THESIS

TIME LOST TO DISEASE IN DAIRY CATTLE: ASSOCIATIONS BETWEEN TWO CONSECUTIVE LACTATIONS

Submitted by

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ABSTRACT

TIME LOST TO DISEASE IN DAIRY CATTLE: ASSOCIATIONS BETWEEN TWO CONSECUTIVE LACTATIONS

In the dairy industry, individual diseases and their effects are normally studied independently. However, in many cases the diseases are all related. The diverse effects of these diseases provide the foundation for creating a measure that incorporates morbidity and removal (death or culling) measures and evaluates the impact diseases can have during lactation. This summary health measure is called the disease-adjusted lactation (DALact) and it represents time lost due to disease and injury. The DALact is a time-based summary measure that represents a new approach to assess the impact of diseases in a lactation.

The objective of this study was to evaluate the association between time lost due to specific diseases and total time lost due to diseases in two consecutive lactations using the DALact.

Health and removal (culling and death) data were obtained from a Colorado dairy with approximately 1,400 lactating cows. A total of 803 cows in their second or greater lactation that calved, were sold, or died from July 1, 2015, through June 30, 2016, were selected. Health data were collected from Dairy Comp 305 for each most recently completed lactation and from the previous lactation. Health events included calving injury, displaced abomasum, diarrhea, hypocalcemia, ketosis, lameness, mastitis, metritis, musculoskeletal injuries, pneumonia, and retained placenta. All cow-level data were imported into SAS® for validation, calculation of DALact and modeling. The DALact was calculated by adding the Days Lost due to Premature Death or

Culling (DLRD) and the Days Lost due to Illness (DLI). DLRD was calculated as the difference between the average completed lactation days in milk for that herd and the days in milk at culling or death. The DLI was the product of the number of cases multiplied by previously established disability weights and estimated disease durations (days) for a specific disease. The PROC GLM procedure was used to model the association of DALacts between the 2 consecutive lactations. A p-value of $\leq$0.05 was considered significant.

Positive significant associations (P<0.001) were found between the DALact of the previous lactation and the current lactation for lameness and mastitis. The total DALact of the previous lactation was significantly associated (P<0.001) with the total DALact of the current lactation. Significant associations (P<0.001) were also found between the mastitis and lameness DALact of the precious lactation with the total DALact of the current lactation.

Identification of diseases and reasons for removal that significantly affect time lost during two consecutive lactations will help producers focus management and preventive measures on diseases having the greatest impact on future productivity and wellbeing.

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CHAPTER 1: INTRODUCTION

The dairy industry has changed significantly in recent decades. Average herd size has increased, a large variety of technologies have been incorporated, and milk production has increased dramatically. Some of the major diseases affecting dairy cattle have been increasing in the percentage of cows affected (e.g., mastitis, lameness) while other diseases have been decreasing (e.g., milk fever, respiratory problems, retained placenta, diarrhea and displaced abomasum) (USDA, 2017). Veterinarians and producers still need to focus efforts on lowering disease morbidity and improving the welfare of the animals.

Dairy profitability relies on milk production, reproduction, and marketability of cows for meat as they leave the herd (Gröhn et al., 2003). Therefore, diseases affecting any of those areas of production will alter the economics of a farm. The negative effects of diseases occur through reduced welfare, lower cow productivity and reproductive performance, treatments cost, premature culling and mortality losses (Grohn et al., 1998, Wells et al., 1998). For example, mastitis has diverse consequences including effects on milk production, conception rates and increases in mortality and culling risk (Cha et al., 2014).

Culling decisions are affected by disease status, milk production, conception status, stage of lactation and parity (Grohn et al., 1998). Diseases can influence these decisions directly when they are acute and severely affect an animal, or indirectly, when disease reduces milk production and/or fertility (Gröhn et al., 2003). It has been reported that milk production significantly affects culling (Rajala-Schultz and Gröhn, 1999) as cows that do not reach a heard-level minimum of milk production are more likely to be culled (Grohn et al., 1998). Similarly, high production has been identified as a factor that protects individual cows from culling (Smith et al., 2000). Regarding reproduction, non-pregnant cows are more likely to leave the herd (Gröhn et al., 2003, De Vries et al., 2010) and longer time to conception increases risk of culling (De Vries et al., 2010).

In the dairy industry, specific diseases and their effects are commonly studied independently through frequency measures such as incidence, mortality percentage, culling risk, etc. However, health disorders are interrelated. As a reference, typical outcome measures of standard diseases of concern are presented in Tables 1.1, 1.2, 1.3, 1.4 and 1.5 and described more in detail within this Chapter. As the dairy industry moves forward, it should evaluate new methods for addressing the impact of disease and acknowledge the strong link between morbidity, forced removals and mortality. Summarizing these impacts could help identify areas to improve animal health and well-being on an individual farm basis.

Table 1.1. Published frequency measures for dairy cattle

Disease	Lactational Incidence Risk (%)	Prevalence (%)	Cows affected over a year period (%)	Source
Diarrhea			1.1	USDA (2017)
Ketosis	1.3 to 18.3			Kelton et al. (1998)
	5[1] – 7[2]			Bar et al. (2007)
		18.8[5]		Dubuc and Denis-Robichaud (2017)
			4.2	USDA (2017)
Subclinical	22.3	28.9		McArt et al. (2012)
Ketosis (SCK)		21.8		Suthar et al. (2013)
Lameness	1.8 to 30			Kelton et al. (1998)
		21.1[3] - 23.9[4]		Cook (2003)
		25.0		Espejo et al. (2006)
			16.9	USDA (2017)
Left Displaced	6.3			Kelton et al. (1998)
Abomasum (LDA)	10 to 20			Doll et al. (2009)
	3[1] - 4[2]			Bar et al. (2007)
			2.2	USDA (2017)
	3 to 7			Reynen et al. (2015)
Mastitis	18			Grohn et al. (1997)
	12[1] – 24[2]			Bar et al. (2007)
			24.1	USDA (2017)
Metritis	2 to 37			Kelton et al. (1998)
	4.2			Grohn et al. (1998)
	7.6			Gröhn et al. (2003)
	8[1] – 4[2]			Bar et al. (2007)
			6.9	USDA (2017)
Milk Fever	0.03 to 22.3			Kelton et al. (1998)
	2[2]			Bar et al. (2007)
			2.8	USDA (2017)

	0 to 10			DeGaris and Lean (2008)
	5			Reinhardt et al. (2011)
Pneumonia	3[1] – 2[2]			Bar et al. (2007)
			2.8	USDA (2017)
Retained Placenta	1.3 to 39.2			Kelton et al. (1998)
(RP)	8.3 to 28.1			Han and Kim (2005)
	6[1] – 11[2]			Bar et al. (2007)
		4.9[5]		Dubuc and Denis-Robichaud (2017)
			4.5	USDA (2017)

[1] Primiparous cows
[2] Multiparous cows
[3] Summer
[4] Winter
[5] Period prevalence

Table 1.2. Economic cost

Diseases	Cost per Case ($)	Source	
Ketosis	145	Kelton et al. (1998)	
	211	McArt et al. (2013)	
	77[1] – 181[2]	Liang et al. (2017)	
SCK	50 to 100	McArt et al. (2013)	
Lameness	305	Kossaibati and Esslemont (1997)	
	302	Kelton et al. (1998)	
	185[1] – 333[2]	Liang et al. (2017)	
LDA	340	Kelton et al. (1998)	
	432[1] – 639[2]	Liang et al. (2017)	
Mastitis	227	Kossaibati and Esslemont (1997)	
	179	Bar et al. (2008b)	
	326[1] – 427[2]	Liang et al. (2017)	
Metritis	329 to 386	Machado et al. (2014)	1
	172[1] – 263[2]	Liang et al. (2017)	
Milk Fever	273	Kossaibati and Esslemont (1997)	
	335	Kelton et al. (1998)	
	247[2]	Liang et al. (2017)	
RP	370	Kossaibati and Esslemont (1997)	
	285	Kelton et al. (1998)	
	206	Guard (1999)	
	150[1] – 313[2]	Liang et al. (2017)	

Primiparous cows
[2] Multiparous cows

Table 1.3. Impacts on Longevity

Diseases	Likelihood of Death	Likelihood of Culling	Mortality	Proportional Culling Rate (%)	Source
Ketosis			1.3[1]	0.2	Gardner et al. (1990)
		NA			Beaudeau et al. (1994)
		Increased			Grohn et al. (1998)
		Increased			Beaudeau et al. (2000)
	Increased				Gröhn et al. (2003)
	Increased	Increased			Ospina et al. (2013)
SCK	Increased	Increased			Raboisson et al. (2014)
Lameness		Increased			Sprecher et al. (1997)
		Increased			Rajala-Schultz and Gröhn (1999)
		Increased			Bicalho et al. (2007)
LDA			5.6[2]		Constable et al. (1992)
		Increased			Rajala-Schultz and Gröhn (1999)
		Increased			Beaudeau et al. (2000)
Mastitis		Increased			Erb et al. (1985)
			1.1[1]	8.7	Gardner et al. (1990)
		Increased			Grohn et al. (1997)
	Increased	Increased			Bar et al. (2008a)
		Increased			Bell et al. (2010)
	Increased				Cha et al. (2013)
Metritis			1.4[1]	0.4	Gardner et al. (1990)
		Increased			Beaudeau et al. (1995)
		NA			Grohn et al. (1998)
		Increased			Rajala-Schultz and Gröhn (1999)
Milk Fever			4[1] - 8.9[2]	0.1	Gardner et al. (1990)
		Increased			Grohn et al. (1998)

		Increased			Rajala-Schultz and Gröhn (1999)
	Increased				Gröhn et al. (2003)
RP			0.1[1]	0	Gardner et al. (1990)
		Increased			Beaudeau et al. (1994)
		NA – Incr.			Grohn et al. (1998)
		NA			Dubuc et al. (2011)
	Increased				Cha et al. (2013)

[1] Mortality (%)
[2] Case fatality rate

Table 1.4. Impacts on milk production

Diseases	Kg/Day	305-d (Kg)	Complete Lactation (Kg)	Source
Ketosis	NA – 4 to 10			Fourichon et al. (1999)
	1 to 2[1] – 1 to 4[2]			Bar et al. (2007)
SCK	NA - 3			Fourichon et al. (1999)
			300 to 450	Duffield (2000)
	1.2			McArt et al. (2012)
		250		Raboisson et al. (2014)
Lameness	1.5 to 2.8			Rajala-Schultz et al. (1999a)
	1.5			Warnick et al. (2001)
		360		Green et al. (2002)
			270 to 574	Huxley (2013)
LDA			353[1] - 700[2]	Detilleux et al. (1997)
	1 to 11[1] – 2 to 16[2]			Bar et al. (2007)
Mastitis			100 to 500	Shim et al. (2004)
	1 to 4[1] – 1 to 6[2]			Bar et al. (2007)
Metritis	1 to 3[1] – 1 to 6[2]			Bar et al. (2007)
		NA[1] – 259[2]		Dubuc et al. (2011)
Milk Fever		NA	NA	Fourichon et al. (1999)
	1 to 3			Rajala-Schultz et al. (1999a)
	1 to 2[2]			Bar et al. (2007)
RP		NA	175	Rajala and Gröhn (1998)
	1 to 3[1] – 1 to 6[2]			Bar et al. (2007)
		753		Dubuc et al. (2011)

[1] Primiparous cows
[2] Multiparous cows

Table 1.5. Impacts on reproduction

Diseases	Days To First Service	Conception Rate at First Service	Days Open	Probability of Pregnancy / Risk of Pregnancy	Source
Ketosis	Increased	Decreased	Increased		Fourichon et al. (2000)
SCK				Decreased	Walsh et al. (2007)
		NA	NA		McArt et al. (2012)
	Increased		Increased		Raboisson et al. (2014)
Lameness	Increased		Increased		Sprecher et al. (1997)
				Decreased	Melendez et al. (2003)
				Decreased	Bicalho et al. (2007)
LDA	NA	NA	NA	NA	Fourichon et al. (2000)
Mastitis	Increased	Decreased			Santos et al. (2004)
				Decreased	Fuenzalida et al. (2015)
Metritis	Increased	Decreased	Increased		Fourichon et al. (2000)
Milk Fever	NA	NA	NA	NA	Fourichon et al. (2000)
	Increased		Increased		Dobson and Smith (2000)
RP		Decreased			Gröhn and Rajala-Schultz (2000)
	Increased		Increased		Han and Kim (2005)
	NA	NA	NA	NA	Könyves et al. (2009)
	Increased		Increased		Gunay et al. (2011)

[1] Primiparous cows
[2] Multiparous cows

1.1 HEALTH EVENTS OF INTEREST

1.1.1 Calving Injury

Calving injury or trauma involves lesions and injuries that occur during parturition, such as lacerations of the birth canal (Cuneo et al., 1993), perineal lacerations, rectovaginal fistula (Farhoodi et al., 2000), dislocation of the coxofemoral joint (Radostits, 2007) and peripheral nerve damage or paralysis that can affect the femoral nerve, sciatic nerve, peroneal nerve, tibial nerve, obturator nerve (Smith, 2009) or the root of the sixth lumbar nerve (The Merck Veterinary Manual, 2005). Musculoskeletal and nerve injuries, as well as other diseases (e.g. milk fever, cancer, neurological alterations), can cause cows to be unable to stand (Green et al., 2008). They are then referred to as downer cows or nonambulatury disabled cows, which have been reported to be within a day of calving in 58% of the cases and mostly caused by calving related injuries (Cox et al., 1986, Stull et al., 2007). If an animal remains in recumbency for more than 6 hours it might develop a secondary recumbency or downer cow syndrome, where there is secondary damage to nerves and muscles due to pressure (Green et al., 2008). Unfortunately, calving injury is not recorded as a health event on all dairy farms, but it is recorded as a cause of death by some dairies. This might explain why we found no publications that refer to calving injury as a singular cause of morbidity.

Dystocia is related to calving injury since it underlies many of the injuries mentioned above. It has been defined as calving difficulty resulting from prolonged spontaneous calving or prolonged or severe assisted extraction (Mee, 2004). It must be clarified that not every dystocia will have a calving injury as an outcome, and not every calving injury is associated with a dystocia. In the US, dystocia is estimated to affect 4.7% of the cows (USDA, 2017), while the incidence reported in Europe and Oceania ranges from 2% to 9% (Rumph and Faust, 2006, Steinbock, 2006, Mee, 2008) and from 3% to 12.6% (Stevenson, 2000, Xu and Burton, 2000), respectively.

An association between dystocia and death and culling has been described in previous articles. Gardner et al. (1990) reported a case fatality rate for dystocia of 7.3%. This high case fatality rate might indicate the presence of a calving injury related to dystocia. Lombard et al. (2003) found that cows with severe cases of dystocia were 1.6 times more likely be culled during that lactation and 4 times more likely to die in the first 14 DIM than cows that did not suffer from dystocia. Unfortunately, this study did not identify the cause of death in order to have a more accurate idea of the impact of calving injury proximate. The same study also reported a significant decrease in milk production for the first 30 DIM in cows with dystocia. Regarding reproductive performance, Fourichon et al. (2000) reported that dystocia increased days to first service and lowered conception rate at first service.

Future studies of calving injury should stablish an accepted definition among producers and veterinarians and evaluate the magnitude of its impact. Producers should be encouraged to record calving injury on a regular basis to identify the problem and to allocate resources toward prevention.

1.1.2 Diarrhea

Diarrhea can be a clinical manifestation caused by a primary bowel disease or a non-specific response to diverse diseases (Smith, 2009). It is characterized by an increase in frequency, fluidity or volume of bowel movements. The most common diseases associated with diarrhea in cattle are: Bovine viral diarrhea (Bovine viral diarrhea virus), salmonellosis (*Salmonella spp*), winter dysentery (*Coronavirus*), Johne's disease (*Mycobacterium paratuberculosis*), simple indigestion due to dietary or nutritional factors, rumen acidosis due to grain overload (The Merck Veterinary Manual, 2005, Radostits, 2007, Smith, 2009), and parasitosis (The Merck Veterinary Manual, 2005, Radostits, 2007). Diseases affecting other systems, such as displaced abomasum, metritis, peritonitis can also cause diarrhea due to generalized toxemia or alteration of the intestinal motility (Smith, 2009).

Although there are clearly a variety of causes of diarrhea, experience suggests that it is often recorded as a singular health event on dairy farms. Due to the multifactorial nature of this clinical manifestation, there are few studies referring to the economic cost, frequency measures and impact on longevity that diarrhea can have on adult dairy cattle. Further studies to identify these impacts as a whole are needed if diarrhea is to be documented as a standalone event.

More meaningful and specific diagnostics and recording systems are necessary in the dairy industry to assess the impact of the various etiologies that eventuate in diarrhea.

1.1.3 Ketosis

Ketosis or hyperketonemia is one of the most important metabolic diseases that affects dairy cattle. It occurs during early lactation and as a response to poor adaptation to the increase in energy demand that characterizes this period (Duffield et al., 2009, Seifi et al., 2011). Ketosis occurs when concentrations of ketones bodies (i.e. acetone, acetoacetate and β-Hydroxybutyrate (BHB)) in blood, urine and milk are higher than normal. The syndrome can present as subclinical ketosis (SCK) when there is an absence of clinical signs and the serum concentration of BHB is around 1,200 μmol/L, or as clinical ketosis (CK) when the serum concentration of BHB is around 1,400 μmol/L and clinical signs are present such as decreased appetite, dry feces, loss of body weight and in some cases nervous signs (vigorous licking, apparent blindness) (Duffield, 2000, McArt et al., 2012, Gordon et al., 2013, Suthar et al., 2013, Berge and Vertenten, 2014, Raboisson et al., 2014). Diagnosis can be made by the identification of clinical signs and by measuring ketone bodies in blood, urine or milk (Ospina et al., 2013, Berge and Vertenten, 2014). Risk factors for ketosis include low energy intake, high BCS at calving and diseases that compromise feed intake (Blood, 2000).

A wide range of frequency measures has been reported for ketosis and SCK (Table 1.1) including estimates of lactational incidence risk (LIR) and prevalence.

Ketosis can have a costly economic impact due to its potentially high prevalence or incidence within a herd. Treatment costs, decrease in milk production, increased days open and higher culling risk were included in the calculation of the costs of ketosis and SCK (Table 1.2).

Berge and Vertenten (2014) stated their opinion that the impact of other diseases during early lactation in cows with ketosis should also be included in the calculations of the cost of ketosis.

Impact on Longevity

Ketosis can influence mortality and culling. Multiple investigators have concluded that there are negative effects of SCK and ketosis on mortality and (Table 1.3). Beaudeau et al. (2000) reviewed 5 studies that showed cows with ketosis had approximately 2 times greater risk of culling in different stages of their lactation. In contrast, an older study from Beaudeau et al.(1994) showed no association between ketosis and culling.

The possible negative effects of ketosis on milk production and reproduction can affect culling decisions. Varied results regarding the effects on milk production were reported in a review performed by Fourichon et al. (1999),   while other studies have found negative effects of ketosis (2007) and SCK (2000, 2012, 2014) (Table 1.4).

Several studies have looked at the impact of ketosis on reproduction. Some reported no differences between cows with SCK and without SCK (2012) while others have found detrimental effects of ketosis and SCK on reproductive indicators (Fourichon et al., 2000, Walsh et al., 2007). For example, Raboisson et al. (2014) reported that cows with SCK had a longer calving-to-first-service interval and calving-to-conception interval of 8 and 16-22 more days, respectively. Table 1.5 summarizes studies that have address this issue.

It is important to emphasize the meaningful impact that can occur with subclinical ketosis. Since SCK is not detectable by the observation of clinical signs, routine monitoring to identify affected animals should be considered as a basic management tool. Good practices to avoid the risk factors, especially high BCS at calving, should be implemented in dairy herds to prevent both CK and SCK.

1.1.4 Lameness

Lameness occurs when cows develop an abnormal gait in response to pain in the foot or limb. The pain is related to the locomotor system and its most common causes are traumatic, infectious and metabolic (Radostits, 2007, Smith, 2009). In dairy cattle, almost 90% of lameness is related to the foot (Shearer et al., 2012), where the disorders causing lameness are classified as infectious (interdigital dermatitis, digital dermatitis, interdigital phlegmon) or non-infectious (laminitis, sole hemorrhages, sole ulcers, white line disease, vertical and horizontal fissures, thin soles, double sole, foreign bodies in sole and corkscrew claw) (Shearer, 2009, Van Amstel, 2009). Some causes of lameness that are not related to the hoof are: joint dislocations (i.e. coxofemoral luxation, patellar luxation, fetlock dislocation, hip dysplasia), fractures, arthritis and trauma (The Merck Veterinary Manual, 2005). To identify lame cows a locomotion scoring system that assesses the posture and gait can be used. After identifying lameness examination of the affected limb should identify the cause of the lameness (Radostits, 2001, Juarez et al., 2003). Some cases require further assessment such as radiography (The Merck Veterinary Manual, 2005) . Lameness severity can be evaluated by a locomotion scoring system, where 1 is assigned to non-lame cows and 5 to severely lame cows (Sprecher et al., 1997, Thomsen et al., 2008). Known risk factors for lameness are diet, high milk production, poor body condition and environmental factors (housing, stall surface) (Sanders et al., 2009).

Lameness frequency measures vary considerably between herds (Table 1.1). Shearer et al. (2012) reported results from the Alberta Dairy Hoof Health Project, where 48.6% of the cows included form Alberta and 57.5% from British Columbia had at least one lesion causing lameness over a period of almost 9 months. The main lesions reported were digital dermatitis, sole ulcer, white line lesion, sole hemorrhage and toe ulcer representing 44.9%, 16.5%, 14.1%, 6.1% and 4.9%, respectively, of the lesions for Alberta, and 40.3%, 12.8%, 13.2%, 7.6% and 5.2%, respectively, of the lesions for British Columbia. Sanders et al. (2009) reported annual incidence risk of 9.8% for thin-sole toe ulcers, 7.8% for sole ulcers, 6.3% for thin soles, 4.8% for white line disease, 3.7% for heel ulcers, 3.1% for leg injuries, 2.1% for sole puncture and 0.9% for toe ulcer. They also reported that, of the total reported lesions, 20% corresponded to thin-sole toe ulcers, 20% to other lesions including digital dermatitis, acute laminitis, unclassified sole hemorrhage, and miscellaneous lesions,16% to sole ulcers, 13% to thin soles, 10% to white line disease, 8% to heel ulcers, 6% to leg injuries, 4% to sole punctures and 2% to toe ulcers. The most recent study from the USDA:APHIS:VS National Animal Health Monitoring System (NAHMS) reported that 2.2% of the cows were affected by injuries (USDA, 2017).

Lameness is one of the most costly diseases of dairy cows (Radostits, 2001, Juarez et al., 2003). Estimated cost have been calculated in several studies (Table 1.2) where treatment, extra time demands on farmer/workers, decreased milk production, death/culling and reduced reproductive performance were taken into account. These last three impacts account for the main losses associated with lameness (Kossaibati and Esslemont, 1997, Radostits, 2001, Huxley, 2013). Cha et al. (2010) calculated the cost of a case of sole ulcer at $216.07, of digital dermatitis at $132.96 and of foot rot at $120.70.

Impact on Longevity

Lameness has been associated with culling in several studies (Table 1.3) and has been reported as one of the main reasons for culling in dairy cows (Chiumia et al., 2013), but more research is needed regarding its relationship with mortality. The NAHMS Dairy 2007 (USDA, 2008) survey reported that 20% of adult cow deaths were due to lameness or injury. McConnel et al. (2008) compared herds with low, moderate and high level of lameness and found that herds with moderate and high levels of lameness had 2.34 and 2.89 times higher odds of having mortality compared to herds with low lameness level.

Lameness can also impact culling due to its effects on reproduction and milk production. Studies that have evaluated impact of lameness on productivity are consistent in reporting decreased milk production (Table 1.4).

Several studies have shown negative impacts of reproduction resulting from lame cows (Table 1.5) (Sprecher et al., 1997, Melendez et al., 2003, Bicalho et al., 2007). Bicalho et al. (2007) found that lame cows were at a 15% lower risk of pregnancy than cows without lame events and cows with a severe lameness score were at 25% lower risk of pregnancy than cows with a lower lameness score. This suggests that the severity of lameness is related to the intensity of the negative impact on reproduction.

1.1.5 Left Displaced Abomasum

Left displaced abomasum (LDA) is mainly a disease of high producing cows (Radostits, 2007). It is a multifactorial syndrome where abomasal atony is always present. A distended abomasum filled with gas and a small under-filled rumen can lead to this condition. It can be diagnosed by percussing the left side of the animal between the ninth and twelfth ribs while ausculting for a high pitched tympanic sound. The majority of the cases occur during the transition period (first 30 to 40 days postpartum) (Blood, 2000, Radostits, 2007, Smith, 2009). Some risk factors associated with LDA are breed, metabolic disorders, diet, presence of other diseases, twin pregnancy early lactation (Doll et al., 2009).This may be attributable to negative energy balance that occurs in postpartum cows (Van Winden et al., 2003) or to changes in the position of the rumen, uterus and abomasum after parturition. Right displaced abomasum (RDA) can occur under the same conditions as LDA, but it is less common (Blood, 2000).

The frequency measures of LDA have been reported to be lower than 10% (Table 1.1), but higher numbers up to 20% have been determined for some herds (Doll et al., 2009). The incidence of RDA is lower than that of LDA, with an incidence ratio of LDA:RDA of 7.4:1 (Blood, 2000).

The cost of a case of LDA (Table 1.2) incorporates decreased milk production, treatment and culling (1998). Van Winden and Kuiper (2003) reported that the cost of a displaced abomasum (DA) case can vary between $250 to $450 and that in North America, DA has the potential to cause losses up to 220 million dollars.

Impact on Longevity

Several studies have reported the negative effects of LDA on culling and mortality (Table 1.3). A review conducted by Beaudeau et al. (2000) reported an increased risk of culling between 1.3 and 6.8 times for cows with DA. Rajala-Schultz and Grohn (1999) found that cows with DA had 7.1 and 2.7 times greater risk of being culled than cows without DA during the first 30 DIM and the month later (DIM 31 to 60), respectively. Boulay et al. (2014) reported that negative outcomes, that included death or culling during the first 30 days after surgical correction of LDA, ranged from 12% to 17%.

Reduced milk production due to LDA can be an indirect cause of culling (Beaudeau et al., 2000) and there is significant research supporting the negative impact of LDA on milk production (Table 1.4). Failure in reproductive performance associated with various diseases can be a cause for culling, but there is no literature to support this association with LDA. Two studies that looked at the effect of LDA on reproduction found no association (Fourichon et al., 2000, Gröhn et al., 2003) (Table 1.5).

Although LDA is not one of the most prevalent diseases in dairy cattle, its potential to generate significant economic costs and to reduce the longevity of affected cows in the herd make

LDA one of the most important diseases of dairy cows (Rajala-Schultz and Gröhn, 1999, Beaudeau et al., 2000, Van Winden and Kuiper, 2003, Boulay et al., 2014)

1.1.6 Mastitis

Mastitis is one of the most common diseases in dairy cows. It can be defined as inflammation of the parenchyma of the mammary gland and its cause can be either infectious or physical. Depending on severity, mastitis can be classified as clinical (CM) or subclinical (SM). Clinical mastitis manifests with visible changes to the milk and mammary gland, and has the potential to systemically affect the animal. Subclinical mastitis does not lead to obvious changes in the milk and mammary gland but can be detected by indirect tests (e.g. somatic cells counts, California mastitis test, electrical conductivity of the milk) (Radostits, 2007, Smith, 2009).

Previous studies have reported LIR for CM (Table 1.1). CM incidence is higher in multiparous than in primiparous cows for the first (LIR 24% vs. 12%), the second case (LIR 8% vs. 2%) and the third case of CM (LIR 3% vs. 1%) (Rajala-Schultz et al., 1999b, Bar et al., 2007).

Mastitis is one of the most costly diseases in dairy cows (Kossaibati and Esslemont, 1997) mainly because of reduction in milk production (Shim et al., 2004). The range of estimated costs of mastitis are shown in Table 1.2.

Impacts on Longevity

Mastitis can affect longevity by increasing the risk of death (Table 1.3). One study showed that multiparous and primiparous cows with an episode of CM had 2.3 and 4.1 higher odds of dying, respectively, compared to cows without CM. These odds increased if there were multiples episodes of CM (Bar et al., 2008a). Culling is another aspect of longevity that is affected by mastitis (Table 1.3). Mastitis is one of the main causes of culling (Cha et al., 2013) and it is a risk factor during the whole lactation (Grohn et al., 1997, Grohn et al., 1998, Rajala-Schultz and Gröhn, 1999, Beaudeau et al., 2000). A study reported that multiparous cows with CM were 3.4 times more likely to be culled the same month they had a mastitis case, and 2.9 times more likely to be culled the month after they had a mastitis case compared to cows without CM. Overall, cows of all parities had a higher risk of being culled for up to 2 month after an episode of CM (Bar et al., 2008a).

The impact on culling can also be related to adverse effects on reproduction and/or reduced milk production. Mastitis has a detrimental effect on milk production (Table 1.4) that can be long term. Comparisons of cows with and without CM have demonstrated that the decrease in milk after a CM episode can be observed through the end of a lactation (Rajala-Schultz et al., 1999b, Bar et al., 2007, Fogsgaard et al., 2015). Bar et al. (2007) estimated that cows with at least one episode of CM in their previous lactation produced 1.2 kg/d less milk in the next lactation compared to non-affected cows. In reproduction, both SM (Lavon et al., 2011, Fuenzalida et al., 2015) and CM can have a negative effects (Table 1.5). A study showed that cows with a case of CM before their first service had around 25 more days open and 6% lower conception rate at first service than cows without a case of CM before their first service (Santos et al., 2004).

Numerous studies show the varied negative effects of mastitis. Taking into account that mastitis can affect a high proportion of animals within a herd, the consequences can be large, including low milk production, poor reproductive performance, premature removal and death of the affected animal.

1.1.7 Metritis

Metritis is a disease of the early lactation period. It can occur during the first 2 to 3 weeks postpartum. It can be defined as an inflammation of the layers of the uterine wall. Most cases are caused by bacterial infections. With metritis, the lumen of the uterus is filled with a purulent or fetid watery red-brown discharge, leading to an abnormally enlarged uterus. Severe cases of metritis, often called puerperal metritis, present with systemic signs such as fever, depression and decreased milk production (Sheldon et al., 2006, Smith, 2009). The active disease can last between 2 and 10 days (Radostits, 2007). Retention of fetal membranes, the calving environment, twins, dystocia and stillbirth are risk factors for metritis (Sheldon et al., 2008, Ghavi Hossein-Zadeh and Ardalan, 2011). Diagnosis of metritis is based on abnormal uterine size within the first three weeks after calving plus abnormal uterine discharge detected on a physical examination. Severe cases are diagnosed when are systemic signs in addition to uterine abnormality (Sheldon et al., 2006, Smith, 2009).

Very broad ranges of LIR of metritis have been reported including studies of conventional and pasture based dairies (Table 1.1).

Economic cost of metritis hasn't been extensively studied. Studies have included cost of treatments, decreased milk production, increased culling risk and poor reproductive performance in the calculation of the cost of a case (Table 1.2).

Impacts on Longevity

Many studies have looked at the association of metritis and culling and contradictory findings have been reported (Table 1.3). Rajala-Schultz and Grohn (1999) found that cows with early metritis (0 to 30 DIM) were 2.2 times more likely to be culled during the first 30 DIM and 1.4 times more likely to be culled at the end of the lactation. This suggests that some producers evaluate the health history of a cow to decide if she is a culling candidate.

When making the decision to cull a cow, milk production and reproductive performance can indirectly influence the farmer or manager (Beaudeau et al., 1995). Varied results have been reported regarding the influence of metritis on milk yield (Table 1.4). A meta-analysis of studies from 1960 to 1998 in intensive dairy regions from North America, Europe, Asia and Oceania summarized effects of metritis on reproduction. The findings demonstrated an association between metritis and 8.2 additional days to first service, a 21.5% lower conception rate at first service, and 17.9 additional days to conception (Table 1.5) (Fourichon et al., 2000).

The associations or effects mentioned above have the potential to increase the risk of cows with metritis of being culled, and thus negatively impact the longevity of cows.

1.1.8 Milk Fever

Milk fever (MF), also known as parturient paresis or hypocalcemia, is a metabolic disease that is most common in high producing dairy cows (Blood, 2000). A generalized muscle weakness occurs due to hypocalcemia and can progress to unconsciousness and death. This syndrome mostly affects mature cows after parturition due to an increased demand for calcium during milk production, but can also affect cows throughout the whole lactation (Goff, 2008). Hypocalcemia can have a subclinical presentation, where the total blood calcium is between 1.4 and 2.0 mmol/L and the cow does not show any clinical signs. Clinical hypocalcemia tends to present with a total blood calcium lower than 1.4 mmol/L (Roche and Berry, 2006, DeGaris and Lean, 2008). Clinical signs include: tremors, ataxia, depression, sternal recumbency, hypothermia and cold extremities, tachycardia with decreased intensity of heart sounds, dry muzzle, and dilated pupils (Blood, 2000, The Merck Veterinary Manual, 2005). Known risk factors for MF are high production levels, postpartum period in aged cows (cows between 5 and 10 years old), diet (Ca, Mg and P content and cation-anion difference) and high body condition score (>3.5) (Blood, 2000, DeGaris and Lean, 2008).

Studies report a large variation in the frequency measures between herds for MF (Kelton et al., 1998, Roche and Berry, 2006, DeGaris and Lean, 2008) and studies from North America, Europe and Australia support this (Table 1.1). Reinhardt et al. (2011) published a study based on the NAHMS 2002 Dairy study data that found the incidence of clinical MF to be 5%, with evidence of subclinical hypocalcemia in 25%, 41%, 49%, 51%, 54%, and 42% of 1st to 6th lactation cows, respectively.

MF has the potential to be a very costly disease. Studies that estimated the cost per case accounted for treatment, reduced milk production, increased days open, labor time, veterinary service and mortality (Table 1.2).

Impacts on Longevity

Negative impacts of MF on mortality and culling have been reported (Table 1.3). Gardner et al. (1990) found that MF was among the five most frequent cause of death reported by producers in California herds, having a proportional mortality rate of 8.9%.They demonstrated a 4% case-fatality rate for MF and a 0.1% of culls linked to MF. Effects on culling were reported by Rajala-Schultz and Gröhn (1999), they found that cows with MF were 2.9 times more likely to be culled during the first 30 DIM when compared to cows without MF.

Studies have reported conflicting results regarding the impact that MF can have on reproduction and milk production (Table 1.4). Regarding reproduction, studies have found negative association with MF (Table 1.5) reporting ,for example, that the calving to conception intervals were 13 days longer for cows with MF compared to cows without MF (2000). On the other hand, in a meta-analysis where 6 studies were analyzed, the author concluded that there was no association between MF and reproduction (Fourichon et al., 2000).

The studies cited in this review present evidence that MF may have important repercussions throughout lactation, even if most cases are concentrated very early in the lactation.

1.1.9 Pneumonia

Pneumonia is an important disease for dairy cattle. It causes inflammation of the lung tissue and bronchi that reduces the gaseous exchange between the alveolar air and the blood (Blood, 2000). Primary agents, mostly viral, invade the tissue of the respiratory tract and foster the establishment and replication of secondary agents, mainly pathogenic bacteria, which are responsible for causing pneumonia (Panciera and Confer, 2010). Fever, depression and pathological breathing sounds are the clinical signs of animals suffering from pneumonia. The diagnosis can be made through the identification of abnormal breathing sounds with a stethoscope and by ruling out other causes of fever and depression. (Virtala et al., 1996).

Bar et al. (2007) reported a LIR for pneumonia of 3% for primiparous and of 1% for multiparous dairy cows. Miller and Dorn (1990) reported an annual prevalence of pneumonia of 19 cases per 100 cow-years for dairy cattle. The National Animal Health Monitoring System 2007 study indicated that in a one year period 3.3% of dairy cows were identified with pneumonia by the dairy employees and 11.3% of cow deaths were due to pneumonia. This is in contrast to 12.4% of preweaned and 5.9% of weaned calves diagnosed with pneumonia, with pneumonia accounting for 22.5% and 46.5% of preweaned and weaned calf deaths, respectively (USDA, 2008).

Studies estimating the cost of pneumonia in dairy cattle are relatively old (Kaneene and Scott Hurd, 1990, Miller and Dorn, 1990, Sischo et al., 1990) and probably do not represent the current cost of the disease. A study that used information from 1986 and 1987 estimated the total cost of pneumonia to be $9.08 per cow-year, including the cost of prevention and occurrence. The cost of occurrence included costs associated with cows that died of pneumonia, weight loss, veterinary costs, labor and milk loss (Miller and Dorn, 1990). The following two studies used data collected for the National Animal Health Monitoring System. A study that used data collected from Michigan dairies estimated the total cost of pneumonia to be $3.95 per cow per year and $14.71 per calf per year, also including prevention costs (Kaneene and Scott Hurd, 1990). A study that used data collected in California estimated the total cost of pneumonia to be $ 9.84 per calf per year. This study only included the costs associated with occurrence without accounting for preventive costs (Sischo et al., 1990).

Impact on Longevity

Few studies have addressed the impact of pneumonia on mortality and culling of dairy cows. McConnel et al. (2008) found that herds with high and moderate levels of respiratory problems had 2.75 and 1.71, respectively, higher odds of being a herd with high levels of mortality compared with herds with fewer respiratory problems. Dohoo and Martin (1984) reported an association between respiratory disease and increased risk of culling during early lactation. Cows with respiratory problems were 7.8 times as likely to be culled compared to cow without respiratory problems. Sharifi et al. (2013) reported an increased risk of culling of 5.17 times for cows with respiratory problems compared to cows without respiratory problems. Conversely, Beaudeau et al. (1994) did not find a significant association between pneumonia and culling.

As mentioned previously, diseases can also have an effect on culling due to negative impact on milk production and reproduction, but this is another aspect of pneumonia that very few studies have addressed. Bar et al. (2007) found that pneumonia decreased milk production in the same week of the diagnosis 7.3 kg per day for primiparous and 8 kg per day for multiparous cows. These authors also found a decrease in milk production in primiparous cows days before the diagnosis that lasted for up to 7 to 8 weeks after the diagnosis, while in multiparous cows, decreased milk production was noted the same week as the diagnosis and lasted for up to 7 weeks. Lukas et al. (2009) found that pneumonia decreased milk production an average of 4kg per day and 254kg total over the lactation. Their study reported that the negative impact on milk production can last for up to 58 days after a diagnosis with decreased production commencing up to 9 days prior to the diagnosis.

More is known about the impacts of pneumonia on dairy calves, where negative effects have been reported in growth (Virtala et al., 1996, Ames, 1997, Donovan et al., 1998), future productivity (Gorden and Plummer, 2010, Stanton et al., 2012) and longevity (Ames, 1997, Gorden and Plummer, 2010). Studies that reviewed previous articles reported that heifers that had pneumonia as a calf were two or more times more likely to die before their initial calving and calved six months later compared to heifers that did not have pneumonia as calves (Ames, 1997, Gorden and Plummer, 2010). A recent study reported some of the different effects of pneumonia on calves (Stanton et al., 2012) Calves with pneumonia had a lower average daily gain leading to weight up to 14.4 kg less than calves without pneumonia at 13 months of age. Also at 13 months, calves that experienced pneumonia were 1.7 cm shorter. While 84% of the calves without pneumonia survived to first calving, only 66% of ones with pneumonia made it to first calving; calves with pneumonia were also in average 12 days older when they calved for the first time. The odds of calving by 25 month of age were 0.6 times lower for calves with pneumonia compared with calves without pneumonia. Heifers that had pneumonia as calves produced 1.1kg less at their first milk test. For this study pneumonia was the main cause of death, accounting for 47% of all death before first calving (Stanton et al., 2012).

The numerous studies on calfhood pneumonia clearly shows that pneumonia has an impact on longevity in calves. More and up-to-date studies are needed to evaluate the impact of pneumonia in adult cows. Calf-based studies evidence many long term negative effects of pneumonia, which can indicate that pneumonia in adult cows may also have long term effects that could be observed in later lactations, impacting the cows productive life. Studies addressing this subject would help to identify the real impact that pneumonia can have in adult dairy cattle, therefore guiding the implementation of better practices to prevent it.

1.1.10 Retained Placenta

When a placenta is not expelled within the first 24 hours after calving it is considered a retained placenta (RP) (Guard, 1999, Sheldon et al., 2008, Dubuc et al., 2011). It is caused by the failure of separation of the cotyledons and caruncles after parturition (LeBlanc, 2008, Smith, 2009). Diagnose of RP is made by the visualization of the fetal membranes hanging from the vulva (Smith, 2009) or by rectal palpation in the cases where the placenta only projects into the vagina or if it remains in the uterus with an open or closed cervix (Hillman and Gilbert, 2008). RP occurs without the presence of clinical signs (e.g. fever, depression) in the majority of the cases, and only a few cases show signs of endotoxemia (Smith, 2009). Known risk factors for RP are dystocia, stillbirth, abortion, milk fever, twin births, caesarean section, multiparous cows and induced parturition (LeBlanc, 2008, Sheldon et al., 2008, Ghavi Hossein-Zadeh and Ardalan, 2011, Gunay et al., 2011).

Similar to some of the previous diseases described, frequency measures for RP are presented in a wide range of values (Table 1.1).

The economic impact of RP shows a considerable difference among studies. Reports included treatment, labor, reduced milk production, impact on reproduction, culling and mortality to calculate estimated cost of RP cases (Table 1.2).

Impact on Longevity

The effect of RP on mortality and culling has not been studied in depth and more research is needed. Summarized results for the effects on mortality and culling are presented in Table 1.3. Results are not very definitive regarding culling. One study found that cows with a case of RP were 1.2 times more likely to be culled during their late lactation, but this result was significant only when a confidence interval of 90% was applied (1994).

RP can indirectly affect culling by having a negative impact on reproduction or milk production. The possible impact of RP on milk production has been reported in many publications, in some cases presenting contrary results (Table 1.4). Several studies support a negative effect of RP on reproduction (Table 1.5). One of those studies found that cows with RP had calving to first service intervals 6 to 8 days longer, 32 to 41 more days open and around 1 point higher service per conception rate compared to healthy cows (Gunay et al., 2011). In contrast, Könyves et al. (2009) did not find any significant association between RP and reproductive parameters**.**

Retained placenta is one of the main risk factors associated with metritis and endometritis and the negative effect on longevity may be caused by metritis or endometritis associated with a case of RP (Han and Kim, 2005, LeBlanc, 2008, Ghavi Hossein-Zadeh and Ardalan, 2011). Further studies are necessary to evaluate if this effect can be attributable exclusively to RP or to RP with metritis or endometritis.

1.2 SUMMARY CONSIDERATIONS

The literature cited above presents evidence of the various ways disease can affect dairy cattle. Diseases that occur early in lactation can impact the performance of the animal and the probability of permanence in the herd at different times throughout the lactation. One disease may also predispose the animal to other disorders such that a disease or groups of diseases may have long-term effects on the life of an animal, even in subsequent lactations.

Tables presented in this chapter show the results from a variety of studies regarding different aspect of the diseases in order to facilitate comparisons, but two clarifications must be made. First, when reviewing different studies related to a disease, some inconsistencies may be observed. For example, the disease definition may be vague in terms of symptoms or there may be differences in diagnostic protocols, or the researchers may have used records with varying consistency and accuracy. These inconsistencies may explain large variations in some of the frequency measures (Sanders et al., 2009). Second, the direct comparison of estimated case costs is not recommended due to factors such as country where the study was performed, study design and time of the study (Tarride et al., 2009). In this review, the studies accounted for similar cost components, but the time when they were performed varied considerably with the majority more than 10 years old, potentially undermining their validity today. In addition to these two clarifications, it is worth mentioning that the way diseases have been studied so far does not facilitate an integrated estimation of the burden they generate in the life of an animal. Every study referenced in this review contributed to the knowledge of the impacts of diseases, whether reporting disease frequency measurements, mortality, impact on milk production, etc., but all of these studies looked at these different impacts independently and they cannot be used alone to assess how a disease affects a dairy farm. For example, calving injury is recorded on some dairies as a reason for removal but may not be recorded as a health event. If left unrecorded as a disease state the conclusion might be that calving injuries do not impact cow health. However, if it is recorded as a culling reason and as a cause of death, the assessment of the mortality or the percentage of culling attributed to it could lead to the conclusion that calving injury clearly impacts cow longevity.

The inability to compare the cumulative impacts of disease using standard metrics, suggest it would be beneficial to create a new health measure for dairy cattle. In response to a similar concern in international public health, human medical epidemiologists created a time-based summary measure to evaluate the burden of diseases in a more standardized manner. The Disability-Adjusted Life Year (DALY) metric was designed to address this issue (Murray et al., 1994) by combining the premature deaths and disability caused by disease in a population into a single measure (Murray et al., 1994).

The dairy industry could benefit from the use of a similar measure to evaluate the impact of diseases in a herd. McConnel et al. (2017b) adapted the DALY to be used in dairy cattle and created the Disease-Adjusted Lactation (DALact). The calculation of the DALact is obtained by adding the Days Lost due to Premature Death or Culling (DLRD) and the Days Lost due to Illness (DLI), where DLRD represent the time lost to mortality and forced removal, and DLI represents the morbidity or active on-farm clinical phase of a disease, thus achieving the combination of morbidity, mortality and culling into a single measure. The DALact provides a standardized time-based measure of the burden of diseases that can help producers to identify the diseases that are causing major losses in productive time and well-being, and thus, focus management and preventive measures to try to diminish their impact. As the concept of the DALact is still evolving, various studies are being conducted to validate this measure as a tool to assess the impact of diseases. The following chapter evaluates the application of the DALact as a predictor of time lost in two consecutives lactations.

CHAPTER 2: TIME LOST TO DISEASE IN DAIRY CATTLE: ASSOCIATIONS BETWEEN TWO CONSECUTIVE LACTATIONS

2.1 INTRODUCTION

In spite of many advances in different fields of dairy production, cow health and well-being remains a primary concern for the dairy industry. The most recent study carried out by the USDA:APHIS:VS National Animal Health Monitoring System (NAHMS) reported a decrease in the percentage of cows affected by some diseases (e.g. retained placenta, milk fever, diarrhea, respiratory problems); however, and of greater relevance, it reported an increase in the percentage of cows affected by mastitis and lameness since the 2007 dairy study (USDA, 2017).

Diseases that affect dairy cattle have been studied for decades using varying outcome measures. Studies that report frequency measures of diseases, such as incidence and prevalence, are widely seen in the literature. Other studies have focused on how diseases can impact dairy cows, using different approaches to assess that question. A very common approach is to estimate the cost of a disease. Some studies have reported results through the simple estimation of the direct and indirect cost per disease case (Kossaibati and Esslemont, 1997, Kelton et al., 1998). A more recent study reported the cost for primiparous and multiparous cows for the most common diseases using a very elaborate model where direct and indirect costs were included and modeled along with market prices and herd performance factors (Liang et al., 2017)

The effects of diseases on milk production and reproductive performance are also frequent approaches for estimating the impact of disease. Regarding milk production, studies have looked at the impacts of various diseases on daily milk production (Rajala-Schultz et al., 1999a, Bar et al., 2007) or across the entire lactation yield (Huxley, 2013). Regarding reproduction, studies have looked at the effect of diseases on multiple outcomes including: days open, days to first service, and conception rate (Fourichon et al., 2000, Santos et al., 2004, Gunay et al., 2011).

Another method for studying the effects of diseases is to look at the impact that calfhood disease events can have on future productivity. Studies have looked at the association between calfhood diseases and survival, milk production, milk components, future disease occurrence (Rossini, 2004), weight gain and reproductive estimates (Stanton et al., 2012).

Other studies have investigated the relationships between diseases in consecutive lactations. Calavas et al. (1996) analyzed the association between diseases occurring in a previous lactation and the disease occurrence in the current lactation. Their results showed significant associations between cases of mastitis, lameness, retained placenta (RP), and milk fever (MF) in two consecutive lactations. A similar study conducted by Bigras-Poulin et al. (1990) demonstrated that the occurrence of RP and MF during a lactation increased the risk of RP in the following lactation. Episodes of mastitis, RP and ketosis increased the risk of mastitis in the following lactation, and RP increased the risk of ketosis in the following lactation. These studies have contributed to the body of evidence related to the cost and long-term effects of disease on the productivity and health of dairy cattle.

Regardless of the important contributions of these studies, this topic needs further research. The effects of individual diseases have been extensively studied. Disease occurrences have been studied without looking at the impacts on herd removal in the long run. Animal welfare is a concept that concerns biological functioning, natural living and affective states of the animals (Fraser et al., 1997), and it is an issue that concerns not only producers but also consumers (von Keyserlingk et al., 2009). Animal welfare lacks a measure that helps to estimate how it is affected by different diseases. The dairy industry needs better methods to assess disease, not only by focusing on the impacts on herd productivity but also on the impacts on welfare. Exploration aimed at integrating these effects could help producers know the areas of health of their livestock that may cause greater impact on well-being, productivity and removal in future lactations.

Summary measures of population health are widely used in human public health. They allow for the assessment of current and changes in population's health over time and present evidence to support the creation of public policies and interventions focused on specific diseases (Arnesen and Kapiriri, 2004, Kassebaum et al.). Efforts made by human medical epidemiologists to create a standardized measure that allows for a comparison of the burden of diseases resulted in the creation of the Disability-Adjusted Life Year (DALY) metric. The DALY is a time-based summary measure that combines deaths and disability caused by disease in a population into a single index, where loss of welfare or quality of life are included (Murray et al., 1994).

A disease-adjusted summary measure has not been implemented in the dairy industry yet. McConnel et al. (2017b) proposed the use of a measure similar to the DALY in measuring the impact of diseases on health and well-being of cows. They are adapting the DALY for use in dairy cattle and developing the Disease-Adjusted Lactation (DALact) metric. The DALact is a time-based measure that accounts for morbidity via the time lost during active on-farm clinical phases of disease, mortality, or culling and combines them into a single measure. This proposed measure represents a standardized way to evaluate the burden of diseases across the continuum of effects. It may help producers optimize their resources by targeting the diseases that are affecting the health, production and well-being to a major extent. Preliminary findings (McConnel, 2017b) from the DALact development indicate that ranking the impact of diseases on dairies using both incidence and the DALact measures provides differing assessments of the importance of diseases. In one study, incidence ranked the three most severe health issues as mastitis, lameness and metritis; whereas, the DALact ranked mastitis as the most severe disease but placed pneumonia and left displaced abomasum as 2nd and 3rd most important. This showed that the use of a summary time measure of health can suggest different areas in need of intervention compared to those highlighted by standard frequency measures.

Consequently, this study was developed to test the utility of the DALact in dairy cattle health management and to explore the use of the DALact as an instrument to identify diseases that generate negative effects in future lactations. We hypothesized that the DALacts for specific and cumulative diseases from a previous lactation (P-Lact) would be associated with DALacts in the current lactation (C-Lact) of the same diseases and of the total DALacts. Therefore, our main objective was to evaluate the association between time lost due to diseases in two consecutive lactations using the DALact as a measure.

2.2 MATERIALS AND METHODS

2.2.1 Study Population

This study included records from cows from a conventional dairy farm in Colorado as the study population. The herd size was approximately 1,400 milking cows and was composed almost entirely of Holstein cows. Cows were selected if they had completed at least two consecutive lactations, and the current lactation was completed (via a dry, sold, or died event) between June 30, 2015 and July 1, 2016. Health, removal (culling and death), reproduction and milk production records were collected from each cow's most recently completed lactation (C-Lact) and from their previous lactation (P-Lact). Health events collected from records were: calving injury, left displaced abomasum, diarrhea, hypocalcemia, ketosis, lameness, mastitis, metritis, musculoskeletal injuries, pneumonia, and retained placenta. A period of five days or more between the same health event was defined as a new case of a disease for an individual cow. Calving injury was recorded only as a cause of death or culling reason and not as a disease on the participating farm. Farm employees entered the events and health data into Dairy Comp 305 based on standard disease terminology and diagnostic protocols provided by herd veterinarians from Colorado State University. Records of removal, reproduction and the health events of interest of the sample were exported from Dairy Comp 305 into Microsoft Excel. Data were imported into SAS® for validation, lactational incidence risk calculations, DALact calculations and statistical analyses.

2.2.2 Data editing

For cows that started a new lactation during the time period of interest but did not finish it during that period, their 2 previous lactations were used for the study. Consequently, cows that started their second lactation during the period of interest but were still lactating when that period ended were removed from the study for lack of two full lactations. Cows of any lactation that aborted during the dry period and did not start to produce milk after the abortion, and were sold or died shortly after the abortion were removed from the study.

2.2.3. Cow Removal Records

The majority of cows that died had a death certificate (McConnel, 2017c) completed by herd veterinarians with the cause of death specified. Dairy workers were in charge of establishing the cause of death of the cows that were not evaluated by veterinarians. A mortality code was entered into Dairy Comp 305 for every cow that died, providing information related to the cause of death; if the cow died by natural causes or was euthanized, and if she did or did not have a death certificate. The dairy owner and managers made the culling decisions and assigned reasons for culling, as well as the biological or economic nature of the decision. Culling was assigned to the 11 diseases of interest and 5 other reasons, with either an economic or biological nature to the decision. Biological decisions were defined as cases where the cow could not stay in the herd because her welfare was severely compromised due to injury or disease. Economic decisions were defined as cases where the cow was sold by choice rather than force and usually because of low milk production or poor reproductive performance (Fetrow et al., 2006). The reasons and nature of the removal reasons were re-evaluated on a case-by-case to identify any inconsistency between the health records prior to removal and the documented reason for removal. A decision tree was built to determine the nature of the culling decision (Figure 1). The days in milk (DIM) at the time of culling or death were obtained from the corresponding event date in the records of the cow.

The use of the culling decision tree (Figure 1) is illustrated using an example of a cow with 70 DIM that had a case of severe mastitis 1 day before she was culled. The mastitis case prior to her removal had a severity score of 2 or 3, indicating severe inflammation of the mammary gland and even systemic symptoms like depression, evidence that her well-being was affected. This cow could follow this path: > 61 DIM, disease ≤ 14 days prior to culling, and disease event only leading to a biological classification of culling due to mastitis. In this case, the cow records did not show any evidence of low milk production, poor reproductive performance (abortion, ≥ 5 times breed), or physical disabilities, and she was not designated as a 'do not breed' (DNB) cow.

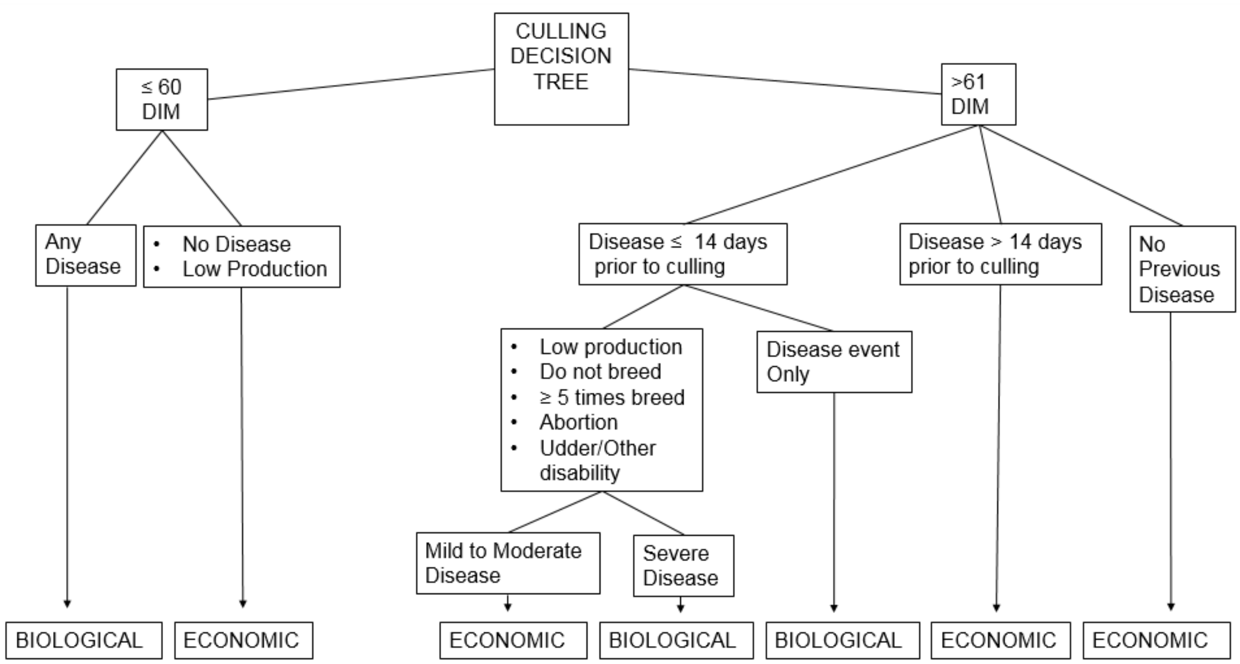

Figure 2.1. Culling decision tree

A similar cow could follow an alternative path as a 70 DIM cow that had a case of mild mastitis right before she was culled. If the mastitis case was mild, assigned with a severity score of 1, it would require treatments and eventuate in loss of milk due to the withdrawal period and a decrease in production. The records of this cow might show that she was bred 6 times and had a

DNB remark, making her a candidate for sale. Considering that this cow was already a candidate for sale for the reasons mentioned above and that the mastitis case was mild, she would be sold for economic reasons. This cow could follow this path: ≥ 61 DIM, disease ≤ 14 days prior to culling, low production / DNB / ≥ 5 times breed / abortion / udder or other disability, mild to moderate disease.

2.2.4 Calculation of DALact

The DALact measure accounts for the time lost in days due to illness and injury (DLI), death and forced (biological) culling. The component that accounts for time lost due to illness and injury (DLI) was calculated as follows: I x DW x L, where I represents the number of cases of a given disease, DW represents the disability weight for that disease, and L stand for an estimated duration of the disease in days. The DW and L are based on literature, experts and the dairy owner's opinion. The disability weights measure the severity with which a certain disease clinically affects an animal on a scale from 0 to 1, were 0 represents perfect health and 1 represents death. Using disability weights, it is possible to account for the time lived with a disease that is considered as lost time or productivity, and the remainder is considered as time lived in good health (Stouthard et al., 1997). Disability weights, shown in Table 2.1, were obtained through a survey of experts in a previous study (McConnel et al., 2017). The producer was asked if he agreed with the proposed disability weights and the estimated disease durations. The other component of the DALact, the days lost due to premature death or culling (DLRD), was obtained by subtracting the DIM at culling or death from the average completed lactation DIM of cows that finished their lactation and started a dry period for this herd (350 days). The DALact was the result of the addition of the DLI and the DLRD (McConnel, 2017b, McConnel et al., 2017). The DALact was calculated for each of the 11 diseases of interest for both P-Lact and C-Lact recognizing that the DALact for the P-Lact was based solely on DLI with no time lost to culling or death. The total DALact was calculated to account for the cumulative effect of disease during a lactation. Total

DALact was obtained adding the DALacts of the individual diseases evaluated in each lactation. For illustration, the DALact of a cow that suffered from 2 cases of mastitis, one case of pneumonia, and died due to pneumonia at 68 DIM would be as follows:

Mastitis DLI = 2 (number of cases) x 0.5 (disability weight for mastitis) x 5 (days of duration for a case of mastitis) = 5 days

Pneumonia DLI = 1 (number of cases) x 0.6 (disability weight for pneumonia) x 4 (days of duration for a case of pneumonia) = 2 days

Combined DLI = 5 + 2 = 7 days

Pneumonia DLRD = 350 (average completed lactation DIM) – 68 (DIM at death) = 282 days

Mastitis DALact = 5 (DLI) + 0 (DLRD) = 5 days

Pneumonia DALact = 2 (DLI) + 282 (DLRD) = 284 days

Total DALact = 7 (combined DLI) + 282 (pneumonia DLRD) = 289 days

Table 2.1. Disability weights and disease duration for the 11 diseases of interest included in this study. Disability weight were derived from a previous study and disease duration was estimated based on literature and expert and producers opinions.

Disease	Disability Weight	Duration (Days)
Calving Injury	0.6	2
Diarrhea	0.4	2
Injury	0.6	5
Ketosis	0.5	2
Lameness	0.5	5
LDA	0.6	3
Mastitis	0.5	5
Metritis	0.5	4
Milk Fever	0.5	1
Pneumonia	0.6	4
Retained Placenta	0.4	2

2.2.5 Descriptive Statistics

Lactational incidence estimates and descriptive statistics were calculated using PROC FREQ in SAS**.** Lactational incidence risk was calculated as the number of cows with a diseases divided by the total number of cows.

2.2.6 Statistical Analysis

Simple regression models were fitted using a generalized linear model (PROC GLM procedure, SAS Inst. Inc.) to study the association between time lost in P-Lact on the time lost on C-Lact. Regressions were fitted for 10 of the studied diseases and also for the total DALact looking at associations between each disease time lost and between each disease and total time lost. Calving injury as a disease was excluded because the producer did not record cases of calving injury. A p-value of ≤ 0.05 was considered to be significant.

2.3 RESULTS

2.3.1 Descriptive Results

A total of 1,205 cows were initially selected that had calved, died, dried off or were sold between June 30, 2015 and July 1, 2016. We removed 397 second lactation cows that did not finish that lactation during the year-long period of interest, and 5 cows of different lactations that aborted, did not start a lactation, and died or were sold. Therefore, 803 cows met the criteria to be included in the study. Figure 2 illustrates the course of the cows initially selected, the cows that were removed from the study, the cows that constituted final sample how those cows finished their last lactation recorded. In the P-Lact, 50.6% of the cows were primiparous and 49.4% were multiparous, including second to seventh lactation cows.

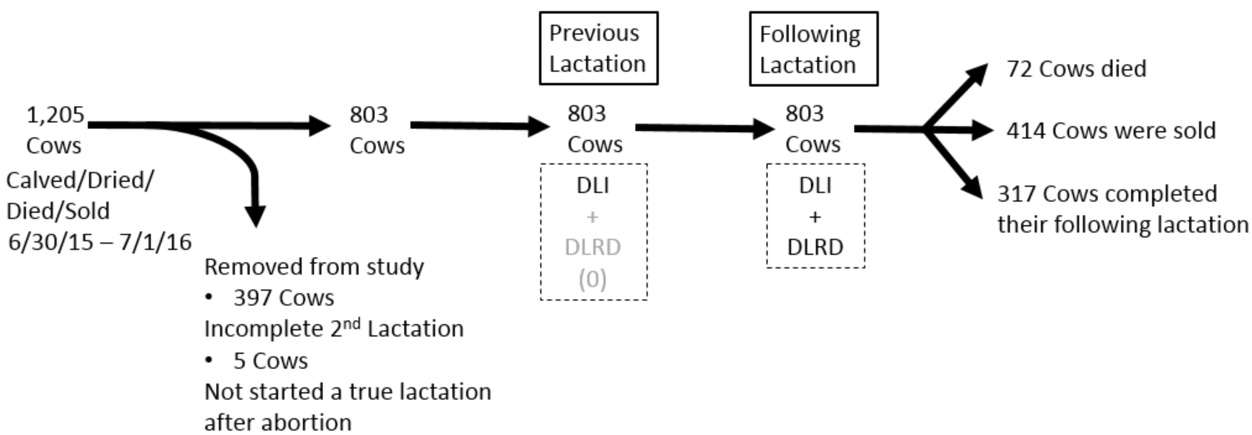

Figure 2.2. Flowchart of cows selected from the study population and their outcomes. Course of cows initially selected, removed and the ones that met inclusion criteria. Records of two consecutives lactations of the cows in the final sample were used to calculate the DLI and the DLRD. The cows finished the last lactation included in this study (i.e. following lactation or C-Lact) due to death, culling or a completed lactation.

During the C-Lact 72 cows died and 45 of them had a death certificate completed by veterinarians. Euthanasia was performed in 45 deaths and 27 cows died on their own. Out of the 72 deaths, 31 (43%) were attributed to diseases investigated in this study. The causes of death are summarized in Table 2.2. The deaths causes that were not within the diseases of interest of this study, are under the category "others" and include causes such as septicemia, bloat, hemorrhagic bowel syndrome, cancer and peritonitis. A total of 414 cows were sold in C-Lact, with 124 (30%) of those categorized as biological culls and 290 (70%) categorized as economic culls. Out of the 124 biologic culling decisions, 91 (73.4%) were due to reasons included in the analysis. The reasons for culling are summarized in Table 2.3.

Table 2.2. Distribution of death causes for 72 deaths out of 803 total enrolled cows during C-Lact.

Disease	n	%
Calving Injury	2	2.8
Diarrhea	1	1.4
Injury	10	13.9
Ketosis	0	0.0
Lameness	0	0.0
LDA	3	4.2
Mastitis	4	5.6
Metritis	4	5.6
Milk Fever	0	0.0
Pneumonia	7	9.7
Retained Placenta	0	0.0
Other	41	56.9
Total	72	100.00

Table 2.3. Distribution of reasons for culling and nature of decision for 414 cows sold out of 803 during C-Lact. The Total column represents the counts and percentage of deaths attributed to each reason. The Nature of Decision column represent the counts and percentage of each reason attributed to either Biological or Economic nature.

Reason	Total		Nature of Decision			
			Biological		Economic	
	n	%	n	%	n	%
Abortion	30	7.25	0	0.00	30	100
Calving Injury	3	0.72	3	100	0	0.00
Diarrhea	5	1.21	5	100	0	0.00
Error*	1	0.24	0	0.00	1	100
Injury	9	2.71	9	100	0	0.00
Ketosis	0	0.00	0	0.00	0	0.00
Lameness	54	13.0	29	53.7	25	46.3
LDA	5	1.21	4	80.0	1	20.0
Low Production	80	19.3	0	0.00	80	100
Mastitis	61	14.7	37	60.7	24	39.3
Metritis	3	0.72	3	100	0	0.00
Milk Fever	0	0.00	0	0.00	0	0.00
Other Diseases	31	7.49	27	87.1	4	12.9
Pneumonia	1	0.24	1	100	0	0.00
Poor Reproduction	124	30.0	0	0.00	124	0.00
Retained Placenta	0	0.00	0	0.00	0	0.00
Transition	6	1.45	6	100	0	0.00
Udder conformation	1	0.24	0	0.00	1	100.00
Total	414	100	124	-	290	-

*A cow not intended to be removed was accidently sold.

During P-Lact, 221 cows (27.52%) finished the lactation without disease while only 97 cows (12.08%) finished C-lact without disease. Lameness, mastitis and metritis had the highest lactational incidence risk (LIR) in P-Lact. Lameness, mastitis and diarrhea had the highest LIR during C-Lact. Milk fever and injury had the lowest LIR in both lactations. Calving injury was not recorded in either of the lactations as a health event, only as a reason for removal, thus its incidence was zero. The LIR for the diseases included in this study are shown in Table 2.4.

The diseases with the highest DALact in both lactations were lameness and metritis. The diseases with the lowest DALact were milk fever and retained placenta. A summary of the DALact outcomes is shown in Table 2.5.

Table 2.4. Count of cows affected, total number of cases and Lactational Incidence Risk (LIR) for 11 diseases included in the study for a previous (P-Lact) and a following lactation (C-Lact) of 803 cows. LIR was obtained dividing the number of cows affected by a disease by the number of cows in the study (803).

Disease	P-Lact			C-Lact		
	Cows affected	Total Cases	LIR (%)	Cows affected	Total Cases	LIR (%)
Calving Injury	0	0	0.0	0	0	0.0
Diarrhea	64	67	8.0	100	105	12.5
Injury	13	13	1.6	22	22	2.7
Ketosis	66	69	8.2	70	72	8.7
Lameness	414	794	51.6	503	1130	62.6
LDA	8	8	1.0	35	36	4.4
Mastitis	227	346	28.3	350	660	43.6
Metritis	73	75	9.1	88	91	11.0
Milk Fever	1	1	0.1	25	25	3.1
Pneumonia	47	49	5.9	53	53	6.6
Retained Placenta	26	26	3.2	66	66	8.2

Table 2.5. Maximum, mean and sum values of DALact for 11 diseases and total DALact. Total DALact represents the cumulative DALact across diseases for an individual cow. Minimum DALact was 0 for all diseases. Max was the maximum DALact value reached for a specific disease within the population of affected cows. The sum total for each disease and for the Total DALact was calculated by adding all of the DALact values across the population of affected cows. The mean DALact for each disease was obtained by dividing the Sum Total values of that disease by the total number cows with cases of that disease. The mean DALact for the Total DALact was obtained dividing Sum Total by the number of cows included in the study (803).

	P-Lact			C-Lact		
Disease	Max	Mean	Sum Total	Max	Mean	Sum Total
Calving Injury	0	0.0	0	346	339.2	1696
Diarrhea	1.6	0.8	53.6	346.8	15.6	1,557
Injury	3	3.0	39	348	203.1	4,468
Ketosis	2	1.0	69	2	1.0	72
Lameness	22.5	4.8	1,985	336	13.3	6,683
LDA	1.8	1.8	14.4	340.8	60.7	2,123.8
Mastitis	20	3.8	865	347.50	25.7	8,996
Metritis	4	2.1	150	347	25.0	2,202
Milk Fever	0.5	0.5	0.5	0.5	0.5	12.5
Pneumonia	4.8	2.5	117.6	346	31.7	1,681.2
Retained Placenta	0.8	0.8	20.8	0.8	0.8	52.8
Total DALact	26	4.1	3,314.9	350.5	36.8	29,544.0

Table 2.6 shows the diseases ranked according to LIR and the total number of days lost (total DALact) for comparison. Lameness, mastitis and metritis ranked first, second and third, respectively in P-Lact for both LIR and DALact. Pneumonia ranked fourth according to total DALact while it ranked sixth according to LIR. Greater differences in both rankings were observed in C-Lact. DALact ranked the three most impactful diseases as mastitis, lameness and injury, respectively. On the other hand, the three most impactful diseases based on LIR corresponded to lameness, mastitis, and diarrhea, respectively. Notably, calving injury was ranked least

impactful except for the total DALact in C-Lact because it accounted for a number of cows that left the herd during early lactation.

Table 2.6. Lactational Incidence Risk (LIR), sum total DALact, and their rankings for the 11 diseases of interest

	P-Lact				C-Lact			
Disease	LIR (%)	LIR Rank	Sum Total DALact	DALact Rank	LIR (%)	LIR Rank	Sum Total DALact	DALact Rank
Calving Injury	0.0	11	0	11	0.0	11	1,696	6
Diarrhea	8.0	5	53.6	6	12.5	3	1,557	8
Injury	1.6	8	39	7	2.7	10	4,468	3
Ketosis	8.2	4	69	5	8.7	5	72	9
Lameness	51.6	1	1,985	1	62.6	1	6,683	2
LDA	1.0	9	14.4	9	4.4	8	2,123.8	5
Mastitis	28.3	2	865	2	43.6	2	8,996	1
Metritis	9.1	3	150	3	11.0	4	2,202	4
Milk Fever	0.1	10	0.5	10	3.1	9	12.5	11
Pneumonia	5.9	6	117.6	4	6.6	7	1,681.2	7
Retained Placenta	3.2	7	20.8	8	8.2	6	52.8	10

2.3.2 Simple Regression Results

Estimates of the change in days lost due to specific diseases in C-Lact for every day lost due to that disease in the previous lactation are presented in Table 2.7. Mastitis and lameness had positive significant associations (*P-value* < 0.001) between DALacts in the two consecutive lactations. Total DALact also had a positive significant association (*P-value* < 0.001) between P-Lact and C-Lact. Time lost due to mastitis in P-Lact had the greatest impact on time lost in C-Lact. Estimate interpretations are as follows: a cow with a lameness DALact of 22.5 days in P-

Lact lost an estimated 50.6 days due to lameness during C-Lact; or a cow that had a mastitis DALact of five days during P-Lact lost an estimated 26 days due to mastitis during C-Lact.

Table 2.7. Summary of simple regression analysis of P-Lact DALact and C-Lact DALact for each disease and cumulative diseases

Disease	Estimate	p-value
Diarrhea	-2.16	0.55
Injury	-1.89	0.60
Ketosis	0.04	0.25
Lameness	2.25	< 0.001
LDA	-1.48	0.79
Mastitis	5.21	< 0.001
Metritis	-1.22	0.48
Milk Fever	-0.03	0.86
Pneumonia	-0.79	0.56
Retained Placenta	-0.05	0.41
Total DALact	4.02	< 0.001

Table 2.8 shows the estimates of the changes in total days lost due to diseases in C-Lact for every day lost due to each specific disease during P-Lact. Lameness and mastitis during P-Lact resulted in positive significant associations (*P-value* < 0.001) with the total DALact in the C-Lact.

Table 2.8. Summary of simple regression analysis of each disease P-Lact DALact and total C-Lact DALact

Disease	Estimate	p-value
Diarrhea	-21.81	0.14
Injury	9.33	0.30
Ketosis	21.47	0.07
Lameness	3.17	< 0.001
LDA	-14.88	0.44
Mastitis	7.58	< 0.001
Metritis	-3.09	0.60
Milk Fever	-80.74	0.68
Pneumonia	0.63	0.91
Retained Placenta	22.72	0.35

2.4 DISCUSSION

Disease frequency measures and the different ways disease can impact dairy cattle and dairy farms have been extensively studied. A novel summary measure for health that aims to integrate morbidity and mortality into a single measure, the DALact, has been proposed as an objective indicator of well-being to be used in dairy farms. The current study examines the use of this summary measure as a tool for the identification of diseases that could negatively impact future lactations in the form of time lost to disease.

In this study we used simple regression to evaluate possible associations between time lost to disease in consecutives lactations. We used a time-based measure that combines time lost due to active diseases and time lost due to premature removal from the herd, the DALact, as both explanatory and response variable. Previous studies have looked at diseases in consecutives lactations. Those studies used a logistic regression approach (Peeler et al., 1994, Calavas et al., 1996) or survival analysis (Hirst et al., 2002), where the explanatory variables were the number of cases of the diseases of interest that occurred in the previous lactation. These differences in the statistical analysis and in the proposed explanatory variables does not allow for direct comparisons in the results of this study with those obtained in previous reports. However, the studies mentioned above and the current study have the common goal of seeking associations for the occurrence of diseases in consecutive lactations. As the DALact is a new concept that is still being developed, there are no more available studies that can be used as a valid point of comparison.

In our analysis looking at specific diseases and the effect of the time lost in P-Lact on the time lost in C-Lact, we found significant associations for mastitis and lameness. For every day lost during P-Lact due to those diseases there was a loss of 5.21 and 2.25 days, respectively, during C-Lact. These results support previous studies that found that mastitis (Bigras-Poulin et al., 1990, Peeler et al., 1994, Calavas et al., 1996) and lameness (Calavas et al., 1996, Hirst et al., 2002) had significant risk of recurrence in two lactations. Our study also highlights the effect of these diseases on premature removal. Cumulative effects of diseases were also assessed, where we found a significant association between total time lost during P-Lact and C-Lact. Similar analyses looking at cumulative effects of health events have not been published. The mastitis and lameness DALact during P-Lact were also significant in their association with total time lost during C-Lact, resulting in 7.58 and 3.17 totals days lost in C-Lact per each day lost due to mastitis and lameness, respectively. This last finding suggests that mastitis and lameness might have an influence in the time lost due to other diseases in a following lactation.

Lameness and mastitis were the diseases with the highest LIR in both P-Lact and C-Lact, whereas the other diseases' LIR ranged from 0.1% to 12.5%. These differences in LIR might explain the differences in statistical significance of the different analyses in this study. Diseases with low incidence are the results of small number of affected cows and this might be the explanation of the lack of statistical significance for associations in consecutives lactations. In some cases, the low incidence may be the result of the way we selected the sample. The cows needed to survive their P-Lact and they had the chance of being removed during C-Lact. That could have limited the number of cases included in this study of some health events during P-Lact. For example, injury is associated to a high probability of removal in this herd: 86% of the cows affected by injury during C-Lact were removed. This might be suggesting that the low incidence and lack of statistical significance in the analysis of some health events during P-Lact is because most affected animals end up being removed from the herd, thus, not surviving P-Lact and being excluded from the sample.

For the purpose of this study, we considered records from only one dairy. This dairy possesses a well-established guideline to determine and record culling reasons for sold animals and has regular access to veterinarians who perform necropsies and complete death certificates on the majority of the cows that die at the farm. The use of these records allowed us to obtain detailed removal records in most cases, which was crucial for the calculations of the DALact. The allocation of causes of death and culling reasons allowed us to identify the diseases that impacted the time lost in consecutives lactations, and helped to guide disease interventions based on their impact.

The current formula for calculating the DALact does not take into account the age or parity number of the cows. This represents a limitation, as several studies have reported associations between age or parity number and disease occurrence (Sanders et al., 2009, Ghavi Hossein-Zadeh and Ardalan, 2011), culling (Bell et al., 2010, De Vries et al., 2010, Cha et al., 2013) and death (Thomsen et al., 2004). Considering this, we identify not including parity number in the analysis as a limitation. Parity number might account for some of the effects of time lost, and it should be included in future DALact studies, either by including it in the DALact formula or as a variable in the analysis.

Dairies across the United States vary in size, type of operation and management practices (USDA, 2016). This study was based on records from only one dairy. Disability weights and disease duration estimates were approved by the producer for their use in estimating time lost to disease. This dairy did not track cases of calving injury unless it was a cause for removal of the herd. The results of this particular study can be applied to the dairy that allowed the use of its records. For the reasons mentioned above, the results of this study should not be applied for dairies in general but provide a template for approaching the impact of disease in one lactation on the next.

2.5 CONCLUSION

This study is part of an initiative that proposes the DALact as a measure of heard health and explores its alternative use looking at associations in consecutives lactations. Days lost due to mastitis and lameness in a previous lactation significantly increased the days lost in a following lactation due to these disorders, and also increased the total days lost in a following lactation. The recognition of these two diseases as major health issues that will affect future lactations will allow the producer to focus management and prevention measures in those diseases that generate more significant long-term effects on the health and well-being of its herd.

CHAPTER 3: DISCUSSION

The disability adjusted life years (DALY) was created by the Word Health Organization (WHO) to be used in the global burden of disease study as a measure of population health (Murray et al., 1994). The purpose of the DALY is to quantify the burden of disease, capturing premature deaths and disabilities caused by diseases under the same measure (Murray and Lopez, 1996). Since then, the DALY has been used to measure the burden of diseases and to effectively allocate resources in health interventions (Homedes, 1996). The DALY has applications in three major areas: prioritization of health services; identification of disadvantaged groups and target of health interventions; and representing measure of output for intervention that allows comparisons. The DALYs have been used to identify major health problems that are affecting a region or a country and, with the help of cost-effectiveness analysis, policy makers can evaluate the most efficient intervention to deal with those diseases (Murray and Acharya, 1997). Therefore, DALYs essentially are used to predict where the most impact can be gained through the allocation of scarce resources to health interventions.

The dairy industry has two great challenges similar to those faced by human public health. Dairy farms have not had a time-based measure that estimates the burden of disease, and they are constantly subject to a limited budget that requires the use of resources in the most efficient way possible. McConnel et al. (2017) demonstrated that a measure similar to the DALY could have applicability in the dairy industry and has adapted it for use in dairy cattle, creating the disease-adjusted lactation (DALact) metric. Unlike the DALY that assesses the burden of disease throughout a person's life, the DALact assesses the burden of disease in a lactation. Based on this feature, it was thought that the DALact could be used to predict how the time lost due to diseases of one lactation could affect the following one.

The DALY quantifies the impact of disease within populations and predicts where resources can be placed so that the greatest benefits are obtained for the population. Similarly, the current study predicted which diseases would have an effect in the following lactation and depending on this, the producer can plan interventions to prevent these diseases from continuing to affect the cattle in current and future lactations. However, there is an important difference between the use of DALY and the use of DALact in this study. The DALY is used at a population level, where the burden of disease is assessed for a particular population, and as a result, interventions are used to reduce or prevent the impact of those diseases. The DALact was originally created for its use in populations also, but in this study we additionally explored its use at an individual level. The DALact was calculated for the 11 diseases of interest and as a total for each cow and those results were fitted in a simple regression model. These results can help to identify the diseases that significantly affect the time lost in a future lactation, and thus, resources can be assigned to preventive measures or management focused on those diseases.

Furthermore, the results from the regression analysis can be applied at a cow level. For example, for each day lost due to mastitis in a previous lactation, a cow was predicted to lose 5 days due to mastitis during a following lactation. This information could be used to apply preventive measures to cows who have had days lost due to mastitis during previous lactation, although this is not recommended since efficient preventive measures should focus on the herd rather than on individuals.

As mentioned above, the DALact accounts for the time lost to disease over a lactation period and not over the life of a cow. This approach captures the burden of disease during a lactation where cows of different age groups are included, but it has limitations. To explain this limitation, consider a first lactation cow that is part of a herd where the average lactation days in milk is 350 days and she is removed at 351 days in milk (DIM). The days lost due to illness (DLI) component of this cow's burden of disease would not be affected and would reflect the time lost due to the clinical diseases she had. However, the days lost due to premature removal or death

(DLRD) component of the DALact would be affected. Because by the time she was removed her lactation DIM would be above average, her DLRD would be equivalent to zero, and consequently, her total DALact would only reflect the DLI. Now, consider a sixth lactation cow from the same herd that is removed at 10 DIM. The DLRD of that cow would be equal to 340, resulting in a high DALact. If those two DALacts are compared, it could be inferred that the second cow was impacted by diseases to a greater magnitude. This approach does not take into account the number of parities or age of the cows and is based only on the DIM of a lactation. The fact that a first lactation cow was removed very early is ignored, as well as its implications for health and well-being. To address this issue, McConnel (2017a) is developing a new measure based on the DALact. This new measure called the Dairy Disease-Adjusted Lifetime (DairyLife) will account for the effect of diseases across the productive life of a cow and not just across a lactation, and it will provide a more accurate estimation of how diseases impact the life and wellbeing of a cow.

Like many others, this study and a previous DALact study used farm records (McConnel, 2017b). On farm records can include information regarding individual cow milk production, health and antibiotic use (USDA, 2016). The availability of health data allows the health of the herd to be monitored through conventional epidemiological measures (Wenz and Giebel, 2012) and, in our case, allowed the use of DALact as a time-based measure of herd health. The last study published by the USDA–APHIS–VS–CEAH–NAHMS reported that 95% of all dairy operations used a record keeping system, where 72.5% and 78.2% recorded information about animal health and culling, respectively (USDA, 2016). A study conducted by Wenz and Giebel (2012) reported that even though the majority of the farms in their study kept records of their diseases of interest, most of those records did not have enough accuracy and consistency to do a valuable herd health assessment. Some issues in record keeping affect their effective use for health evaluation (such as recording a health event more than once per clinical episode or the use of multiple health event entries or codes for a single disease) and can be addressed by veterinarians or researchers, but it is a time consuming process and is not practical. Another issue that affects the utility of the records is the common practice of recording health events associated with a treatment as opposed to recording health events and attaching treatments to those events (Parker Gaddis et al., 2012, Wenz and Giebel, 2012). The information regarding diseases that are not recorded through this process is lost and there is no way to recover it. An accurate estimation of the burden of diseases on a farm requires records that capture diseases not only in the presence of a treatment. Wenz and Giebel (2012) give recommendations for the recording of health data regarding disease event, event remark, treatments and lesion location in the case of mastitis and lameness. They also state that the establishment of health data-recording protocols is an alternative to address the problems with the record keeping. Nevertheless, the establishment of protocols aimed to improve recording of health events is not enough and, to avoid protocol drift, it should be followed by monitoring and feedback by stakeholders in compliance of the protocol (Wenz, 2007).

The subclinical presentation of diseases such as mastitis and ketosis are often ignored in farm records. Subclinical presentations do not show evident clinical signs and they are not detected unless a diagnostic test is used; consequently, there is no record of diseases with subclinical presentations. However, subclinical diseases like subclinical mastitis (SM) and subclinical ketosis can impact the reproductive performance (Raboisson et al., 2014, Fuenzalida et al., 2015), the milk production (de Graaf and Dwinger, 1996, McArt et al., 2012), and even though there are currently no studies that have evaluated whether they cause pain or discomfort, their potential impacts on welfare should not be ignored.

New technologies represent an opportunity for the detection and recording of these subclinical diseases. Technologies for the detection of some subclinical and clinical diseases developed over the last decades are now becoming available to be used on farms, allowing the producer and farm personnel to analyze samples on the farm or, in the case of milk analyzers attached to the milk line in the milking parlor, to obtain real-time results from the tests. If SM is used as example, it is known that the milk of a cow with SM has alterations in the electrical conductivity (Norberg et al., 2004) and in the lactate dehydrogenase levels (LDH) (Batavani et al., 2007). On farm technologies can perform an analysis of the milk of each cow being milked and detect changes in the conductivity or in the levels of LDH consistent with SM, thus, allowing for SM to be recorded. The availability of records of subclinical diseases thanks to the implementation of technologies for their detection would also help develop a better understanding of the disease burden of dairy cows. Currently, subclinical diseases do not have disability weights and their duration has not been established for DALact calculations and analysis, so that in the future we should consider their estimation.

The present study examines the use of the DALact as a predictor of time lost to diseases in a future lactation. As a continuation of this study, we intend to explore the use of DALact in a survival analysis, where the effect of the DALact of a current and a previous lactation would be translated into a removal hazard risk. The DALact is a project that is still developing. More studies are needed to validate its use and to disseminate its potential as a measure of animal health and welfare.

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