessation and reduced milking frequency to dry off does, methodology chosen was largely dependent on doe-specific factors, including udder health status (as determined by California Mastitis Test; CMT), and if the does were “drying themselves up” or not (e.g., milking is ceased abruptly for low production does, and milking frequency is reduced in high production does).
Table 3.3. Lactation, dry period, and reduced milking frequency lengths as reported by producers

Length of time does were milked, dry period length and the number of days the milking routine was altered for does before dry off. Most producers indicated a range of number of days, therefore, mean and SD are presented for the minimum and maximum values indicated. Survey returned by 101 respondents, but sample size varies as not all producers responded to every question.

<table>
<thead>
<tr>
<th></th>
<th>Mean Minimum(^1)</th>
<th>Mean Maximum(^2)</th>
<th>Range</th>
<th>Producers (n)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduced milking frequency length</td>
<td>7 ± 4</td>
<td>9 ± 6</td>
<td>1 – 21</td>
<td>35</td>
</tr>
<tr>
<td>length before dry off (d)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dry period length (d)</td>
<td>36 ± 25</td>
<td>57 ± 17</td>
<td>0 – 150</td>
<td>92</td>
</tr>
<tr>
<td>Length of lactation (d)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Primiparous does</td>
<td>313 ± 92</td>
<td>336 ± 102</td>
<td>150 – 760</td>
<td>91</td>
</tr>
<tr>
<td>Multiparous does</td>
<td>342 ± 121</td>
<td>412 ± 212</td>
<td>150 – 1500</td>
<td>86</td>
</tr>
</tbody>
</table>

\(^1\)Smallest number of days in the reported range

\(^2\)Largest number of days in the reported range

Many producers indicated that they utilized a teat dip at dry off, but use of intramammary antibiotics and internal/external teat sealants (e.g., ‘dry off therapy’) was minimal (Table 3.2). In their open-ended responses, only 3 producers discussed udder health issues at dry off. Two of these mentioned using CMT results to guide which does should be given selective intramammary antibiotic therapy at dry off.

3.3.2 Dry period length and length of lactation

Mean dry period length is expressed as a minimum and a maximum (Table 3.3) given that producers noted a range of days. It should be noted that the minimum includes the skipped dry periods from the producers that do not always dry off; if these are removed, the minimum mean and SD is 49 ± 13 dry days. While producers were aiming for lactation cycles of approximately a year in both primiparous and multiparous does, there was a great deal of variability, particularly in the multiparous does. For instance, 6% of the producers indicated they practiced “duration milking” (e.g., milking for as long as the does will produce), particularly for high producing multiparous does; a further 4% said they were actively attempting to manage their does for extended lactations of 2 – 5 years, citing improved health status and avoiding kids as the motivating factors. Interestingly, a few producers openly criticized standard 305 day lactation lengths; for example, one producer stated, “You just don’t choose that route [to force does to dry off]. If you have goats that don’t dry off easily, milk them longer before you breed them back: 400-500 days”. 
3.3.3 Priorities at dry off and concerns for common dry period health concerns

When asked to select their top priority for deciding to dry off a doe, the most popular option was days until kidding (53%). Interestingly, although only 17% of respondents reported having the ability to monitor the milk production of individual does, 46% said that their top priority for making dry off decisions was milk production. One producer indicated that health status was the top priority. Producers ranked their concern for subclinical and clinical IMIs similarly, with approximately one third stating that they were “moderately” or “very” concerned. Over half of the producers were “moderately” or “very” concerned about pregnancy toxemia and ketosis (Figure 3.1).

Figure 3.1. Producer reported concern for common health risks encountered during the dry period

Concern expressed on a 5-point scale. Subclinical IMIs (light grey, n = 90), clinical IMIs, (dark grey, n = 91) and pregnancy toxemia and ketosis (black, n = 90). Survey returned by 101 respondents, but sample size varies as not all producers responded to every question.
3.3.4 Factors affecting dry period length

The majority of dry off practices did not affect dry period length. Minimum (excluding those with skipped dry periods) and maximum dry period lengths were not affected by whether a producer always dried off does or sometimes kept them milking ($P = 0.5$), nor was there an effect of type of milk cessation method used (abrupt cessation of milking versus reduced milking frequency; $P = 0.2$). Producers that used feed restriction versus those that did not (1 vs. 0) before dry off had longer dry periods (44.6 vs. 31.3, SED = 5.1 d; $P = 0.01$); the covariate of number of milking does was a negative influence ($P = 0.002$). Overall line equation for this model was: dry period length (d) = (13.3*feed restriction) – (0.05*does) + 55.0)

No effect of concern for subclinical IMIs, clinical IMIs or pregnancy toxemia and ketosis were noted on minimum and maximum dry period length ($P > 0.4$). When producers listed days until kidding as their top priority for deciding when to dry off does versus the other possible priorities (1 vs. 0), there was a tendency for the minimum dry period length to increase (42.4 vs. 33.2, SED = 5.0 d; $P = 0.07$); the covariate of number of milking does was a negative influence ($P = 0.02$). Overall line equation for this model was: dry period length (d) = (9.2*days until kidding priority) – (0.04*does) + 40.8. Conversely, when producers listed milk production as their top priority for deciding when to dry off does versus the other possible priorities (1 vs. 0), the minimum dry period length decreased (30.9 vs. 41.4, SED = 5.0 d; $P = 0.04$); the covariate of number of milking does was a negative influence ($P = 0.02$). Overall line equation for this model was: dry period length (d) = (-10.5*milk production priority) – (0.04*does) + 49.2. There was no effect of these top dry off priorities on the maximum dry period length.

3.4 Discussion

While some variability exists in how a non-lactating period is achieved in dairy cows, it is considered an established part of dairy cow management. There are numerous benefits with regard to increased milk production when cows are provided a dry period (see review by Bachman and Schairer, 2003) and collectively these benefits likely act as strong motivators affecting the motivation by producers to implement a dry period. In dairy goats, however, the necessity and methodologies of dry off are more ambiguous. A key contributor to this situation is likely milk production persistency seen in some goats (Safayi et al., 2010). In the current study, over a third of producers noted that they managed does according to their milk production, which resulted in some does being dry and other does
skipping the dry period entirely. A further third of the producers indicated that while they aimed to provide a dry period, they did allow persistent goats to continue milking. Indeed, the commentary added by a number of producers highlighted the relatively common opinion that thwarting persistent milk production has negative health consequences for the doe and the kids.

Indeed, metabolic issues were a consideration for the participants in the current study, with over half of the producers expressing that they were moderately or very concerned about pregnancy toxemia and ketosis. This may explain why many producers reported shorter dry period lengths; dairy cow research gives merit to reducing the dry period as a means of reducing the negative energy balance that may lead to ketosis (Rastani et al., 2005; de Feu et al., 2009; Jolicoeur et al., 2014). Recent work with goats found that fewer does developed pregnancy toxemia and ketosis when they were kept milking (Zobel et al., submitted). The negative impacts of a forced dry period on the kids has not been studied, but Laporte-Broux et al. (2011b) reported lower kid BW from does that were fed a restricted diet for the last 60 d of gestation (e.g., the dry period). Unfortunately, in the current study, survey responses did not consistently provide a time period in which feed restriction was utilized. Research is required to assess what level of feed restriction may affect the kids.

Research examining the effect of dry period omission on milk production in goats is minimal and results are mixed. Caja et al. (2006) found that goats that failed to have a dry period showed reduced milk production in the next lactation. Conversely, Fowler et al. (1991) reported no effect on milk yield when a dry period was omitted, albeit on a small group of goats. Given the positive effects of providing a dry period on milk production in dairy cows (Bachman and Schairer, 2003), it is possible that in the current study, the producers that attempted to provide a dry period were assuming that milk production would also be positively affected. However, none of the producers specifically mentioned a concern for next lactation milk production. Unfortunately, we failed to ask producers if they had experience with dairy cow management, as this might have motivated dry off decisions in their goat herds.

Similarly to the reasoning given by producers opting to continue milking high production does without a dry period, there were strong opinions expressed about the importance of allowing milk production persistence of individual does to dictate lactation lengths. This strategy is supported by Salama et al. (2005), who found no negative effect on milk production, and actually found an improvement in milk components, when does
were milked for over 600 d. Extended lactations may have both positive welfare outcomes (e.g., reducing the number of kiddings decreases the likelihood of parturition related diseases, promoting doe longevity), as well as positive economic outcomes (e.g., Lormore and Galligan, 2001).

The mean dry period length in this study ranged from 50 – 60 day, a range similar to that reported for dairy cows (Kuhn et al., 2006), and dairy ewes (Hernandez et al., 2012). Surprisingly a few producers reported that they purposely managed for long dry periods. For instance, producers selling milk seasonally (as has been described in French Lacaune dairy sheep; Barillet et al., 2001) aimed for lactation lengths of as little as 150 d, which would result in long dry periods. Other producers, wanting to avoid a surplus of kids or doe metabolic issues, or those with persistent goats, aimed for multiple years of continued milking. A few of these producers indicated they would provide extended dry periods when necessary. While long dry periods have been linked to reduced milk production in cattle (Kuhn et al., 2006), O’Connor and Oltenacu (1988) argued that longer dry periods may be beneficial for reproductive success, particularly in mature animals.

In the current study, dry period length tended to increase when the producer aimed to dry off does at a preset number of days before kidding. Conversely, dry periods decreased when the producer’s top priority at dry off was milk production. It was not possible to measure milk production at dry off in this study, but clearly future studies should make every effort to quantify milk production if possible. In dairy cows, it has been suggested that a shorter (e.g., 30 d) dry period can still allow for sufficient mammary recovery (Bachman and Schairer, 2003; Kuhn et al., 2006) and has the positive economic effect of providing an extra 30 d of milk (Santschi et al., 2011b). Goat producers drying off based on milk production, and therefore milking longer, may be at an advantage compared to those aiming for a set dry period length.

Regardless of the intended method, the majority of producers reported that at least occasionally they kept does milking because of persistent milk production. In an attempt to reduce milk production before dry off many producers changed feeding routines and a few restricted water. Water restriction will reduce feed intake (Burgos et al., 2001) and in combination reduce milk production. Nonetheless, water restriction is not a recommended practice (CARC, 2003; NFACC, 2009), and raises serious welfare concerns. Changes in feed can cause metabolic disturbance (e.g., goats: Laporte-Broux et al., 2011a; cows: Odensten et al., 2007b) and hunger (cows: Valizahreh et al., 2008), but the types of feed restriction reported in the current study varied considerably. A sudden change to a straw-
based diet would likely cause hunger and perhaps other problems, but a gradual reduction in the percentage of concentrates included in a mixed ration may be less problematic for welfare (but likely also less effective at achieving dry off). We encourage future work on the efficacy and welfare effects of changes in feeding practices at dry off.

Many producers attempted to decrease milk production by reducing milking frequency. Early work in cows demonstrated the effectiveness of this technique at not only reducing milk production (Natzke et al., 1975), but also at improving the immune function of the mammary gland at the time of dry off, when paired with a change in feeding regime (Bushe and Oliver, 1987). Reducing milking frequency before dry off has become less common for dairy cows with the advent of intramammary antibiotics and internal and external teat sealants. Indeed, abrupt cessation of milking coupled with these products (e.g., dry off therapy) is the commonly recommended practice (NMC, 2006) for controlling IMIs in dairy cattle.

Regardless of milk cessation method (abrupt or reduced milking frequency), producers expressed minimal concern about IMIs. About half of the respondents indicated they used teat dip at dry off. Teat dip does not provide the long-term protection against bacteria that is provided by intramammary antibiotics, teat sealers and sealants and only a very small number of producers reported using these products. This low usage is not surprising given that the available scientific evidence only supports its use for IMI treatment, and not prevention (Paape et al., 2001). Furthermore, there is a lack of products specific for use in goats. Moreover, the relatively low prevalence (e.g., 5%; Contreras et al., 2007) of clinical infections (which can be readily identified), coupled with a higher prevalence (e.g., 6.5 – 65%; Contreras, 1999) of subclinical infections (typically asymptomatic), likely results in lower concern of udder health issues in dairy goats, compared to dairy cows.

Motivation for choosing one milk cessation method over another was not specifically targeted in the current survey, but the common theme expressed by many producers (that persistent milk production was encountered, and guided their decisions at dry off) may provide a simple answer: milk cessation method was chosen based on milk production. For instance, producers opting to cease milking abruptly are doing so with goats that are already producing minimal milk, and those that ceased milking gradually are doing this in higher producing goats. Many producers listed milk production levels that they thought were too high to successfully initiate and achieve dry off, but these levels were highly variable, likely because few producers were able to monitor individual milk production. As
previously noted, dairy cow dry off management has witnessed a shift from reduced milking frequency at dry off to an abrupt cessation of milking. Given that this methodology is now receiving criticism due to its potential impacts on animal welfare, it would be prudent and proactive if follow-up work addressed the actual motivation of goat producers for choosing an abrupt versus a gradual milk cessation method, with a particular focus on monitoring milk production levels.

In dairy cows, there is considerable consistency in measures used to achieve dry off; milking is typically ceased abruptly (Blowey and Edmondson, 2010) to achieve predetermined dry period lengths known to promote milk production, and cows are often provided dry cow therapy, to prevent new and treat existing IMIs (NMC, 2006). Feed changes are often employed with the end goal of reducing milk production as quickly as possible (Bushe and Oliver, 1987; Tucker et al., 2009; Ollier et al., 2014). The current study indicates that the dry off procedures are less consistent for dairy goats. Figure 3.2 illustrates the interaction between factors motivating dry off, and the methodology used to achieve it (or in some cases avoid it), as reported by Ontario dairy goat producers.

It is clear that the priority that producers give to a set number of dry period days versus milk production at dry off strongly influences the type of subsequent dry off management that is practiced. Over half the producers indicated their priority was dry period days, however half of these also indicated that they periodically allowed continued milk production of individual does to dictate a deviation from this priority. When this happened, feed restriction, changing milking frequency and water restriction were all mentioned as possible options to reduce milk production. The success of these techniques then dictates whether a dry period is short or completely omitted. The descriptive nature of this study prevented determining how this variability in practices affects important factors such as milk production in the next lactation, and doe and kid health; clearly, on farm work is now necessary to evaluate these effects.
Figure 3.2. Illustration of how producers’ top priority at dry off guides the steps taken to cease milking and achieve a dry period

When achieving a set dry period length is a top priority, dry periods may be longer because the producer will be less likely to employ methodologies to reduce milk production; however, some producers aiming for set dry period lengths, may still attempt to address milk production if it is deemed to be too high. When milk production is the top priority, producers will employ active or passive methods to reduce milk production. When successful, typically a shorter dry period is achieved. When unsuccessful, producers will continue to milk the does, providing no dry period.
3.5 Conclusions

The management of goats at dry off differs considerably from that used in dairy cows. Dry off practices varied among farms and appear to be primarily influenced by milk production persistence. Some producers reported providing dry periods based on milk production, opting to keep high production does milking. Others reported aiming to always provide a dry period, but many of these individuals stated that they occasionally allowed persistent goats to continue milking. Extended lactations were suggested as means for dealing with persistent goats, avoiding an excess of kids and reducing metabolic challenges. Producers that managed for a set number of days until kidding tended to have longer dry periods, while those managing dry off based on milk production had shorter dry periods. Minimal concern for IMIs was reflected in udder care practices at dry off. Concern was higher for metabolic issues like pregnancy toxemia and ketosis. This study demonstrated that many producers are motivated to manage goats according to their milk production, resulting in many goats not following the 305 day annual lactation cycle commonly utilized in dairy cow management.
4 Validation of Data Loggers for Recording Lying Behaviour in Dairy Goats\textsuperscript{2}

4.1 Introduction

Measures of standing and lying behaviour have been used in the assessment of welfare of farm animals in many applications. For instance, in dairy cattle, links have been found between increased standing and mastitis (Medrano-Galarza et al., 2012), claw horn lesions (Proudfoot et al., 2010), overall lameness (Ito et al., 2010) and bedding, cleanliness and flooring (Ito et al., 2014). Less work has been done on dairy goats, but studies to date have used changes in lying behaviour to assess how goats respond to separation and re-integration within groups (Patt et al., 2013), to determine the effects of different stocking densities (Loretz et al., 2004; Andersen and Bøe, 2007), and to evaluate the positive impacts of environmental enrichment (Aschwanden et al., 2009). In the majority of goat studies to date, video and direct observation were used to assess lying and standing time and bouts. Unfortunately, video can be difficult to install in some commercial farms and video recordings are labour intensive to analyze. Live observations may disturb the goats’ behaviour (due to presence of the observer) and again are labour intensive, especially if many animals are followed over an extended period. Data loggers can automate recordings and provide more detailed coverage over a longer period than is typically practical for video or live observations. Patt et al., (2012) utilized data loggers but the authors made no mention of validating these loggers for use on goats.

Data loggers, specifically accelerometers (e.g., devices that record g-force acceleration values) have been readily adopted into research. Several devices are commercially available for use on dairy cows. For instance, the IceTag Sensor (IceRobotics Ltd., Edinburgh, UK) has been successfully used to monitor lying behaviour (Gibbons et al., 2012), but the size of these products makes them unsuitable for use on goats. The HOBO Pendant G data logger (Onset Computer Corporation, Bourne, MA) is smaller and can be used on goats but to date this device has only been validated for use on dairy cows (Ledgerwood et al., 2010) and dairy calves (Bonk et al., 2013). The aim of this study was to validate the use of these data loggers for goats. Our 3 objectives were to: 1) determine appropriate cut-off points for coding lying and standing, as well as lying side, in the raw g-

force data collected by HOBO data loggers, 2) determine a suitable correction factor for dealing with data abnormalities caused by other activities (e.g., perching, scratching and urination), and 3) assess the validity of using the data loggers on both mature, pregnant does, as well as younger, non-milking goats.

4.2 Materials and methods

Two commercial farms in southern Ontario, Canada were enrolled. HOBO Pendant G data loggers were attached vertically (with the rounded base closest to the ground), on the inside of the rear left leg (above the metatarsophalangeal joint) of a subset of goats on each farm. This orientation resulted in the data logger’s x-axis pointing upwards, and the z-axis pointing inwards towards the animal’s leg, with the logger label showing. Attachment was done with veterinary self-adherent bandage (Vetrap, 3M, St. Paul, MN) and pieces of foam to minimize any chafing. Loggers were set to record in 1-min intervals; this allows for more than 3 wks of continuous data collection. Due to the vertical placement of the logger only the g-forces for the x- and z-axes were recorded (the y-axis does not change when the logger is vertically oriented). Logger data were downloaded via HOBOware Pro V3 (Onset Computer Corporation, Bourne, MA) and raw g-force values were exported as CSV files, which were then imported into SAS for further analyses.

On Farm 1, four mature, multiparous Saanen X Alpine does were monitored using video. Prior to monitoring, these does were housed in a group with 30 other late gestation does (approx. 120-130 d); all does were fitted with data loggers. The Video-Monitored does were selected based on differences in colour and ear characteristics (e.g., black, white, grey and La Mancha). During the monitoring period, these four does were moved to a smaller pen (3 x 4 m) immediately adjacent to the home pen. All management remained the same as in the home pen. All goats had ad libitum access to water and a chopped hay and silage mixture. Approximately 100 g of corn and commercial supplement per goat was top dressed 3 times daily. Does were not milking at the time of observation. Two cameras placed above the monitored pen (Panasonic HDC TM-900) recorded video continuously for 3 d. All instances of lying and standing behaviour were coded from the 72 h of video (Observer XT, Noldus Information Technology, Leesburg, VA). All other behaviours with potential to affect the data logger orientation were noted (e.g., perching on back legs, urination and lifting rear legs for scratching). For comparison to logger data, daily values (for each goat on each of the 3 d) were calculated for lying time, lying bouts, and shifts in lying position between left and right sides. Standing behaviour (i.e., time, bouts, bout duration)
was calculated for descriptive statistics only. One 3 h block of video was re-watched to
determine intraobserver reliability for distinguishing between lying and standing events
(Cohen’s kappa = 0.84). Lying and standing behaviours were also measured using loggers
(but not video) for the 30 does remaining in the home pen; these results from the Home Pen
does are provided for descriptive purposes only.

On Farm 2, five Saanen cross doelings (non-bred) and one whether (neutered male)
were housed in a single pen 3 x 6 m bedded with straw. All goats were between 8 – 12 m
old. These animals were approximately half the size of the mature, late gestation does on
Farm 1. All six animals had data loggers attached as described above. Individual animals
were marked with hair dye to facilitate identification on video. Hay was fed twice a day and
*ad libitum* water access was provided. One camera (Panasonic HDC TM-900) recorded
video continuously for 3 d. Lying and standing behaviour was continuously coded from the
video. The full 72 h of video was used to calculate 3 d values for lying time and lying bouts,
for each goat. Differences in lying side (between left and right), as well as perching,
scratching and urination behaviours, could not be reliably coded on this farm due to the
camera’s view angle (constrained by a low ceiling). One 3 h block of video was re-watched
to determine intraobserver reliability for discerning between lying and standing events
(Cohen’s kappa = 0.88).

### 4.3 Results and discussion

#### 4.3.1 Objective 1

The raw data on the x- and z-axis ranged from -3.2 g to 3.15 g. To avoid any data
handling issues caused by negative data points, a value of 3.2 was first added to the raw
data collected by the data loggers (Ledgerwood et al., 2010) resulting in an adjusted range
of 0 – 6.35. To determine appropriate cut-off points, PROC UNIVARIATE (SAS 9.2) was
used to generate separate frequency distributions of the adjusted x- and z-axis values for
the data from Farm 1. Cut-off points established by Ledgerwood et al. (2010) for dairy cattle
were first plotted onto these distributions and used to assist in the visual identification of six
potentially feasible cut-off points for use in goats. Next, the adjusted x- and z-axis values
were converted to binary values, using the potential cut-off points to associate 1 for
standing and 0 for lying (x-axis) and 1 for lying on right side and 0 for lying on left side (z-
axis). This created a 3-day, minute-by-minute dataset for each goat, which were then
combined into datasets for each axis. A rotated logger resulted in the z-axis data of one
goat being discarded from the data for the group of does monitored by video. Video data was also converted into a minute-by-minute binary dataset and merged with the datasets from the data loggers. The final datasets used in the video comparison were comprised of 17280 data points (x-axis) and 12960 data points (z-axis). PROC FREQ (SAS 9.2) was used to determine sensitivity, specificity and percentage of false readings (i.e., when the data logger coded lying as standing and vice versa) for each possible cut-off point (Table 4.1).

Table 4.1. Sensitivity, specificity and false readings between video data and data logger data

Values used to establish cut-off points for the x- and z-axis (Farm 1, Video-Monitored does).

<table>
<thead>
<tr>
<th>Cut-off point1</th>
<th>Sensitivity Value (95% CI) (%)</th>
<th>Specificity Value (95% CI) (%)</th>
<th>False Readings (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>X-axis (lying/standing)2,3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.45</td>
<td>99.1 (98.9-99.3)</td>
<td>98.7 (98.4-98.9)</td>
<td>1.2</td>
</tr>
<tr>
<td>2.55</td>
<td>99.1 (98.9-99.3)</td>
<td>98.8 (98.6-99.0)</td>
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<tr>
<td>2.65</td>
<td>99.1 (98.9-99.3)</td>
<td>98.9 (98.7-99.1)</td>
<td>1.0</td>
</tr>
<tr>
<td>2.75</td>
<td>99.1 (98.8-99.3)</td>
<td>99.0 (98.8-99.2)</td>
<td>0.98</td>
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<tr>
<td>2.85</td>
<td>99.0 (98.7-99.2)</td>
<td>99.0 (98.9-99.3)</td>
<td>0.95</td>
</tr>
<tr>
<td>2.95</td>
<td>98.8 (98.5-99.0)</td>
<td>99.1 (98.9-99.3)</td>
<td>1.0</td>
</tr>
<tr>
<td>Z-axis (left/right)4,5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.025</td>
<td>61.9 (60.1-63.1)</td>
<td>99.7 (99.1-99.9)</td>
<td>33.4</td>
</tr>
<tr>
<td>3.55</td>
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<td>99.8 (99.6-99.9)</td>
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<td>99.4 (99.1-99.7)</td>
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<td>97.8 (97.3-98.3)</td>
<td>1.1</td>
</tr>
<tr>
<td>3.95</td>
<td>99.9 (99.7-100.0)</td>
<td>93.2 (92.4-94.0)</td>
<td>3.4</td>
</tr>
</tbody>
</table>

1All raw g-force data was first adjusted by 3.2 to ensure all values were positive
2Possible test cut-off points were chosen around previously established cut-off point (dairy cows = 2.55; Ledgerwood et al., 2010)
3Total data points = 17280 (4 goats, 3 d, 1440 data points per d)
4We found poor sensitivity when using the previously established cut-off point (dairy cows = 3.025; Ledgerwood et al., 2010) and therefore increased the starting test cut-off point to 3.55 as identified visually from the frequency distribution of the raw z-axis data
5Due to a rotated logger, the z-axis data of one goat was discarded, resulting in total data points = 12960 (3 goats, 3 d, 1440 data points per d)

Best cut-off points were chosen based on the highest sum of sensitivity and specificity, as well as the lowest false readings; these cut-off points were determined to be 2.75 (x-axis) and 3.75 (z-axis). While the standing/lying cut-off point was similar to previously established values in dairy cows (x-axis: 2.55; Ledgerwood et al. (2010), the cut-off point for determining left and right lying side was different (z-axis: 3.025; Ledgerwood et
The reason for this discrepancy is not clear, but may be due to a combination of factors including differences in anatomy, body size, lying posture and bedding. The established cut-off points are suitable for use when the loggers are oriented with the x-axis pointed upwards, and the z-axis pointing inward. If loggers are applied upside down and/or backwards, the raw data must be inversed before the adjustment value of 3.2 (discussed earlier) is added.

4.3.2 Objective 2

Perching on rear legs, lifting rear legs to scratch, and urination can alter the orientation of the rear legs, and potentially result in an apparent transition from standing to lying or vice versa. Since these behaviours often occur for less than 1 min, the 1-min data logging interval avoided capturing many of these erroneous data points; nonetheless, since video analysis revealed that Farm 1 goats spent an average of 19 ± 12 min daily perching on rear legs, lifting rear legs to scratch and/or urinating, it is pertinent to understand the potential impact of these behaviours on the loggers. Therefore, a number of filters were assessed. The raw data from each axis (with value of 3.2 added to ensure all positive numbers) was first converted to binary values using the established cut-off points from Objective 1 and filters were applied to either remove single (1-min event) or double (2-min event) recordings of ‘0’s in a string of ‘1’s or vice versa. Filtered data were then summarized to determine daily lying time and bouts (x-axis), and shifts in lying position between left and right sides (z-axis) for each goat for each filter. Standing behaviours (i.e., time, bouts, bout duration) were also calculated for descriptive statistics only. Next, Pearson correlation coefficients (PROC CORR; SAS 9.2) between video and data logger lying data were used to assess filters. A total of 12 data points (3 d for 4 goats) were used for the x-axis data and 9 data points (3 d for 3 goats, due to a rotated logger) were used for the z-axis data. Use of a 1-min event filter resulted in the best relationships between video and data logger lying data estimates (Table 4.2).
Table 4.2. Pearson correlation coefficients comparing lying behaviour and video

Coefficients calculated between daily lying time, lying bouts, as well as left and right side lying time and bouts recorded from video and from data loggers (Farm 1, Video-Monitored does).

<table>
<thead>
<tr>
<th>Behaviour</th>
<th>No filter</th>
<th>1-min filter</th>
<th>2-min filter</th>
</tr>
</thead>
</table>
| Lying (x-axis)
| Time              | 1.0***    | 1.0***       | 1.0***       |
| Bouts              | 0.65*     | 1.0***       | 0.92***      |
| Lying side (z-axis)
| Side changes      | 0.85**    | 0.99***      | 0.99***      |
| Right side time    | 1.0***    | 1.0***       | 1.0***       |
| Right side bouts   | 0.69*     | 0.98***      | 0.98***      |
| Left side time     | 1.0***    | 1.0***       | 1.0***       |
| Left side bouts    | 0.93***   | 0.99***      | 0.93**       |

1Logger data filtered to remove single observations (1-min event)
2Logger data filtered to remove double observations (2-min event)
3Daily behaviours for 3 d of data for 4 goats (n = 12)
4Due to a rotated logger, z-axis data from one goat was discarded, resulting in 3 d of data for 3 goats (n = 9)
* P < 0.05, ** P < 0.01, *** P < 0.0001

The data filters were also assessed using plots of the difference between the two measurement methodologies against their mean, following Bland and Altman (1986) (Figure 4.1). For lying time, the lowest mean difference between video and data loggers (-2.3 ± 3.0 min) was found with the 1-min filter. While a mean difference of 0 min would be ideal, the relative flexibility of goats in their leg position while lying meant that on a few occasions some data points were very close to the cut-off point; this in turn resulted in a few lying points (often at the end of a lying bout when a goat was rising and stretching) being recorded incorrectly by the logger. Using either no filter, or the 2-min filter, resulted in larger mean differences (-4.3 ± 3.5 min and -4.6 ± 3.4 min, respectively). Similarly, the 1-min filter also resulted in the lowest mean difference between video and data loggers for lying side changes (0.2 ± 0.8 changes). As anticipated, applying no filter resulted in a larger negative mean difference between video and data loggers for lying side changes (-7.9 ± 2.7 changes). Applying the 1-min filter allowed for removal of some perching, scratching and urination events that the data logger would otherwise incorrectly code as a lying event. Because goats are relatively active, with numerous shifts between standing and lying and between left and right side lying changes, applying the 2-min filter resulted in the data loggers underestimating the number of lying side changes (mean difference: 0.8 ± 1.1 changes).
Figure 4.1. Bland Altman plots comparing the difference in means recorded by video and by loggers for lying time and lying side changes

Difference in means (video - data logger) plotted for lying time (A, B, C) and lying side changes (D, E, F), using no filter (A, D), a 1-min event filter (B, E) and a 2-min event filter (C, F). A solid line indicates mean difference and dotted lines represent 2 SD from the mean difference. The x-axis shows the average of video and data logger values. Lying time (x-axis) data is for 3 d from 4 goats (n = 12) and lying side changes (y-axis) is for 3 d from 3 goats (n = 9) due to a rotated logger on one goat. (Farm 1, Video-Monitored does).
Other measures followed a similar pattern; all benefited most from the 1-min filter (lying bouts: 0.5 ± 0.8; left side lying time: 1.0 ± 5.9; left side bouts: 0.1 ± 0.3; right side lying time: -3.4 ± 4.5; right side lying bouts: 0.1 ± 0.8). For right and left side lying time, we observed one outlier that the logger coded as 12 min on the right side but video showed that the goat was lying on her left side (plots not shown). This was the only such outlier on the Bland Altman plots and video analysis showed that the goat was lying in an atypical position (with legs outstretched behind her).

The complete minute-by-minute dataset, filtered using the 1-min filter, PROC FREQ (SAS, 9.2) was utilized to determine sensitivity, specificity and percentage of false readings between x-axis standing (1) and lying (0), as well as z-axis left side lying (1) and right side lying (0), from the video versus the data loggers. Data loggers showed high sensitivity and specificity and low false readings (x-axis: sensitivity = 99.7%, specificity = 99.5%, false readings = 0.43%; z-axis: sensitivity = 99.9%, specificity = 99.3%, false readings = 0.38%).

Table 4.3 shows descriptive statistics for all the measured lying and standing behaviours for the four Video-Monitored does, as well as the 30 does which remained in the adjacent home pen from which the four does was chosen.

**Table 4.3. Descriptive statistics for daily lying and standing behaviours**

Behaviour means calculated using 3 d of data per goat, for both the does monitored by video and the remaining group of goats from which these monitored does were chosen (Farm 1).

<table>
<thead>
<tr>
<th>Behaviour</th>
<th>Video-Monitored Does</th>
<th>Home Pen Does</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>Lying/standing (x-axis)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lying time (min)</td>
<td>870</td>
<td>61</td>
</tr>
<tr>
<td>Lying bout duration (min/bout)</td>
<td>62</td>
<td>20</td>
</tr>
<tr>
<td>Standing time (min)</td>
<td>571</td>
<td>61</td>
</tr>
<tr>
<td>Standing bout duration (min/bout)</td>
<td>40</td>
<td>15</td>
</tr>
<tr>
<td>Lying/standing bouts (#)</td>
<td>15</td>
<td>5</td>
</tr>
</tbody>
</table>

| Laterality (z-axis)              |       |       |         |       |       |         |
| Lying side changes (#)           | 24    | 5     | 18-35   | 21    | 5     | 10-34   |
| Right side lying time (min)      | 399   | 100   | 264-523 | 432   | 117   | 143-921 |
| Right side lying bouts (#)       | 11    | 4     | 7-19    | 11    | 3     | 3-18    |
| Left side lying time (min)       | 468   | 89    | 347-616 | 440   | 113   | 670-42  |
| Left side lying bouts (#)        | 13    | 2     | 10-16   | 11    | 3     | 3-20    |

1Data for 3 d of behaviour of the 4 Video-Monitored does (n = 12 for lying/standing, x-axis; due to 1 rotated logger, n = 9 for laterality, z-axis)
2Data for 3 d of behaviour of 30 does which remained in the home pen from which Video-Monitored does were chosen (n = 90 for lying/standing (x-axis); due to 6 rotated loggers, n = 72 for laterality, z-axis)
Higher lying times (14.5 ± 1.0 h/d, Video-Monitored does; 14.5 ± 1.4 h/d, Home Pen does) were found compared to previous goat work (e.g., 12 h/d in Patt et al. (2013) from direct observation) and dairy cow work (e.g., 11-12 h/d in Ito et al. (2009) from loggers). The difference may be explained by stage of gestation of the goats; the goats were in late gestation and therefore likely motivated to spend more time lying down.

Lying bouts and lying bout duration in dairy cows are typically calculated under the assumption that at least 1 min of standing occurs between each lying bout (allowing for the total number of lying bouts to be a sum of left and right side lying bouts). This approach is justified since these animals generally have relatively long lying bout durations and standing events intersecting changes in lying sides. However, video from the current study showed that dairy goats differed from cows in the way they shifted between lying bouts and left and right lying sides, perhaps due to a difference in housing as well as size compared to dairy cattle. Goats frequently shifted between left and right lying sides within the same lying bout, and they often did this very quickly (on average just 8 ± 5 sec) by rising on their rear legs and dropping to the opposite side. Shifts in lying sides were also associated with brief (41 ± 12 sec) standing events triggered by urination and defecation. Both of these types of events averaged less than 1 min and thus would often be missed by data loggers set to record every minute. Rather than having a standing bout between each side change, as is typically seen in cows, the logger data in goats would shift abruptly from one side to another. Therefore, methods used for calculating lying bouts in dairy cows (i.e., sum of left and right lying bouts) would overestimate the actual number of lying bouts in goats. We calculated lying bouts according to the x-axis data (e.g., changes between lying and standing events), and the sum of shifts between right and left lying sides (recorded on the z-axis) was referred to as lying side changes.

Lying bout duration (i.e., daily lying time / daily number of lying bouts) has been used as a possible indicator of potential discomfort in cattle (Gomez and Cook, 2010; Ito et al., 2014), but we suggest caution when interpreting this measure in goats. For instance, the four Video-Monitored does assessed on Farm 1 had an average lying bout duration of 62 ± 20 min/bout (and 73 ± 19 min/bout for the Home Pen does); these values are less than bout durations reported for cows (88 ± 30 min; Ito et al., 2009), but still suggestive of goats lying for long periods of time. However, a frequency distribution plot of bout durations (Figure 4.2) for all of Farm 1 goats showed that there was a large number of small values; the adult does were very active and had many short lying bouts. Video-monitored does on Farm 1 had an average of 15 ± 5 lying bouts and 24 ± 5 shifts between left and right sides; does
from the home pen on this farm had an average of 12 ± 4 lying bouts and 21 ± 5 shifts between left and right sides. The calculated average of lying bout duration failed to reflect the level of activity shown by the shift between lying sides. This may be due to goats being smaller and lying on a bedded pack, making it possible for them to shift lying orientation without rising. The number of daily lying side changes, and perhaps side changes within a bout, may be a better indicator of restlessness or discomfort.

Figure 4.2. Frequency distribution of lying bout durations of mature dairy goats
Lying bouts from 34 adult dairy goats over 3 d (Farm 1, Video-Monitored does and Home Pen does), plotted in 10-min bins. Does were extremely active, and split their daily lying times into many short lying bouts (e.g., less than 10 min in length).

Data logger application is a challenge. Care is needed to avoid too much tension (resulting in circulation issues) and not enough tension (resulting in logger rotation). On Farm 1, where laterality was measured, we noted some data logger rotation around the goats’ legs (1 out of 4 loggers rotated in our Video-Monitored does, and 6 out 30 loggers rotated on the Home Pen does). Such rotation does not affect lying and standing measures, but prevents laterality calculations, as the z-axis data is unreliable. To ensure that z-axis data has not been confounded by rotation, we strongly recommend that frequency distributions for each logger’s z-axis data be plotted and compared against the established cut-off points. Logger data that does not show a clear bimodal distribution (Figure 4.3) should not be used in laterality calculations.
Figure 4.3. Frequency distributions of z-axis data for a correctly positioned logger and a rotated logger

Adjusted z-axis data for two data loggers over 3 d, plotted in 0.05 bins. Logger A did not rotate around the goat's leg, and has a clear bimodal distribution at the established cut-off point of 3.75 (arrow). Logger B rotated around the goat's leg, and lacks a clear bimodal distribution at the established cut-off point of 3.75 (arrow).

4.3.3 Objective 3

Our final objective was to validate the loggers on the younger animals followed on Farm 2. The cut-off points established in Objective 1 were again used to convert the data into binary values and a 1-min filter was used to remove erroneous data. PROC FREQ (SAS, 9.2) was then used to determine sensitivity, specificity and percentage of false readings between standing (1) and lying (0) from the video versus the data loggers, using the minute-by-minute data for six goats. Three days of data were compared, except in the case of one goat for which there was only 2 d of data due to a data logger battery failure (total data points = 24480). Data loggers had high sensitivity (99.8%) and specificity (99.4%) and low false readings (0.36%). Descriptive statistics of daily lying time and lying bouts were also calculated. The young goats averaged 8.5 ± 3.2 h/d lying spread over 8 ± 4 bouts/d. One goat stood for a very long time each day; when this goat was removed from the calculation, the average lying time was 9.4 ± 1.6 h/d. Overall, the loggers provided accurate measures of lying time and bouts in younger goats when compared to the video.
4.4 Conclusions

The broad aim of this study was to validate data loggers for monitoring lying behaviour in goats. More specifically, we identified goat-specific cut-off points for g-force acceleration data points recorded on the x- and z- axes and determined the best filter for erroneous data. Using the cut-off points and filter established, we showed that the loggers could record lying behaviour in both mature, pregnant does and younger (8–12 mo) goats. Left and right side lying position was established for the mature does; however, caution during application of the loggers was necessary to prevent adversely impacting circulation, while at the same time preventing rotation of the logger around the leg. Overall, we determined that the loggers are appropriate for use in goats to record lying behaviour.
5 Ketonemia in Dairy Goats: Effect of Dry Period Length and Impact on Lying Behaviour

5.1 Introduction

The transition between lactations is a challenging time for dairy animals in commercial production systems. A number of management practices (e.g., feed changes, cessation of milking, dry period length), as well as the physiological transitions between lactational and non-lactational states and vice versa, have the potential to negatively affect welfare. A dry period is generally recognized as important for achieving optimal milk production in cows (Bachman and Schairer, 2003) and ewes (Hernandez et al., 2012), and in some cases does (Caja et al., 2006); its positive effect on metabolic health is less certain.

The end of the dry period and the beginning of the next lactation are frequently associated with a period of negative energy balance. This can be a consequence of increasing energy requirements of the growing fetus(es) before parturition, as well as from the increasing metabolic demands of milk production after parturition. Although many animals are able to cope and recover from negative energy balance by metabolizing body fat, some animals metabolize too much fat, become overwhelmed with the associated by-products (e.g., non-esterified fatty acids (NEFAs) and ketone bodies), and develop pregnancy toxemia (before parturition) and ketosis (following parturition). While ketosis may persist subclinically in cows, creating milk production losses (e.g., Rajala-Schultz et al., 1999, Goldhawk et al., 2009), pregnancy toxemia is often fatal in does and ewes if not diagnosed in a timely manner (e.g., Rook, 2000; Lima et al., 2012). In cows, the link between short or no dry periods and reduced risk of ketosis is clear (Rastani et al., 2005; de Feu et al., 2009). The metabolic health impact of carrying multiple fetuses (Forbes, 1968; Navarre and Pugh, 2002), and of poor quality or restricted feed during the dry period (Laporte-Broux et al., 2011a), are well known in does and ewes. However, the effect of dry period length has received little attention in these species.

Lethargy is commonly cited as a symptom of ketosis in cows, but evidence of reduced activity in sick animals has only recently been described (Itle et al., 2014). No similar evidence exists for does and ewes. Identifying when metabolically challenged animals begin showing behavioural changes might help with early identification. This approach could be particularly important in small ruminants, since prognosis is poor by the stage at which clinical symptoms are documented. The majority of behavioural monitoring of goats to date has used either live observation (Loretz et al., 2004; Patt et al., 2013) or
video (Loretz et al., 2004, Aschwanden et al., 2009). These methodologies have limited application in large commercial settings. Accelerometer-based data loggers are efficient in monitoring activity levels in cows (e.g., Ito et al., 2009; Medrano-Galarza et al., 2012), but to date their application in goats have been minimal (e.g., Patt et al., 2012), and they have not been applied during kidding or to assess health status.

The aims of this study were to assess the how does with pregnancy toxemia and ketosis vary in regards to provision of a dry period and dry period length, as well as to explore the merits of using changes in lying behaviour (as assessed using data loggers) as early indicators of these metabolic states in dairy goats.

5.2 Materials and methods

This study was conducted in accordance to the University of British Columbia’s Animal Care Certificate A12-0249 and the University of Guelph’s Animal Use Protocol 1636 as well as the Behavioural Research Ethics Board at the University of British Columbia (H12-02311) and the University of Guelph’s Research Ethics Board (12NV014).

5.2.1 Farms and animals

Ten commercial dairy goat farms in southern Ontario, Canada participated in this trial. At the time of enrolment, farms were milking on average ± SD 326 ± 176 does (range: 100 – 650 milking does). From these farms, a total of 420 multiparous, late gestation does (mean ± SD: 42 ± 18 does/farm) were enrolled. Of these, 231 does were still milking and 189 does were already in the dry period. Most does were cross-bred, and were predominantly Saanen, Alpine and La Mancha; one farm was composed entirely of the Saanen breed. Does were cared for according to each farm’s established management protocols, and no changes to housing or general care were made by the research team. Feeding practices fell into one of three broad categories: 1) mixed forage supplemented with grain or concentrate, 2) total mixed ration (TMR), or 3) complete pellet supplemented with straw and/or hay. All farms dried off their does late in lactation, but one farm employed selective dry off management, keeping high producing does milking.

5.2.2 Lying behaviour

Approximately 2 wks before each doe’s anticipated kidding date, a HOBO Pendant G data logger (Onset Computer Corporation, Bourne, MA) was attached vertically to a rear leg above the metatarsophalangeal joint using self-adherent veterinary bandage (Vetrap, 3M, St. Paul, MN) and foam pieces. Loggers were set to record at 1-min intervals. Loggers
were removed and replaced every 21 d until approximately 2 wks of lying behaviour before and after kidding was collected for each doe. Data were summarized according to the methodology outlined in Zobel et al. (in press) to calculate daily lying time and lying bout frequency for each doe. Early kiddings, doe deaths, logger failures and lost loggers resulted in an average of 19 ± 4 d of logger data per doe.

5.2.3 Ketonemia

Pregnancy toxemia and ketosis are associated with ketonemia, or elevated blood β-Hydroxybutyrate (BHBA). BHBA was measured using a Precision Xtra meter (Doré et al., 2013; Pichler et al., 2014) on blood samples collected via jugular venipuncture. Samples were collected at least once before kidding; if a doe did not kid within 14 d of her first sample, a second sample was taken. Samples used to establish pre-kidding BHBA levels were collected on average 7 ± 4 d before kidding. The first post-kidding sample was taken 9 ± 4 d after kidding. Any doe with elevated BHBA level (BHBA = 0.9 – 1.6 mmol/L) (Ramin et al., 2005) was flagged and sampled again every 5 ± 2 d until BHBA either dropped below this threshold, or until it reached clinical levels (BHBA ≥ 1.7 mmol/L). On average, these does with elevated BHBA levels were sampled 2.6 ± 1.1 times. Prevalence of does that only had elevated BHBA levels (BHBA = 0.9 – 1.6 mmol/L; n = 104) was calculated for descriptive purposes, but these does were not included in the final analysis. The final, complete dataset contained the remaining does categorized into the following groups: HEALTHY (both pre- and post- kidding samples BHBA < 0.9 mmol/L; n = 243), PREGTOX (pre-kidding BHBA ≥ 1.7 mmol/L; n = 15, includes 2 does which had BHBA ≥ 1.7 mmol/L before and after kidding) and KETOSIS (post-kidding BHBA ≥ 1.7 mmol/L; n = 58). A total of 11 does died during the trial (PREGTOX, n = 7 does, KETOSIS, n = 2 does, and 2 does that died of other causes).

5.2.4 Dry period length, dry period provision and milk production

Dry period length was recorded for 227 does on 8 of the farms. Producers also provided the dry period length they intended to achieve. Daily milk production was recorded following kidding using computerized milking equipment matched with management software on 4 farms, and matched with manual, paper-based recording on 3 farms. One of these farms housed kids together with the does, resulting in low milk production after kidding. Three farms were not able to provide milk production data. Daily milk production for the first two weeks after kidding was used to calculate a single mean milk production value for each doe for that two-week period.
5.2.5 Statistical analysis

5.2.5.1 Feeding practices

The complete dataset (HEALTHY, n = 243; KETONEMIC, n = 73, combination of PREGTOX and KETOSIS) was used to test the effect of feeding practice on health status. A logistic regression (PROC GLIMMIX) with a binary distribution and a Logit link function was used. Health status was included as a fixed effect, and doe nested within farm was the random effect. The number of kids a doe was carrying was included as a covariate. The logit-transformed results have been back-transformed and are presented as means and 95% confidence intervals (CI), and include an odds ratio for the odds of an animal being sick, based on the farms feeding management practice.

5.2.5.2 Dry period length, dry period provision and milk production

Does with dry period length and milk production values were identified from the complete dataset. This information was used to create a sub dataset containing 147 does from 7 farms, where each doe had a dry period length and a health status (HEALTHY, n = 119; KETONEMIC, n = 28, includes PREGTOX and KETOSIS). Complete milk production was missing for 8 does, resulting in a slightly smaller sub dataset for milk production (HEALTHY, n = 115; KETONEMIC, n = 24).

After removing all does which did not receive a dry period (e.g., dry period length of 0 days; does which were continuously milked, either by accident or planned on one farm; n = 19), the relationship between health status (healthy or ketonemic) and dry period length was assessed with a mixed model in SAS (PROC MIXED). Health status was the fixed effect and the farm’s feeding practice and the number of kids a doe was carrying were included as covariates. Parity of does and milk production for the previous lactation were unavailable. Doe nested within farm was designated as the random effect. The residual term of the model was doe and the error term was doe nested within farm. The effect of health status (healthy or ketonemic) on milk production following kidding was assessed using a similar model, except that the does that did not have a dry period (n = 19) were included, and that dry period length was also included as a covariate. The results are presented as means and SED, and line equations.

One farm from the above dataset managed does on an individual animal level and opted to not provide a dry period, when late lactation does were producing more than 1 kg/d. The does on this farm were given a binary categorization of their dry period status: 0 (no dry period, n = 16) or 1 (dry period, n = 28). To test the effect of provision of a dry
period (continuous milking through to kidding versus a dry period of any length) on health status (healthy or ketonemic), a 2-tailed Fisher’s exact test was performed.

5.2.5.3 **Lying time and lying bout frequency**

After removing 11 does that did not have logger data, the HEALTHY does on all 10 farms (n = 232), were used in mixed models (PROC GLIMMIX, SAS 9.2) to test the fixed effect of day relative to kidding on lying time and lying bout frequency, with doe nested within farm as a random effect. Farm feeding practice and the number of kids a doe was carrying were included as covariates. Covariance structure auto-regressive type 1 (AR1) was chosen for the lying time model, according to the smallest Aikake’s Information Criterion, and covariance structure variance components (VC) was chosen based on a Chi-Square/DF ratio close to 1.0 (lying bout frequency). Least squares means and SEM were plotted for lying time by day relative to kidding and least squares means and 95% CI were plotted for lying bouts by day relative to kidding; based on these plots, contrast statements were written to test the mean differences between d of interest surrounding kidding (d-2, d-1, d0, d1, d2), and 5 periods were then identified for use in the health status models: P-2 (d-12 to d-2 relative to kidding), P-1 (d-1 relative to kidding), P0 (d0, kidding day), P1 (d1 relative to kidding) and P2 (d2 – d12 relative to kidding).

Separate datasets were created for testing health status and lying behaviour, since it was anticipated that differences would exist between does which became ill prior to kidding (pregnancy toxemia) and does that became ill following kidding (ketosis). Five does with insufficient data logger data were removed (1 doe with pregnancy toxemia died with only 1 day of data and 4 does with ketosis had failed or missing loggers). Final datasets contained 232 healthy does and 14 pre-kidding ketonemic does (PREGTOX) and 54 post-kidding ketonemic does (KETOSIS).

Mixed models (PROC GLIMMIX, SAS 9.2) were used to assess the effect of health status (healthy or ketonemic) on lying time (Gaussian distribution with Identity link function) and lying bout frequency (Poisson distribution with a Log link function) for both PREGTOX and KETOSIS datasets. Health status (healthy or ketonemic) was included as a fixed effect, and doe nested within farm and period nested within doe were random effects. The number of kids a doe was carrying was included as a covariate. An interaction between health status and period was tested. Differences between health status on each period were tested post-hoc using Dunnett’s 2-tailed tests. For lying time, results are presented as means and SED and line equations. For lying bout frequency, the logit-transformed results
have been back-transformed and are presented as means and 95% confidence intervals (CI). The residual term of the models was period nested within doe and the error term to test the effect of health status was doe nested within farm. Based on the best-fit statistics, auto-regressive type 1 (AR1) covariance structure was selected for KETOSIS models and variance components (VC) covariance structure was selected for PREGTOX models.

For all models, residuals were calculated and examined for normality and homogeneity of variances. Possible outliers were also identified using residuals; data points that were 3 or more times the inter-quartile range away from the first and third quartile were considered outliers. Based on this method, the HEALTHY dataset (n = 232), used to illustrate typical doe lying behaviour around kidding, had 11 outliers removed (7 from the lying time model, and 4 from lying bout frequency model). The KETOSIS dataset had 1 outlier removed from the lying time model.

5.3 Results

5.3.1 Prevalence of ketonemia

All but one farm had some prevalence (22 ± 13%, range = 0 – 48%) of elevated BHBA levels (BHBA = 0.9 – 1.6 mmol/L). In regards to ketonemia (BHBA ≥ 1.7 mmol/L), some farms had reasonably low prevalence of ketonemia before kidding (n = 5 farms; PREGTOX mean ± SD: 4 ± 6%, range = 0 – 15%) and after kidding (n = 8 farms; KETOSIS mean ± SD: 14 ± 15%, range = 0 – 50%). One farm avoided all issues, with no elevated BHBA levels, and no ketonemia before and after kidding. Overall, ketonemia following kidding (n = 58 does) was more prevalent than before kidding (n = 15 does). Figure 5.1 illustrates prevalence of ketonemia across farms grouped according to feeding practice. Both the number of kids a doe was carrying, and the farm’s feeding practice affected health status. The odds of does becoming ketonemic when carrying triplets compared to singles or twins were greater by a factor of 2.4 (95% CI: 1.1 – 5.2); \( P = 0.04 \), while the odds of does becoming ketonemic on farms feeding a complete pellet diet compared to those feeding a total mixed ration or forage supplemented with concentrate were greater by a factor of 4.5 (95% CI: 1.0 – 20.1; \( P = 0.05 \)).
Figure 5.1. Prevalence of ketonemia before and after kidding on each farm

Prevalence of ketonemia (blood BHBA ≥ 1.7 mmol/L) before kidding (PREGTOX; n = 15) or after kidding (KETOSIS; n = 58) on 10 commercial dairy farms (total does enrolled = 420). Does with blood BHBA < 0.9 mmol/L classified as HEALTHY (n = 243) and those with elevated levels (blood BHBA 0.9 – 1.6 mmol/L; n = 104) are not shown on graph.

5.3.2 Dry period length, provision of a dry period and milk production

All but one farm indicated they aimed for a 60 d dry period. The observed dry period ranged from 0 – 109 d dry (mean ± SD: 40 ± 22 d). Excluding the does that were not provided a dry period, does that stayed healthy before and after kidding had shorter dry periods compared to does that developed ketonemia (43 vs. 55 ± 4 d; \( P = 0.002 \)). The type of feed a farm was feeding and the number of kids a doe was carrying did not influence the model (\( P > 0.4 \)). On the farm that opted to keep some of its does milking, while giving other does dry periods, there were more ketonemic does (both PREGTOX and KETOSIS) in the dried off animals (11/28 does) compared to those that were kept milking (1/16 does) (Fisher’s exact test, \( P = 0.04 \)).

Milk production was negatively affected by health status, the type of feed a farm was feeding, and the number of days in the dry period. The overall line equation for this model
was: milk production (kg/d) = –(0.5*ketonemic) – (0.7*complete pellet feeding) – (0.01 days in dry period) + 3.8) ($P = 0.04$). The number of kids a doe was carrying did not affect milk production in the first two weeks of lactation ($P > 0.5$).

5.3.3 Lying behaviour

Healthy does on all 10 farms maintained their lying time until d-1, at which point they spent less time lying. Soon after kidding, they returned to their pre-kidding levels (Figure 5.2). On average, does carrying triplets lay longer than does carrying singles or twins (15.1 vs. 14.1, SED = 1.0; $P = 0.02$). There was an increase in lying bouts as does neared kidding (lying bouts/d = 0.36 $d$ + 19.5; $P < 0.0001$), with the greatest increases on d-1 and d0 (Figure 5.3). There was no effect of number of kids a doe was carrying on lying bouts. The type of feed a farm fed was not influential to either lying time or lying bout frequency of healthy does.

![Figure 5.2. Mean daily lying time for healthy does before and after kidding](image)

**Figure 5.2. Mean daily lying time for healthy does before and after kidding**

Daily lying time for 12 d prior to and 12 d following kidding for healthy does with lying behaviour data from all 10 farms (no ketonemia for the entire study; blood BHBA < 0.9 mmol/L; $n = 232$). SEM is from model testing effect of day relative to kidding on daily lying time.
In does that became ketonemic before kidding (PREGTOX), there was an overall difference (15.5 vs. 12.8 h/d, SED = 0.9; \( P = 0.002 \)) in the lying time compared to the healthy does. Does with ketonemia before kidding spent more time lying down during all periods (Table 5.1). Does carrying triplets tended to have longer lying times by an 1.0 h/d (\( P = 0.07 \)). The type of feed farms were feeding did not have an effect on the model.

### Table 5.1. Mean daily lying time for does with ketonemia before kidding (pregnancy toxemia) compared to healthy does

Mean daily lying time of does with ketonemia (blood BHBA ≥ 1.7 mmol/L) before kidding is compared to daily lying time of does that maintained normal levels (blood BHBA < 0.9 mmol/L) for the entire study. Due to doe deaths, the comparison was only possible for the first 3 periods relative to kidding.

<table>
<thead>
<tr>
<th>Period relative to kidding</th>
<th>Ketonemic (( n = 14 )) Lying time (h/d)</th>
<th>Healthy (( n = 232 )) Lying time (h/d)</th>
<th>SED</th>
<th>( P )-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>-2(^a)</td>
<td>17.7</td>
<td>15.4</td>
<td>1.0</td>
<td>0.02</td>
</tr>
<tr>
<td>-1(^b)</td>
<td>16.0</td>
<td>13.2</td>
<td>1.1</td>
<td>0.02</td>
</tr>
<tr>
<td>0(^c)</td>
<td>13.0</td>
<td>9.8</td>
<td>1.1</td>
<td>0.005</td>
</tr>
</tbody>
</table>

\(^a\) Period -2: mean of d -12 to -2 relative to kidding

\(^b\) Period -1: d-1 relative to kidding

\(^c\) Period 0: d0, kidding day
There was no interaction between period relative to kidding and health status (healthy or ketonemic) in terms of lying time. Furthermore, while there was no difference between ketonemic and healthy does in the frequency of daily lying bouts before kidding, all does increased the number of lying bouts between P-2 and P-1 ((Mean (95% CI): 16.8 (15.8 – 17.8) vs. 20.5 (19.4 – 21.8) bout/d; \( P < 0.0001 \)). The number of kids a doe was carrying did not affect lying bouts (\( P > 0.6 \)).

In does that developed ketonemia after kidding (KETOSIS), overall lying time was higher compared to does that stayed healthy throughout the study (14.5 vs. 13.5 h/d, SED = 0.5; \( P = 0.02 \)). There was an interaction between period and health status (\( P = 0.03 \)), with ketonemic does lying down more on the days around kidding (P-1, P0 and P1) (Table 5.2). Does which were carrying triplets lay down 1.3 h/d more than those carrying singles or twins (\( P = 0.004 \)). The farm’s feeding practice also affected the model, with does on complete pellet feeds lying nearly an hour longer compared to does on farms feeding total mixed rations or forage supplemented with concentrate (\( P = 0.01 \)). In regards to lying bout frequency, there was a tendency for ketonemic does to get up and down less frequently than healthy does during P-2 (mean and 95% CI): 14.8 (13.2 – 16.6) vs. 16.8 (15.9 – 17.7); \( P = 0.06 \) and P-1 (mean and 95% CI): 18.3 (16.2 – 20.6) vs. 20.4 (19.3 – 21.6); \( P = 0.09 \)). The farm’s feeding type and the number of kids a doe was carrying did not affect lying bouts (\( P > 0.5 \)).

**Table 5.2. Mean daily lying time for does with ketonemia after kidding (ketosis) compared to healthy does**

Mean daily lying time of does with ketonemia (blood BHBA ≥ 1.7 mmol/L) after kidding is presented and compared over 5 periods to the lying time of does that maintained normal levels (blood BHBA < 0.9 mmol/L) for the entire study.

<table>
<thead>
<tr>
<th>Period relative to kidding</th>
<th>Ketonemic (n = 54)</th>
<th>Healthy (n = 232)</th>
<th>SED</th>
<th>( P )-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Lying time (h/d)</td>
<td>Lying time (h/d)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-2&lt;sup&gt;a&lt;/sup&gt;</td>
<td>16.2</td>
<td>15.7</td>
<td>0.5</td>
<td>0.34</td>
</tr>
<tr>
<td>-1&lt;sup&gt;b&lt;/sup&gt;</td>
<td>14.7</td>
<td>13.5</td>
<td>0.5</td>
<td>0.05</td>
</tr>
<tr>
<td>0&lt;sup&gt;c&lt;/sup&gt;</td>
<td>12.2</td>
<td>10.2</td>
<td>0.6</td>
<td>0.001</td>
</tr>
<tr>
<td>1&lt;sup&gt;d&lt;/sup&gt;</td>
<td>13.7</td>
<td>12.5</td>
<td>0.6</td>
<td>0.03</td>
</tr>
<tr>
<td>2&lt;sup&gt;e&lt;/sup&gt;</td>
<td>15.5</td>
<td>15.2</td>
<td>0.5</td>
<td>0.54</td>
</tr>
</tbody>
</table>

<sup>a</sup> Period -2: mean of d -12 to -2 relative to kidding
<sup>b</sup> Period -1: d-1 relative to kidding
<sup>c</sup> Period 0: d0, kidding day
<sup>d</sup> Period 1: d1 relative to kidding
<sup>e</sup> Period 2: mean of d2 to d12 relative to kidding
5.4 Discussion

Pregnancy toxemia and ketosis have a variety of physical signs, such as ataxia, reduced activity levels, teeth grinding, and anorexia (Menzies and Bailey, 1997; Brozos et al., 2011). However, these signs are often associated with other diseases, making blood and urine ketone body levels (e.g., as indicated by elevated β-hydroxybutyrate, BHBA; ketonemia and ketonuria, respectively) helpful in reaching a diagnosis. This study measured ketonemia using on-farm blood testing. There is some debate about the precise levels of BHBA that should be considered diagnostic. For example, Marteniuk and Herdt (1988) defined severe pregnancy toxemia and ketosis as BHBA above 3.0 mmol/L. Ramin et al. (2005) used blood BHBA levels between 0.8 and 1.6 mmol/L to indicate subclinical pregnancy toxaemia. Ismail et al. (2008) used 0.86 mmol/L as a threshold for subclinical pregnancy toxemia. In the current study, does that died had a mean blood BHBA of 5.0 mmol/L and ranged from 1.7 to 6.9 mmol/L. Given this combined evidence, we used a cut-off of 1.7 mmol/L to define both pregnancy toxemia and ketosis. A limitation of the current study was the inability to continue testing to determine how long BHBA remained above 1.7 mmol/L. We encourage future research to use more frequent, longer-term sampling.

On one farm, none of the does sampled had negative energy balance. This farm had experienced cases of pregnancy toxemia in the past and had developed a protocol for managing late gestation does, which included supplementing does carrying multiple kids, feeding a number of small meals throughout the day, and feeding highly palatable forage. It is unclear which, if any of these changes, were responsible for the excellent health status of does on this farm before and after kidding. Overall, the prevalence of ketonemia before kidding in this study was low, with only half of the farms having any cases; this result is consistent with previous studies (e.g., Melby et al., 1986). Unfortunately, mortality associated with these cases was very high, again consistent with previous literature (Malher et al., 2001; Lima et al., 2012).

In the current study, all but one farm had higher levels of ketosis than pregnancy toxemia. This outcome was unanticipated, as veterinary resources (e.g., Andrews, 1997; Edmondson and Pugh, 2004) typically focus on pregnancy toxemia, and metabolic issues following kidding are less discussed. Since the latter condition is linked to the increasing metabolic demands of milk production (e.g., Goldhawk et al., 2009), and improvements in nutritional formulations are resulting in rapidly increasing milk production in dairy goats (e.g., Monzón-Gil et al., 2010; Goetsch et al., 2011), we suggest that ketosis will be a growing issue in dairy goats.
The present study found a negative impact of ketonemia on milk production, which is similar to the work showing milk production losses in cows (e.g., Rajala-Schultz et al., 1999; Goldhawk et al., 2009). These losses, coupled with treatment costs (Guard, 1994), have motivated a large body of literature examining this disease in cows. One emerging discussion centers on reducing ketosis by manipulating dry period length. While not all studies agree (see review by van Knegsel et al., 2013), decreasing or skipping the dry period seems to improve energy balance following calving, in part due to less variation in feed intake (Rastani et al., 2005; de Feu et al., 2009; Jolicœur et al., 2014). While we found no direct effect of dry period length on health status, longer dry periods were linked to reduced milk production. The results of the current study also indicate that does which remain healthy have shorter or skipped dry periods. Unfortunately, this does not indicate that managing does for shorter dry periods actually reduces the risk of pregnancy toxemia and ketosis given the possible confound between does self-drying and ketonemia. While all but one farm indicated they managed their does based on a fixed number of days until kidding (e.g., 60 d dry), the large range in dry periods observed indicates that the majority of these farms actually dried off does based on their milk production, meaning that the actual dry period of the does was influenced by milk production persistency. While the relationship between milk production persistency and metabolic health status are not well understood, possible benefits of continued production were observed on one farm where dry periods were skipped if does continued to produce more than 1 kg/d. However, it can be argued that healthier does will continue to produce more milk than does that are already compromised. Thus, it is possible that does with longer dry periods were already metabolically challenged or at a higher risk of illness. Randomly assigning dry period in a controlled trial, using dairy goats where parity and the previous lactation’s milk production is known (unlike in this study) is necessary to disentangle the effects of dry period length on metabolic function (similar to studies on cows; Rastani et al., 2005). However, as demonstrated by Caja et al. (2006), assigning shorter dry periods may be difficult as lactation persistence varies in does resulting in some does spontaneously self-drying.

Two other factors noted for their influence in challenging goats metabolically around kidding are kid numbers and feeding regime. The number of kids a doe is carrying is pertinent because multiple fetuses reduce rumen capacity (Forbes, 1968), limiting feed intake ability and thus promoting negative energy balance. Energy requirements in late gestation can more than double in ewes carrying twins and triplets compared to those carrying singles (Navarre and Pugh, 2002). Schumbohm and Harmeyer (2008) showed that
twins increased the susceptibility of ewes to pregnancy toxemia. Similarly, Lima et al. (2012) found that does with pregnancy toxemia carried more kids compared to controls (2.7 vs. 2.0 kids). In the current study, we found a similar pattern with greater odds of ketonemic in does carrying triplets.

The second factor with potential to affect energy balance is feeding regime. Our results did show that almost half of all the cases of ketosis were observed on the 3 farms feeding a “complete pellet” supplemented with straw and sometimes hay. We also observed that does on these farms were at increased risk of becoming ketonemic. These results should be viewed with caution given that the purpose of the study was not to evaluate the effect of feeding practices on health status. However, the findings do provide evidence that more insight is needed regarding the effects of concentrate and forage type (e.g. pelleted versus textured feed) on ketonemia in does. Further work investigating feed management practices that avoid negative energy balance in early lactation is also encouraged.

Once pregnancy toxemia is diagnosed, the prognosis is often poor (Lima et al., 2012). This situation was reflected in the protocols put in place by the farms with which we worked. Only a few of the producers attempted to treat does after the animals began to show clinical symptoms. On one farm, the protocol was to euthanize the dam, and perform a caesarean section to save the kids. With earlier diagnosis of sick or at risk animals it may be possible to develop more effective treatment protocols.

Using lying behaviour for identifying health issues in cows has become increasingly popular with the advent of accelerometer-based monitoring devices. These monitors have been used to determine lying behaviour (Ito et al., 2009), as well as to evaluate the interaction between lying behaviour with mastitis (Medrano-Galarza et al., 2012), lameness (Ito et al., 2010) and clinical ketosis (Itle et al., 2014). The current study found that these devices are useful for identifying behavioural changes in dairy goats. Healthy does showed increases in activity nearing parturition, and dramatic drops in lying times in the day before, day of and day after kidding. Similar patterns have been noted in cows (Huzzey et al., 2005). While the ketonemic does in the present study displayed similar patterns, the changes were not as pronounced as in the healthy does. Ketonemic does generally spent longer lying down in the days before kidding compared to their healthy counterparts; this difference was especially obvious in the does with negative energy balance prior to kidding. Since our monitoring period only collected data 12 d before kidding, future work should monitor does even earlier, as this may help identify when lying time changes begin relative to kidding.
All does reduced lying time on the day of kidding, but the ketonemic does did not have such a dramatic decrease as does that stayed healthy. These results contrast those of Itle et al. (2014), who found that severely ketotic cows stood more than healthy cows. Itle et al. (2014) also found that ketotic cows did not increase their activity level on the day of calving, whereas in the present study ketonemic does had the same number of lying bouts as healthy does. In fact, the number of times does got up and down was lower overall compared to healthy does, which was not the case for Itle et al. (2014). In the latter study, cows were moved to a calving pen when parturition was imminent, while in the current study does remained in a relatively static group pen until after kidding. It is possible that the lack of pen movement in the present study resulted in does feeling comfortable to stay lying down for longer, while the cows in Itle et al. (2014) study were faced with a new environment that is known to result in restlessness and more standing bouts (Proudfoot et al., 2013).

Most of the lying behaviour differences in this study were more evident for does that were ketonemic before kidding. We may have been better able to detect health effects pre-kidding because management at this time was more similar among farms than it was after kidding. For instance, all of the farms housed pre-kidding does together in groups, and new does were not typically added to these groups. Introducing new individuals into a group of goats has been shown to disturb normal behaviour (Patt et al., 2012). Further, while stocking density was not recorded, all does were able to lie down with minimal disturbance in the kidding areas. Andersen and Bøe (2007) showed that goats spend more time resting simultaneously when provided more space. In comparison, both the group dynamics and the space provision for goats after kidding were more variable among the farms. The lying time of the healthy does from all 10 farms corresponded to this, with very consistent daily time spent lying prior to kidding, and more variable lying time in the days after. Patt et al. (2012) found that goats tended to self-isolate when moved into a new group, increasing their lying time. It is possible that because of their move into a lactating pen, both ketonemic and healthy does were behaving similarly in regards to lying time. Furthermore, it is possible that this move might have contributed to the development of ketonemia after kidding, since introduction into a new group is associated with reduced time spent feeding (Patt et al., 2012). Further work on ketotic does in more controlled settings is encouraged. Finally, since low ranking (Andersen and Bøe, 2007) and younger (Szabò et al., 2013) does tend to be most affected by constraints and changes in their environment, future work should consider social status and age.
5.5 Conclusions

Ketonemia following kidding (i.e., ketosis) was more prevalent than ketonemia before kidding (i.e., pregnancy toxemia). Does with shorter dry periods were more likely to be healthy before and after kidding. When does were managed to have no dry period, more animals remained healthy compared to those that were dried off. We suggest that reducing or eliminating dry periods in dairy goats is a promising management practice. Further, does with pregnancy toxemia had higher lying times before kidding. Does with ketosis showed decreased lying times on the day of and day after kidding only and had reduced activity levels, with fewer lying bouts overall. These results suggest that automated measures of lying behaviour are a promising indicator of pregnancy toxemia and ketosis.
6   General Conclusions and Discussion

Over the course of completing the experimental work and the associated chapters that are described within this thesis, a number of observations and reflections are worthy of additional discussion. The majority of these thoughts arose throughout the course of writing the individual chapters, and for the most part, began with the phrase, “if I were to do this again, I would…”. As my dissertation journey drew to a close, and I critically reviewed this compilation of thoughts (which incidentally had grown quite large), I realized that while part of my amassed critical observations were the result of co-author, committee member and scientific community review, the harshest judgments were my own. Although initially unsure of where to start with this final chapter, I found that by reading through my collection of thoughts, I began to smile. I then sat back and reflected on the last 4 years and upon doing so noted that I had this overwhelming feeling of gratification; not only had my compilation of thoughts provided me with an outline for the limitations section of this dissertation, I also realized that I was witness to my growth as a scientist.

I now realize that the process of doing a Ph.D. is much more than just doing a series of experiments; it is largely about personal growth and self critique. These skills are essential as they are what guide the best possible future research. One of the most rewarding things about being a researcher is the ability to constantly seek more from the data and from oneself.

Below I will briefly summarize the primary findings of the experimental chapters. I discuss these in the broad context of the literature and identify strengths, weaknesses and future research directions.

6.1   Thesis findings

The overall goal of the collection of studies that are presented in this dissertation was to improve our understanding of the animal welfare effects of some key management practices associated with transitioning dairy cows and goats between lactations. More specifically, my interests lay in 1) better understanding how the cessation of milking (dry off) is achieved and whether management practices used to initiate dry off were associated with any negative effects on welfare, including aspects of health, natural behaviour and affective states, 2) determining if the management of animals during the non-lactating (dry) period impacted health before and after parturition and 3) determining to what extent behavioural measures could be used to assess welfare at these times. The review presented in Chapter
1 set out to identify the crucial gaps in this area of science by examining the published literature from the perspective of the three key concepts of animal welfare: biological functioning, affective states, and natural living (Fraser et al., 1997). The majority of the research examining the dry period and dry off has focused on biological and health perspectives in both dairy cows and dairy goats. Indeed, the literature has large gaps in understanding how the animal experiences the dry off process as well as the effects of deviating from a natural lactation cycle. The cow literature was sparse in these areas and there is virtually no research focused on this topic in goats.

Chapter 2 aimed to evaluate how dairy cows respond to a commonly recommended milk cessation practice and found that abruptly ceasing milking at dry off not only promotes milk leakage, but also encourages continued motivation to be milked in high production cows. Chapter 3 focused on goat producer management and concerns around the dry period and found that producers were divided in their opinion on the necessity of the dry period. For some, milk production persistency was a priority when making dry off decisions. Producers also identified a strong concern for metabolic issues in goats during the dry period, providing merit for on-farm work examining these issues. Indeed, I decided examining metabolic health on farms would be an excellent way to explore one of my broad thesis goals to use behavioural changes as a means of evaluating the animal experience during dry off and the dry period. However, before this was possible, the use of data loggers for behavioural monitoring first needed to be validated (Chapter 4). The study found that HOBO data loggers were useful for measuring standing and lying behaviour in goats. My work also showed that this technology has promise for monitoring laterality of lying, but that given the differences in lying behaviour compared to cows caution is warranted when interpreting the results. The final study (Chapter 5) described the impact of the dry period on metabolic status, and evaluated how goats altered their lying behaviour in response to this status. Longer dry periods were associated with more metabolic challenge in goats, and these goats showed longer lying times and reduced general activity, particularly before kidding.

This thesis addressed a number of dry period related literature gaps; broadly, I was able to highlight that some dry off management practices affect motivation in cows, that the management of goats and cows differs considerably and thus the adoption of recommendations based on cow studies must be viewed with caution when applied to goats, and that monitoring behaviour in goats to identify animals that are sick or at risk of becoming ill is a promising area of research.
6.2 Consideration of work within current literature

While work from almost four decades ago (Natzke et al., 1975) examined similar milking cessation methods as used in Chapter 2, my study is the first to demonstrate that milk leakage is mitigated in high production cows by using a gradual decline in milking frequency for dry off. High milk production increases the risk of IMIs (Rajala-Schultz et al., 2005), as does milk leakage (Klaas et al., 2005). Current cow dry off guidelines (aimed at reducing dry period IMIs; NMC, 2006), suggest pairing dry off therapy products with abrupt cessation of milking; these guidelines include a recommendation that maximum milk production at dry off be 15 kg/d. It is this second point that likely receives too little consideration. Many dry period IMI studies fail to report milk yield at dry off (e.g., Bradley et al., 2011; Dufour and Dohoo, 2012). Considering the links between IMIs, milk leakage and high milk production, this oversight should be addressed in future work. A second important point of interest regarding milk production is the impact it may have on the animal’s affective states at dry off.

One of the most interesting observations in Chapter 2 was the apparent response to a change in milking routine. Cows that received continued milking at a reduced frequency in the days before complete cessation of milking did not increase their standing at the gate; this result is consistent with those of Tucker et al. (2007) who also found no increased standing when milking frequency was reduced. Performing management changes gradually reduces the negative behavioural responses relative to when those changes are performed abruptly (e.g., weaning of beef calves: Price et al., 2003; Loberg et al., 2008; early introduction to milking parlour of buffalo heifers: Polikarpus et al., 2014). Conversely, the cows that had their milking ceased abruptly spent significantly more time standing at the exit gate compared to before their routine was changed. This behavioural response was immediate and prolonged, lasting for the entire 8 d observation period. Keeling et al. (2008) proposed that when an animal is motivated to acquire something, it initiates a reward cycle where the highest positive affective state occurs once the reward is acquired. Thus, it can be argued that thwarting the cow’s motivation to leave the pen at milking time would not allow for the completion of the reward cycle. The cows waited at the gate to leave the pen at milking, but were never milked; since it has been suggested that the display of seemingly unrelated behaviours (in this case standing at the gate) can be an indicator of frustration when an animal cannot perform something it is motivated to do (e.g., Dawkins, 1988), I suggest that abrupt cessation of milking causes frustration in cows.
Chapter 3 provided a description of common dry off practices that can guide future research. The effects of continuous milking have been studied in research settings (e.g., Fowler et al., 1991; Caja et al., 2006) but not on commercial farms. My work has shown that milk production persistency is a constraint faced on many farms. On one third of the farms, persistency led to variable dry period lengths, and in some, a desire to deviate from traditional annual lactation cycles. This finding is consistent with those of García-Peniche et al. (2012) who reported that the average length of time between kiddings could be quite variable (mean ± SD: 382 ± 85). The work in Chapter 3 identified an interesting contradiction between management of cows and goats. The problems associated with the dry period in cows (e.g., IMIs, high morbidity around calving) have received much attention, with dozens of papers focusing on management and nutritional improvements that could be made (e.g., reviews by Bradley and Green, 2004; Ingvartsen, 2006; Grummer, 2008; Mulligan and Doherty, 2008). Yet, almost all this work is done within the accepted annual lactation cycle. Conversely, the results of Chapter 3 point to a greater desire by goat producers to avoid the problems associated with the dry period in goats (e.g., producing surplus kids, metabolic issues) by deviating from the conventional lactation cycle. Therefore, flexibility in goat management pertained to both reduced or omitted dry periods and extending lactation lengths. Concerns regarding metabolic health are one of the driving forces behind this.

In the work described in Chapter 5, variable dry periods were observed across the 10 farms visited, with one producer actively managing some of his goats with no dry periods. On these farms, a link between longer dry periods and increased pregnancy toxemia and ketosis in goats was noted; of course the observational nature of this study meant that the causality of this relationship could not be established. Generally, the dairy cow literature shows that providing no dry period negatively affects milk production (reviewed by Bachman and Schairer, 2003; Grummer and Rastani, 2004). These milk production effects are less clear in goats (Fowler et al., 1991; Caja et al., 2006), and the current study demonstrates positive metabolic health effects of providing little or no dry period.

In many species, monitoring standing and lying behaviour is a useful indicator of health status (e.g., sows: Fitzgerald et al., 2012; cows: Ito et al., 2010; ), and of the impacts of social and physical environments on individual animals (e.g., ewes: Averós et al., 2014; goats: Andersen and Bøe, 2007). Most behavioural monitoring in goats has been via direct observation (e.g., Loretz et al., 2004) and video (e.g., Aschwanden et al., 2009). Patt et al.
(2012) do describe using data loggers (different than those validated in Chapter 4) in their study, but failed to provide any indication that the loggers were validated for use on goats. Chapter 4 showed that cut-off points may not in fact be transferable between species, even when using the same technology. The work in this Chapter also aided in the refinement of code available online to anyone wanting to use the loggers in subsequent research. Of final interest is that this study illustrated that goats have many short lying bouts, quite different from cows housed in free stall systems, yet similar to those housed on bedded packs (Ledgerwood et al., 2010). This is a significant finding, as it means that lying bout duration, which is calculated using the daily lying time divided by the number of lying bouts, would not be particularly representative of most of the actual lying bout durations in goats, and hence need to be interpreted with caution. The validation presented in Chapter 4 was necessary to support future behavioural studies in goats.

6.3 Strengths

Students graduating from the University of British Columbia’s Animal Welfare program are all expected to develop one key trait; we are expected to have learned the importance of, and have developed the ability to, provide practical solutions to animal welfare issues. It was this that motivated me to ensure that in addition to adding to the current body of scientific literature as described above, every Chapter presented in this thesis had some practical applicability. Since the publication of the study in Chapter 2, the Canadian Bovine Mastitis Research Network (CBMRN) added a recommendation in their most recent factsheet (Santschi et al., 2013) for including gradual cessation of milking into the dry off routine for high production cows.

While I discuss the benchmarking concept further in Section 6.5.2, briefly, the combination of Chapters 3, 4 and 5 fuelled the first (as far as I am aware) benchmarking effort in goats. With an eventual aim of promoting management improvements, benchmarking is a growing tool in animal welfare research (e.g., dairy cows: von Keyserlingk et al., 2012; beef cows: González et al., 2012). An example of the reports prepared for the producers involved in the Chapter 5 study is provided in Appendix A. A few producers in this study commented that, while they encourage research, they feel very disconnected from it. Providing each producer their results compared to the other study farms, not only demonstrated areas of improvement, but likely aided in gaining their trust and hopefully secured their involvement in future research. This work also provided a clear template for disseminating research results back to producers.
Lastly, as the advantages of behavioural monitoring becomes well known on dairy cattle farms (Rutten et al., 2013), these technologies will likely become more popular in the dairy goat industry as well. The changes in lying time observed in Chapter 5 may be used to identify at-risk goats. It is my hope that as producers move towards electronic identification of their cows and goats, and as accelerometer-based data loggers become more affordable, these two technologies could be combined. In turn, the acceleration cut-off points established in Chapter 4 could help refine the algorithms necessary for interpretation of the data collected.

6.4 Limitations

Reviewing dry period management from a three-faceted welfare perspective resulted in what could be argued as a disproportionally weighted document. The vast majority of the paper in Chapter 1 describes the advances in dry period related research from a biological functioning perspective; while this format serves the purpose of highlighting literature gaps, it leaves the reader a bit overwhelmed with one section of research and eager for more research in the other two sections (affective states and natural living).

The work in Chapter 2 has two key limitations. First, the study highlighted differences in an IMI risk factor (milk leakage) based on milk cessation method used, yet the sample size did not allow for the assessment of treatment effect on IMIs. The herd size at the UBC Dairy Education and Research Centre results in an average of 20 – 30 cows being dried off each month, thus, assessing impact of milk cessation method on IMIs was not possible in the time available to undertake this study. Future studies should consider performing this type of work on larger commercial facilities but would need to be cognisant of other challenges (e.g., lack of experimental control; Chapinal et al., 2014). The second limitation in this project was the feeding regime. While pairing milking cessation treatments with a change in feed quality was done to have practical relevance, this change disrupted lying behaviour. Vasseur et al. (2012) hypothesized that the feeding time increases in lactating cows (as reported by DeVries et al., 2003) were the cause of reduced lying times. Further, while cows are noted to decrease their feeding time in preference of lying time when their access to these resources is limited (Munksgaard et al., 2005), the cows in the current study had unlimited access to their lying stalls, and the food was the restricted resource. Restricting feed has been shown to increase movement in goats (Laporte-Broux et al., 2011a), which would also correspond to reduced lying time. Therefore, due to the
restricted feeding in the study outlined in Chapter 2, any milking cessation method treatment effects on lying behaviour were confounded by the feed change.

When designing the measures that would be taken during the descriptive study in Chapter 3, I relied heavily on the dairy cow literature (e.g., Vasseur et al., 2010; von Keyserlingk et al., 2012) but in retrospect there were a number of pertinent questions that I should have included. For example, asking the producers about their background knowledge (e.g., previous agriculture experience, particularly with dairy cows) may have been helpful in understanding decisions being made by the producers. Furthermore, asking a producer to quantify milk production at dry off would have been beneficial. While I had avoided this question because I anticipated few producers would actually be monitoring milk production, direct conversations with producers later proved that many producers would have happily estimated milk production in terms of a readily available measuring device (e.g., "medium Tim Horton's coffee cup"). Given this apparent willingness of producers to quantify milk production, there is merit in developing a cost effective way for doing so.

The validation presented in Chapter 4 occurred on two commercial farms, presenting some unique challenges. While small pens are common for housing goats in research settings (e.g., Andersen and Bøe, 2007; Nordmann et al., 2011), commercial farms typically house goats in large groups (e.g., Anzuino et al., 2010); the latter do not lend themselves well to monitoring with video (which are needed to validate the loggers). Therefore, a pen was improvised on the first farm, and multiple cameras were mounted allowing for monitoring lying sides (laterality); however, this pen held only 4 goats. The second farm had a larger pen holding 6 goats, but it was in a building with low ceilings and rock walls which allowed for only one camera to be mounted. Therefore, while a total of 10 goats were used for the validation of the loggers to monitor lying and standing, after the loss of data due to logger rotation, only 3 goats were used to validate laterality. Positively, these goats were chosen from a large group of 34 animals also wearing data loggers; the laterality information calculated for this larger group was similar to the goats used for validation. Further all animals have 3 d worth of data; this was similar to the amount of data used in the experiments described in Bonk et al. (2013). Nonetheless, more animals would have been ideal and have been used for other validations (e.g., 24 cows with 3 d; Ledgerwood et al., 2010).

Finally, the study in Chapter 5 had a combination of limiting factors, including large between farm variability, equipment failures, the study being part of a larger project and the inevitable outcomes that come from working directly with human participants. While 10
farms were monitored, lost loggers, lack of disease prevalence, and varying availability of goats on each farm, resulted in a relatively small prevalence of pregnancy toxemia goats. While all farms had milk monitoring abilities, failure of these systems on a number of the farms led to just over half of the goats enrolled in the study having milk production data. The data collected in this study was part of a larger project that was examining dairy goats across the entire dry period (see Appendix A for details of all the factors measured). While this was helpful in the sense of getting a good overview of each farm’s management strengths and weaknesses, it resulted in fewer resources being available for monitoring each variable. Further, in an effort to collect enough data on sick animals, many goats were enrolled after cessation of milking had already taken place, resulting in an inability to report dry period length for these animals (since producer dry off records were minimal). Lastly, on one farm the producer became overly involved in the day to day monitoring of the goats. When I began finding ketotic animals this individual wanted to immediately begin altering management, which created a bit of a conundrum, particularly because the producer admitted to not having been aware of such issues in their herd until I began the trial. This situation could have been avoided by my being more transparent about trial expectations, and the ability of the producer to intercept. However, despite this producer interfering I do not believe the results were overly biased; the sickness prevalence was just likely lower on this farm.

6.5 Future research directions

There are three separate areas in which I would focus future research on the critical period beginning just before the cessation of lactation and ending in the weeks following parturition: 1) affective states, 2) benchmarking and, 3) deviating from the common accepted annual lactation cycle.

6.5.1 Affective States

While there appears to be a growing body of literature indicating that cessation of milking has the potential to cause pain due to udder distension (e.g., Bertulat et al., 2013; Silanikove et al., 2013), confirming this has been problematic. Changes in lying behaviour in response to udder pain does show promise, but confounding factors (as demonstrated within my own work) have prevented concrete links between milking cessation and changes in lying time. Cows with IMIs do show decreased lying times (Medrano-Galarza et al., 2012)
suggesting that this measure has promise. I encourage future dry off research to include this measure, but with better controls for confounding variables (e.g., feeding changes).

I also recommend more work investigating the motivation for milking after cessation of lactation is initiated. It may be argued that the inclination of cows to continue standing at the gate around milking time when their milking was abruptly ceased (see Chapter 2) may simply have been a response to a change in routine. Future research could test motivation to be milked by assessing if cows would be willing to work for access to milking. Motivation has been tested using operant tasks, where animals are trained to work to obtain a resource; this may include pressing a lever (e.g., horses: Søndergaard et al., 2011) or pushing through weighted doors/gates (e.g., sheep: Jackson et al., 1999; cichlid fish: Galhardo et al., 2011). Since cows already showed that they would stand by the gate during milking time, a logical way to measure motivation would be to teach them to push on that gate prior to dry off. Motivation for milking could be assessed by how much weight they would be willing to push to access the milking parlour.

Lastly, both past research in cows (e.g., Bushe and Oliver, 1987; Odensten et al., 2007a), and the descriptive study of goat producers described in Chapter 3, demonstrate that feed changes are an important part of achieving reduced milk production before dry off. More work is needed to determine what level of change in feed quality and quantity promotes a decrease in milk production, while at the same time minimizing feelings of hunger. Valizaheh et al. (2008) found that cows offered oat hay vocalized more than cows offered grass hay. The grass hay was more palatable, and cows ingested nearly twice as much of it as those offered oat hay. Grass hay also contained one-third more protein; studies in humans indicate that higher levels of protein help promote satiety (Veldhorst et al., 2008; Johnstone, 2013). Both hay options reduced milk production to below 10 kg/d within 2 d, suggesting that future research could focus on identifying feed options that are palatable and perhaps promote better satiety via alteration of protein levels. This work could also include an IMI prevention component. Busche and Oliver (1987) showed the advantages of pairing gradual milk cessation with a change in feed quality on the mammary gland’s immune defenses; this is particularly pertinent as concern over blanket use of dry period antibiotics grows (Scherpenzeel et al., 2014). It would be advantageous to understand alternatives to preventing IMIs, particularly ones that minimize negative affective states.
6.5.2 Benchmarking

As concern for animal welfare grows in many parts of the world (e.g., Elzen et al., 2011; Jacques, 2014; von Keyserlingk and Hötzel, 2014; Spooner et al., 2014), so has the need for measuring and making improvements in production animal sectors. A precursor to making improvements is the development of benchmarks; benchmarks provide established standards to which future measurements can be compared (Drew, 1997). Continuing with this concept, the act of benchmarking is an intentional process aimed at informing an existing state and consequently improving it (Moriarty and Smallman, 2009). While it is most frequently applied around the world in business settings (e.g., Carpinetti and de Melo, 2002), regardless of what system to which it is applied, the key component of benchmarking is the idea that best possible practices are sought out and improvements in the system are made by implementing these best practices (Partovi, 1994). Thus, it follows that the benchmarking concept fits well into the today’s growing societal push for addressing animal welfare concerns in commercial animal production. Many studies have sought to describe and quantify the care of different species of production animals on a large scale (e.g., horses: Pritchard et al., 2005; goats: Anzuino et al., 2010; cows: von Keyserlingk et al., 2012). While there is merit in collecting such descriptive data as a foundation for informing and guiding future research, delivering the information back to the source serves a further goal – promoting improvements. Indeed, Le Gal et al. (2011) proposed that research should shift from the current linear approach of results being disseminated from the researcher to the advisor to the producer, and more towards a participatory paradigm that encourages interaction between all individuals; this creates an informative environment that guides the research and motivates improvement. For instance, follow-up with a subset of the dairy cow farms from von Keyserlingk et al. (2012) showed that many of the farms made improvements in their lameness and hock lesion scores a year after having received benchmarking feedback (Chapinal et al., in press). Hence, to serve the dual purpose of completing well-rounded on-farm research, and also of identifying possible barriers preventing implementation of changes, I suggest that future on-farm research aim to become more interactive. Effort should be made to include a component that provides results to participants, and a second component that follows-up with those participants after a period of time to assess the effects of providing feedback. In my own work, I was able to complete the first component (Appendix A); while no formal efforts have yet been arranged for follow-up, a number of the producers have done so on their own in response to their reports.
6.5.3 Deviating from standard lactation cycle

The results from Chapter 3 suggest that some goat producers manage their animals with lactation cycles different from what has been established for cows. While I found some benefits of reduced and skipped dry period lengths in my on-farm research, due to the nature of working on numerous commercial farms, these benefits were fraught with confounding factors. I propose more structured, experimental work be conducted to evaluate dry period length on milk production in the next lactation, IMI cure rates, and metabolic health in goats, as has been conducted in cows. It would be particularly advantageous to include goats with demonstrated milk production persistency in such work. Similarly, I recommend expanding research into extended lactation lengths and evaluating the factors that allow for persistent milk production.

Not only will work examining extended lactations, and generally deviating from an annual lactation cycle be useful in guiding dairy goat management, I believe it may be able to add insight into dairy cow management. This suggestion stems from the question of whether dairy cow welfare can continue to be maintained within today’s system. Historically, many dairy farmers were focused on longevity. For instance, the average British Holstein cow achieved an average of 4 lactations in 1950 (Rendel and Robertson, 1950). However, as increased milk production became the key focus, longevity declined. Hare et al. (2006) estimated that fewer than 30% of today’s cows reach 4 lactations. Indeed, in 2006 that average had dropped world wide, with cows in the USA surviving on average only 2.8 lactations (Knaus, 2009). A survey of 103 US farms (Caraviello et al., 2006) found that producers culled 34% of their herd annually.

A few options exist for addressing this situation of declining animal longevity. One option is to continue working within the current system. Hundreds of studies focus on reducing diseases around calving via nutrition and management (e.g., Mulligan and Doherty, 2008; Grummer, 2008; Esposito et al., 2014), improving housing (e.g., Haskell et al., 2006; Chapinal et al., in press) and improving reproduction (e.g., Pryce et al., 2004; Moore and Thatcher, 2006). Despite improvements in some areas, problems persist. A second option is to explore the possibilities of deviating from current practice in one key aspect – the lactation cycle. While research in this area is sparse, it is possible that many of the current issues in cows stem from the annual lactation cycle that is so entrenched. In goats, where management of the lactation cycle appears to fairly dynamic, reproductive concerns are minimal; this can be seen by the fact that while estrous manipulation and artificial insemination in goats is discussed (Holtz, 2005; Abecia et al., 2011), natural
reproduction is still common (Martin et al., 2004). In cows reproduction is largely an artificial process utilizing hormonal synchronization and timed artificial insemination programs (Caraviello et al., 2006). Another example is parturition-related disease; while goats are susceptible to some kidding-related conditions, these appear to be lower in prevalence (e.g., Melby et al., 1986; Chapter 5 of this thesis) compared to cows (McArt et al., 2012). Of course in both of these examples, there are many determinants involved, but it is possible that more flexible management of the lactation cycle would be helpful. Pryce et al. (2004) suggested that exploring unconventional lactation lengths in cows could help with reproduction issues. I believe that by using the goat, and its difference in lactation cycle management, as a model, we may be able to identify means for avoiding some of the most common concerns faced today in dairy cows.

6.6 General conclusion

The studies presented in this thesis have allowed me to identify some of the gaps in the dry off and dry period literature. I explored affective states at dry off in cows, risk factors for udder health issues in cows and metabolic issues in goats, and described the methodology employed by goat producers to transition their goats from one lactation to the next. To do this research I also validated data loggers for monitoring lying behaviour changes in goats, which I then applied for early identification of metabolic health status. During this process, I developed a list of three distinct areas where future research could focus. First, continued effort is needed towards identifying affective states such as pain, hunger and frustration caused by milk cessation practices at dry off. Second, further work should consider incorporating the producer as part of the research process, in order to have the most applicable outcomes. And third, a shift in research focus from the currently utilized annual cycle may be beneficial for identifying management better suited for today’s high producing animals.
References


CARC, Canadian Agri-Food Research Council. 2003. Recommended code of practice for the care and handling of farm animals - Goats. Ottawa, Canada.


Pinedo, P. J., C. Fleming, and C. A. Risco. 2012. Events occurring during the previous lactation, the dry period, and peripartum as risk factors for early lactation mastitis in cows receiving 2 different intramammary dry cow therapies. J. Dairy Sci. 95:7015–7026.


Appendices

Appendix A: Example benchmarking report for providing producer feedback

Report presented in data was collected as part of large project from which Chapter 5 data was acquired. Each of the 10 producers involved in the project received a bound copy of their results as compared to the other farms.

Section 6.5.2 discusses the merits of such benchmarking reports.
Survey of Dairy Goat Management Practices
Confidential Report
Prepared For: Producer Jane

This confidential report summarizes the data collected by researchers that visited your farm in 2013. Your farm was one of 10 farms participating in the study. For your information, your farm's performance is compared to these other farms. We have provided suggestions for how you can make improvements.

Overview of Measurements

1. Dry off practices
2. Subclinical mastitis
3. Hoof care & lameness
4. Body condition scores
5. Pregnancy toxemia & ketosis
6. Activity levels
7. Kid immunity status & early growth rate

Most measures were made on the 36 study does [or their kids] that we followed for the project.
Lameness and body condition score are shown for a random subsample of 54 other does on your farm.

Interpreting the Results

You are provided your farm’s average [all your does averaged], as well as the average found on the other farms for each of the measurements taken. The range of values from each farm [highest, average, lowest] is presented graphically as well, and your value is shown with a circle.

The highest value achieved by one of the farms

The lowest value achieved by one of the farms

Depending on the measurement, it may be good to get a high number [e.g., milk production], might be a spot for improvement [e.g., high ketosis level], or is simply for information purposes [e.g., lying time].

Dr. Ken Leslie, Dr. Marina von Keyserlingk and PhD candidate Gosia Zobel
# 1. DRY OFF PRACTICES

There is very little research regarding the best methodology for drying off goats, which leaves farms to figure things out on their own. The purpose of this section is to share details among farms.

It should be noted that 1 farm was actively choosing to skip the dry period on some high production does (and milking continuously through to the kidding) without ill effects on milk production after kidding.

## Days dry

<table>
<thead>
<tr>
<th></th>
<th>Your farm</th>
<th>Average of all farms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Highest</td>
<td>99</td>
<td>32</td>
</tr>
<tr>
<td>Lowest</td>
<td>53</td>
<td>6</td>
</tr>
</tbody>
</table>

### Number of days does are dry

<table>
<thead>
<tr>
<th></th>
<th>Highest</th>
<th>Lowest</th>
</tr>
</thead>
<tbody>
<tr>
<td>99</td>
<td>53</td>
<td>32</td>
</tr>
<tr>
<td>53</td>
<td>32</td>
<td>6</td>
</tr>
<tr>
<td>35</td>
<td>6</td>
<td>0</td>
</tr>
</tbody>
</table>

## No dry period (goats are kept milking)

<table>
<thead>
<tr>
<th></th>
<th>Your farm</th>
<th>Average of all farms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Highest</td>
<td>30%</td>
<td>30%</td>
</tr>
<tr>
<td>Lowest</td>
<td>0%</td>
<td>0%</td>
</tr>
</tbody>
</table>

### Percent of goats on each farm not dried off

<table>
<thead>
<tr>
<th></th>
<th>Highest</th>
<th>Lowest</th>
</tr>
</thead>
<tbody>
<tr>
<td>30%</td>
<td>30%</td>
<td>0%</td>
</tr>
<tr>
<td>30%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>6%</td>
<td>6%</td>
<td>0%</td>
</tr>
</tbody>
</table>

## Milk production last week before dry off

<table>
<thead>
<tr>
<th></th>
<th>Your farm</th>
<th>Average of all farms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Highest</td>
<td>0.7</td>
<td>0.7</td>
</tr>
<tr>
<td>Lowest</td>
<td>0.5</td>
<td>0.5</td>
</tr>
</tbody>
</table>

### Milk production last week before dry off

<table>
<thead>
<tr>
<th></th>
<th>Highest</th>
<th>Lowest</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.7</td>
<td>0.7</td>
<td>0.5</td>
</tr>
<tr>
<td>0.6</td>
<td>0.6</td>
<td>0.5</td>
</tr>
<tr>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
</tr>
</tbody>
</table>

## Milk production in 1st week of next lactation

<table>
<thead>
<tr>
<th></th>
<th>Your farm</th>
<th>Average of all farms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Highest</td>
<td>3.1</td>
<td>2.3</td>
</tr>
<tr>
<td>Lowest</td>
<td>1.4</td>
<td>1.4</td>
</tr>
</tbody>
</table>

### Milk production 1st week after kidding

<table>
<thead>
<tr>
<th></th>
<th>Highest</th>
<th>Lowest</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.1</td>
<td>2.3</td>
<td>1.4</td>
</tr>
<tr>
<td>2.3</td>
<td>2.3</td>
<td>1.4</td>
</tr>
<tr>
<td>1.4</td>
<td>1.4</td>
<td>1.4</td>
</tr>
</tbody>
</table>

## Milk production in 2nd week of next lactation

<table>
<thead>
<tr>
<th></th>
<th>Your farm</th>
<th>Average of all farms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Highest</td>
<td>4.1</td>
<td>3.0</td>
</tr>
<tr>
<td>Lowest</td>
<td>2.0</td>
<td>2.0</td>
</tr>
</tbody>
</table>

### Milk production 2nd week after kidding

<table>
<thead>
<tr>
<th></th>
<th>Highest</th>
<th>Lowest</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.1</td>
<td>3.0</td>
<td>2.0</td>
</tr>
<tr>
<td>3.0</td>
<td>3.0</td>
<td>2.0</td>
</tr>
<tr>
<td>2.0</td>
<td>2.0</td>
<td>2.0</td>
</tr>
</tbody>
</table>

## Suggestions

You achieved above average post-kidding milk production. While all farms indicated they were aiming for a 60 day dry period, the average was actually less. On your farm, the dry periods ranged from 28 – 64 days.

Lack of dry period on other farms did not seem to affect milk production (the farm that achieved the highest average milk production did not dry off 30% of their goats). Some research indicates that not drying off high production animals helps to maintain a steady energy state. Since you are extremely proficient in monitoring your individual doe milk production, you could consider looking at shortened dry periods.

Key points about milk production:

- The two highest producing farms were feeding a TMR, and mixed forage top-dressed with corn and pellets, respectively
- The highest producing farm managed goats by individual milk production (kept goats milking that were high producing, rather than drying them off)
- Lowest milk production was seen in 2 out of 3 pellet feeding farms
2. SUBCLINICAL MASTITIS

Bacteriological analysis was done on samples taken before dry off and after kidding.

Pathogens varied between farms, but the most common were Coagulase Negative *Staphylococci* (CNS) and *Staphylococcus aureus*.

<table>
<thead>
<tr>
<th>Infections at dry off</th>
<th>Worse</th>
<th>Better</th>
</tr>
</thead>
<tbody>
<tr>
<td>Your farm</td>
<td>24%</td>
<td></td>
</tr>
<tr>
<td>Average of all farms</td>
<td>41%</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Infections at kidding</th>
<th>Worse</th>
<th>Better</th>
</tr>
</thead>
<tbody>
<tr>
<td>Your farm</td>
<td>44%</td>
<td></td>
</tr>
<tr>
<td>Average of all farms</td>
<td>51%</td>
<td></td>
</tr>
</tbody>
</table>

Suggestions

Does kidded out with a higher number of infections than at dry off. It is likely does were being exposed to pathogens during the dry period (e.g., via insufficient clean bedding) or shortly after kidding (e.g., milking hygiene practices needing improvement).

While a large portion (76%) of the infections on your farm was CNS, it should be noted that compared to the other farms, your farm had the largest variety of other pathogens identified (*Staphylococcus aureus*, *Escherichia coli*, *Trueperella pyogenes*, and *Serratia spp.*). While CNS goes largely undetected (as it does not typically raise somatic cell count [SCC]), these infections can reduce milk production and may weaken the does’ defense against other pathogens. Your farm was one of 4 on which we found one or more cases of clinical mastitis.

CNS pathogens are opportunistic and many reside on the teat ends. Improved milking hygiene (e.g., teat dipping before and after milking), as well as ensuring goats are lying on clean bedding, is recommended. Delivering fresh feed after milking encourages animals to continue standing, providing time for the teat canals to close before lying down. These measures will also help you reduce the prevalence of infections due to other contagious pathogens found on your farm.

6 farms had no clinical infections. Your farm was one of 4 on which we noticed one or more clinical cases.

Overall, infection prevalence was high on your farm. These levels just demonstrate a need to better address the udder health on your farm.
3. HOOF CARE & LAMENESS

Hooves were scored according to a 4-point scale. Below we have listed goats with excessive hoof overgrowth and toe curling (score of 3 or 4) since this level of overgrowth can lead to hoof rot, impede normal walking and cause lameness.

The percent of goats with an obvious limp or impaired walking (lameness) is also shown.

<table>
<thead>
<tr>
<th>Hoof length – study does [score 3 or 4]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Your farm</td>
</tr>
<tr>
<td>Average of all farms</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Hoof length – subsample of other does on your farm [score 3 or 4]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Your farm</td>
</tr>
<tr>
<td>Average of all farms</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Lameness – subsample of other does on your farm [walking with obvious limp or impairment]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Your farm</td>
</tr>
<tr>
<td>Average of all farms</td>
</tr>
</tbody>
</table>

Suggestions

When we checked a subsample of other does on your farm, they had very high hoof scores. However, the lack of lameness, and excellent hoof scores in the study does, indicates that a few management changes would likely result in your farm achieving excellent hoof scores all around.

Farms that achieved minimal hoof length in all their goats had a scheduled trimming routine, typically 3 or more times per year.

Hoof care is challenging in goats, but it is important due to impact on health and welfare of the animals. Lameness is associated with decreased milk production. In addition to excessive hoof length, lameness is also caused by joint swelling associated with CAE (a viral infection); CAE is known to decrease milk production. **You are commended for transitioning your herd to CAE negative.**
4. BODY CONDITION

Body condition scoring (BCS) is used to assess whether goats are too thin, too fat, or at a good weight. A visual score can be accurately assigned to thin goats (low BCS). Determining fatness (high BCS) typically involves handling the animals.

Goats that were obviously thin (BCS less than or equal to 2) were noted.

<table>
<thead>
<tr>
<th>Body Condition Score – subsample of other does on your farm</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Your farm</strong></td>
</tr>
<tr>
<td><strong>Average of all farms</strong></td>
</tr>
</tbody>
</table>

Suggestions

Your BCS was good.

If you do notice any does being overly thin or lacking rumen fill (as is pictured in the photo above), it would be advantageous to the longevity of that doe to address her on an individual basis, either via supplementing her individually in the parlour when she is milked, or by separating her into a smaller pen. In dairy cattle, it has been show that individuals that struggle do so because they are not competitive within a large group. Something else to be aware of is that chronically thin does may be experiencing other issues include underlying infections, paratuberculosis (John’s), infected teeth, pneumonia, parasites, etc.

You were one of the most motivated producers with whom we worked in regards to your feed sampling schedule and general nutrition knowledge. Feeding a comprehensive forage + top dressed diet appeared to work well for you in regards to maintaining body condition in your adult does. We encourage you to continue working with your nutritionist towards developing the best possible feeding regime for your herd.
5. PREGNANCY TOXEMIA & KETOSIS

We monitored the blood ketone levels of your goats before and after kidding. Levels above 1.7 mmol/L are considered abnormal and indicative of a compromised metabolic state (e.g., pregnancy toxemia and ketosis).

<table>
<thead>
<tr>
<th>Pregnancy toxemia (prior to kidding)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Your farm</td>
<td>0%</td>
</tr>
<tr>
<td>Average of all farms</td>
<td>4% (Five farms achieved 0%)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Ketosis (after kidding)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Your farm</td>
<td>0%</td>
</tr>
<tr>
<td>Average of all farms</td>
<td>16%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Suggestions</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>You were the only farm with which we worked that avoided all metabolic issues.</td>
<td></td>
</tr>
</tbody>
</table>

You not only avoided abnormal (1.7mmol/L +) ketone levels, you nearly avoided even mildly elevated levels (between 0.9 - 1.6 mmol/L), as your farm only had one doe that measured 1.1 mmol/L prior to kidding.

We encourage you to continue your feeding regime, and your continued attention to individual does, particularly around the few weeks prior to kidding.

In case you are curious about what was occurring elsewhere, on a few of the farms we noticed that does which became sick actually tended to produce more milk in the first two weeks after kidding; this was an interesting finding! It is potentially indicative that the early lactation diets being fed were not meeting the energy needs of the does. In response, the does would either produce less milk (and test as healthy), or would continue to maintain high milk production levels, perpetuating the negative energy balance (and test as being ketotic).
6. ACTIVITY LEVELS

Very little is known about typical daily goat lying times and how often they get up and down (lying bouts). This project was the first to document these behaviours using electronic devices.

The activity of a goat may be an indicator of how comfortable she is in her housing. Uncomfortable does may be more restless (have more lying bouts) and may lie down for less time each day.

The data collected also allowed us to determine that healthy goats have fairly consistent daily lying time patterns, and have a large, predictable drop in lying time on kidding day. Does that later become sick may not display this pattern and may continue to lie down for a long time even on kidding day.

<table>
<thead>
<tr>
<th>Lying TIME (before and after kidding) (healthy does only)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Your farm</strong></td>
</tr>
<tr>
<td><strong>Average of all farms</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Lying TIME (kidding day) (healthy does only)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Your farm</strong></td>
</tr>
<tr>
<td><strong>Average of all farms</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Lying BOUTS (before and after kidding) (healthy does only)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Your farm</strong></td>
</tr>
<tr>
<td><strong>Average of all farms</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Lying BOUTS (kidding day) (healthy does only)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Your farm</strong></td>
</tr>
<tr>
<td><strong>Average of all farms</strong></td>
</tr>
</tbody>
</table>

A comparison between healthy goats (green lines) and goats which develop ketosis (red lines) shows that although all goats lay down a lot less on the day of kidding, this change was less pronounced in the goats which later become sick. Also, goats that became sick were getting up and down less up to 12 days before they kid.

**Discussion**

Your goats tended to get up and down less than the average of other farms. This may be an indicator that your environment is comfortable and encourages goats to stay lying for longer bouts. This research project was the first to ever collect lying behaviour using data loggers in commercial dairy goats. **We are extremely appreciative for your participation in this foundation data collection.** The use of data loggers is a promising tool for early identification of metabolic disease.
7. KID IMMUNITY STATUS & EARLY GROWTH RATE

Immunoglobulin G (IgG) levels are good indicators of passive transfer of immunity from the colostrum (or replacer) to the kid.

We used a value of 12 mg/ml of IgG in the blood serum to determine if a goat kid “failed” in regards to passive transfer of immunity.

Kids were also weighed at least twice to estimate early growth rate.

<table>
<thead>
<tr>
<th>Failure of passive transfer of immunity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Your farm</td>
</tr>
<tr>
<td>Average of all farms</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Early growth (daily weight gain in grams)</th>
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</thead>
<tbody>
<tr>
<td>Your farm</td>
</tr>
<tr>
<td>Average of all farms</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Percent of kids with showing poor weight gain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Your farm</td>
</tr>
<tr>
<td>Average of all farms</td>
</tr>
</tbody>
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<table>
<thead>
<tr>
<th>Suggestions</th>
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</table>
| Your farm had average rates of failure of passive transfer of immunity, however it should be noted that a few farms were able to achieve very low failure rates; therefore you are encouraged to explore your colostrum management protocol. A good rule of thumb is to feed at least 10% of the kid’s body weight as soon as possible after birth (and within 12 hours). It may be helpful to split this colostrum amount into 2 or more smaller feedings, particularly for weaker kids. On average your kids [both males and females] weighed 3.9 kg at birth. Therefore, you would feed at least 400 grams of colostrum. As a note, if you are heat-treating colostrum, research has shown that longer (60 minutes) at a lower temperature (57.2°C) was effective at eliminating harmful pathogens, while not diminishing the quality of the colostrum.

Your early growth rate was below average, and lower than reported in previous research. It may be advantageous to check that kids are actually drinking all milk that is provided to them, particularly in the cold months when they will be less motivated to drink cold milk/milk replacer. Frequent cleaning of feeding equipment will help ensure kids consume the milk. Water should be available 24 hours/day.

For your interest, compared to the other farms, your birth weights were inline with the average of 3.9 kg for females, but slightly below the 4.3 kg average for males.