Monitoring liveweight to optimise health and productivity in pasture fed dairy herds

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— Abstract —

Technological advances now make it possible to continuously record and monitor a range of outcomes on dairy farms including individual cow milk yields, environmental temperature and rainfall. These facilities enhance the ability of herd managers to recognise deviations from what is accepted as normal, prompting timely corrective intervention. The objective of this thesis is to demonstrate how liveweights recorded using walkover weighing (WoW) technology can provide information that can be used to better-manage a range of activities on dairy farms, particularly reproduction and herd health.

Analysis of daily WoW recorded over the first 100 days of lactation have shown that the standard deviation of daily LW measurements across parities was 17 kg on average. A near perfect association between liveweights measured statically and WoWs (concordance correlation coefficient 0.99, 95% CI 0.99 to 1.0) was observed. After controlling for the effect of liveweight at calving and long term liveweight change using a mixed-effects linear regression model, the autocorrelation between WoWs recorded on successive days was 0.21, decaying to zero by eight days. This study showed that by using a standalone automatic WoW system positioned in the exit race of a rotary milking parlour, it was possible to record LWs of individual cows on a daily basis and, with controlled cow flow over the weighing platform (allowing for sufficient succession distance to prevent congestion), results were similar to those recorded using conventional, static weighing techniques.

Two observational studies were conducted to investigate the relationships between LW, LW change (ΔLW) and clinical lameness. In the first study, LW loss in the first 50 days in milk increased the risk of a lameness event being diagnosed after 50 days in milk by a factor of 1.80 (95% CI 1.00 to 3.17). The risk of lameness was greatest for high yielding cows that lost excessive LW (risk ratio 4.36, 95% CI 4.21 to 8.19). The second study quantified ΔLW immediately before and after the diagnosis of lameness events. For lame cows, liveweight decreased up to three weeks before the date of diagnosis and for up to four weeks after. The total liveweight loss arising from a single lameness episode was, on average, 61 kg (95% CI 47 to 74 kg). The results of this study show how liveweight records for individual animals can be used to enhance a herd manager's ability to detect lame cows and present them for treatment. Prompt detection and treatment of lame cows presents an opportunity to shorten recovery times, with positive follow-on effects in terms of animal welfare.

ΔLW was assessed as a means for enahancing the sensitivity and specificity of oestrus detection. The sensitivity and specificity of detecting true oestrus events using ΔLW combined with tail paint and visual observation was 0.86 and 0.94, respectively. The effect of ΔLW in the first four weeks after calving (ΔLW_{long}) and LW change around the time of the Planned Start of Mating (ΔLW_{short}) on the time taken for cows to conceive relative to the Planned Start of Mating was quantified. Planned Start of Mating to conception intervals were influenced by LW change during both of these periods, though ΔLW_{short} had a greater effect compared with ΔLW_{long}. The findings of this study better define the impact of long- and short-term liveweight change on reproductive performance, providing the opportunity to design feeding programmes in pasture fed dairy herds that have positive effects on fertility.

The studies presented in this thesis contribute knowledge to the role of LW monitoring as a tool to better-manage seasonally calving, pasture fed dairy herds. While 'traditional' usage of walkover scales on dairy farms has involved the recording of LW and LW change as a means for monitoring and adapting changes to the herd feeding program, the studies presented here have shown how LW

records have the potential to provide information that can be used to better manage a range of herd level activities, particularly those related to reproductive management and health.

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Nomenclature

Δ	Change
ΔBCS.LW	Change in body condition score and/or liveweight
ΔLW	Liveweight change
ACF	Autocorrelation function
AI	Artificial insemination
AIC	Akaike's Information Criterion
BCS	Body condition score
BW	Breeding Worth
BMSCC	Bulk milk somatic cell count
CI	Confidence interval
CL	Upgraded Irish Holstein-Friesian
DHF	Dutch Holstein-Friesian
DIM	Days in milk
EB	Energy balance
F1	Jersey $\times$ Holstein-Friesian cross
GH	Growth hormone
H	Holstein
HF	Holstein-Friesian
IGF-I	Insulin-like growth factor-I
JE	Jersey
JH	Jersey Holstein cross
LAMIDX	Lameness index
LIR	Lmeness incidence risk
LW	Liveweight
MB	French Montbeliarde
MJ	Megajoule
MS	Milksolids

NEB	Negative energy balance
NR	French Normande
NZHF	New Zealand Holstein-Friesian
NZHF70	High genetic merit Holstein-Friesian of New Zealand origin, 1975
NZHF90	High genetic merit Holstein-Friesian of New Zealand origin, 1998
OESTIDX	Oestrus index
OR	Odd ratio
PSC	Planned Start of Calving
PSM	Planned Start of Mating
REML	Restricted maximum likelihood
RR	Risk ratio
TPVO	Tail paint and visual observation
SE	Standard error
TR	Time ratio
USHD	North American High Durable Holstein-Friesian
USHP	North American High Producing Holstein-Friesian
USHP90	North American with high Breeding Worth, 1998
VFI	Voluntary feed intake
WLD	White line disease
WoW	Walk over weighing

List of Publications

Alawneh JI, Stevenson MA, Williamson NB, Lopez-Villalobos N, Otley T (2011) 'Automatic recording of daily walkover liveweight of dairy cattle at pasture in the first one hundred days in milk'. *Journal of Dairy Science* 94 (9), 4431 – 4440.

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Alawneh JI, Laven RA, Stevenson MA (2011) 'The effect of lameness on the fertility of dairy cattle in a seasonally breeding pasture-based system.'. *Journal of Dairy Science* 94 (11), 5487 – 5493.

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Alawneh JI, Stevenson MA, Williamson NB, Lopez-Villalobos N, Otley T (2011) 'The effects of liveweight loss and high milk production on the risk of lameness in a seasonally calving, pasture fed dairy herd'. 16th Symposium and 8th Conference Lameness in Ruminants, Millennium Hotel Rotorua, New Zealand, 28 February – 3 March 2011.

Alawneh JI, Laven RA, Stevenson MA (2011) 'The impact of lameness on the fertility of dairy cattle in a seasonally breeding pasture-based dairy herd'. 16th Symposium and 8th Conference Lameness in Ruminants, Millennium Hotel Rotorua, New Zealand, 28 February – 3 March 2011.

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Alawneh JI, Stevenson MA, Lopez-Villalobos N, Otley T (2009) 'Automated daily body-weight measurements in dairy cattle at pasture and its association with lameness in early lactation'. Proceedings of the 12th Symposium of the International Society for Veterinary Epidemiology and Economics, Durban, South Africa, 10 – 14 August 2009.

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CHAPTER 1

General introduction

The New Zealand climate results in a distinctive seasonal pattern of pasture availability and quality (Lambert et al. 2004, Waghorn & Clark 2004). Pasture growth and the quality of pasture grown (if availability is not a problem) is sufficient to support dairy production throughout the year. To match the availability of feed with nutrient requirements dairy herds are managed to ensure that calving is concentrated within relatively short period of time (8 to 12 weeks) starting in either the early autumn (February – March) or spring (July – August). To achieve these objectives the breeding period is restricted to approximately twelve weeks, comprised of four to eight weeks of artificial breeding (Macmillan & Asher 1990) followed by a period of natural mating using herd bulls. Cows not conceiving during this twelve-week period are usually culled. In this context the New Zealand dairy system differs from high production, non-seasonally calving and often zero-grazing intensive dairy systems throughout the world that routinely use varying amounts of concentrate feeds to maximise production and minimise the effect of inadequate levels of feed intake on health and fertility (Holmes et al. 2002).

Seasonally calving, pasture based dairy farming systems pose many challenges for herd managers. For example, the average New Zealand dairy cow must have a calving interval of around 365 days to maintain a herd calving pattern that allows nutrient requirements to be matched with pasture production. Within this 365 day interval, 282 days are required for pregnancy leaving only about 83 days for cows to resume normal cyclicity and conceive (McDougall et al. 1995, Holmes et al. 2002, Morton 2004). The challenge for those managing New Zealand dairy herds is to control factors such as stocking rate, pasture allowance and use of supplementation to ensure that the ration offered meets feed requirements so that required short and long term production goals are met.

Table 1.1: Application of control electronics to the dairy and beef cattle industries. Source: Cobben et al. (1987).

Area	Application
Environment	Temperature, humidity, air velocity, CO_2 concentration.
Animal health	Pulse rate, blood pressure, body and milk temperature, milk conductivity, respiration rate.
Nutrition	Food intake, rumen pH, milk quality (protein, fat), stool content (pH).
Fertility	Oestrus detection, pregnancy detection, calving monitors.
Production control	Weight, meat fat content, milk quality (protein, fat).

Compared with overseas counterparts, dairy herds in New Zealand are generally larger and have lower numbers of full time labour units per cow (Lean et al. 2008, Anonymous 2010). These characteristics limit the ability of herd managers and their staff to assess the wellbeing of individual animals (Lean et al. 2008, Peiper et al. 1993, Spahr & Maltz 1997). To overcome this problem a number of technologies have been developed to record details of either individual animals or their environment, as listed in Table 1.1 (Cobben et al. 1987, Frost et al. 1997). While technologies now exist to record a vast array of information about the herd, the environment and individual animals it is important that end users (i.e. herd managers) are able to interpret information collected from these systems and modify their management appropriately when abnormalities are detected (Devir et al. 1996, de Mol & Woldt 2001).

In this thesis individual cow liveweight (LW) estimates were recorded twice daily over three milking seasons in a single seasonally calving, pasture fed dairy herd in Palmerston North, New Zealand. These data, along with biographical details and key lactation event information (dates and details of calvings, services and disease diagnoses) were then analysed to better define how this information could be used to improve herd reproductive and health performance. This thesis is presented as a series of papers, either published or prepared for publication. Each chapter shows the stage of preparation each paper has reached at the date of thesis submission. As a result there is some repetition of background information, materials and methods used in each chapter.

Each chapter contains a brief review of the literature relevant to the subject presented. The primary objective of the review (Chapter 2) is to provide broad overview and context. Chapter 2 is presented in two sections. The first reviews factors that influence animal LW and/or changes in body conditon score (BCS).[1] The second reviews automated systems

[1] Throughout this thesis body condition score is reported using a 1 to 5 scale, unless stated otherwise.

for monitoring animal productivity with an emphasis on LW monitoring tools.

Five research chapters follow. Chapter 3 provides a description of the experimental setup used to capture and record LW records from individual cows in the study herd. The aims of this chapter were to: (1) describe LW records retrieved by a standalone automatic walkover daily weighing system; (2) describe the frequency and nature of outlier LW records measured by the system and develop an approach for excluding identified outlier LW records; (3) quantify the agreement between cow LWs measured using the walkover system and those measured statically; and (4) describe the autocorrelation between LW measurements in order to provide recommendations around how frequently dairy cows need to be weighed to detect LW change in the early lactation period.

Chapters 4 to 7 provide examples of the way individual cow LW records can be used as a herd management tool. Two specific areas are addressed here: (1) the relationship between LW and reproductive performance and (2) the relationship between LW and the incidence of lameness. In terms of reproductive performance, Chapter 5 documents the ability of LW change as a means for predicting oestrus events in dairy cattle. Chapter 6 quantifies the effect of LW change in the first four weeks after calving ($\Delta \mathrm{LW}_{long}$) and LW change around the time of the Planned Start of Mating ($\Delta \mathrm{LW}_{short}$) on the time taken for cows to conceive relative to the Planned Start of Mating.

Chapters 4 and 7 investigate relationships between LW, LW change and clinical lameness. In Chapter 4 LW and LW change in the immediate postpartum period are assessed as risk factors for clinical lameness events. In Chapter 7 LW change immediately before and after the diagnosis of lameness events is quantified. These chapters illustrate the complex relationship between LW and dairy cattle health where, in this example, LW and LW change is shown to be both a risk factor for (Chapter 4) and a consequence of (Chapter 7) lameness. Figure 1.1 illustrates this concept graphically.

Chapter 8 draws all of the concepts identified in Chapters 2 to 7 together, in an attempt to develop general conclusions regarding the role of LW monitoring as a tool for management of seasonally calving, pasture fed dairy herds. While 'traditional' usage of walkover scales on dairy farms has involved the recording of LW and LW change as a means for monitoring and adapting changes to the ration, the studies in this thesis show how LW records have the potential to provide information that can be used to better manage a range of herd level activities, particularly those related to reproductive management and

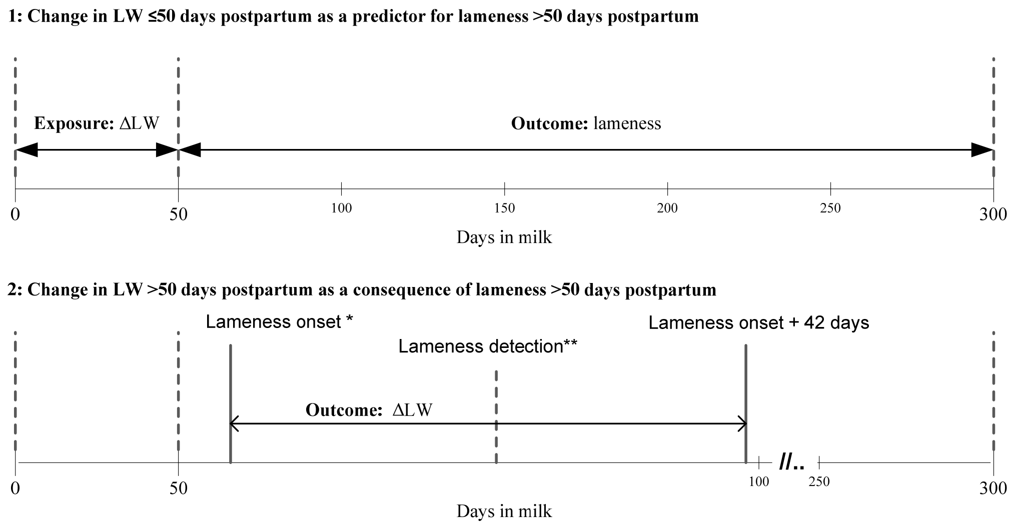

Figure 1.1: Schematic diagram showing the application of the two different approaches applied to investigate the correlations between LW change (ΔLW) and lameness throughout a lactation. lameness onset*; an estimate based on Chapter 7 results.

health.

CHAPTER 2

Literature review

2.1 Determinants of liveweight change

LW in cattle increases with age but the rate of increase steadily decreases until mature LW is achieved at approximately 5 years (Touchberry & Batra 1975). Like milk yield (Peiper et al. 1993, Berry et al. 2002), LW can be modified by changes in daily dry matter intake (DMI). In pasture based systems this can occur by making alterations to stocking rate and pasture allowance (Baudracco et al. 2010), pasture quality (Roche, Turner, Lee, Edmeades, Donaghy, Macdonald, Penno & Berry 2009) and the timing and type of supplementation offered (McCarthy et al. 2007).

LW change (ΔLW) during a lactation is influenced by many physiological and environmental factors such as calving and calving conditions (e.g. peripartum disease), BCS at calving, seasonal conditions, parity, breed, genetic effects, and reproductive status (Devir et al. 1995, Roche, Friggens, Kay, Fisher, Stafford & Berry 2009). Also, ΔLW is influenced by the interaction between management, physiological and environmental (Forbes 1995, Dalley et al. 2001) factors (termed imposed ΔLW throughout this review; defined as LW change resulting from interaction between management, physiological and environmental factors) with a cow's genetic potential to partition energy for milk production (Roche, Friggens, Kay, Fisher, Stafford & Berry 2009). The genetic potential to partition energy into milk production contributes more towards between-animal variation in LW than imposed ΔLW which contributes more towards within-animal LW variation (Roche, Friggens, Kay, Fisher, Stafford & Berry 2009).

Between-animal variation in ΔLW is an entity requiring an understanding of the underlying physiological relationship that links management, physiological and environmental factors with a cow's genetic capacity for milk production (Section 2.1.1). To illustrate, high stocking rates reduce the level of dry matter or herbage allowance which reduces daily DMI per animal. This compromises cows nutritionally and creates a deficit in available dietary energy, leading to a state of negative energy balance (NEB). Dependent on BCS, daily energy balance and genetic potential for milk production, the duration and extent of mobilisation of body tissue and therefore LW loss will vary (Roche et al. 2006, Berry, Macdonald, Penno & Roche 2006, McCarthy et al. 2007). To account for this between-animal variation in a single herd, Baudracco et al. (2010), in a meta-analysis of 31 studies, reported that farm managers should maintain a herbage allowance of around 78.4 kg DM.cow^{-1}.day^{-1}. These authors stated that this level of herbage allowance was enough to allow each cow in a herd to ingest sufficient DM (estimated to be around 18.8 kg DM.day^{-1}) to meet the nutritional requirements for maintenance and production.

In Ireland McCarthy et al. (2007) collected LW and BCS records over 584 individual cow lactations. Data were collected every three weeks over 5 years resulting in 20,611 LW and 7,920 BCS records in total. These authors reported that although the imposed effect of environment on LW and BCS change was homogenous across cow stains (New Zealand Holstein-Friesian [NZHF], North American high producing Holstein-Friesian [USHP] and North American high durable Holstein-Friesian [USHD]) within each feeding system (high grass allowance, increased stocking rate, and increased concentrate supplementation systems) the NZHF strain had significantly greater average BCS (3.10) compared with the USHP (2.76) and USHD (2.87) strains. Also, the interaction between cow strain, feeding system, production and LW loss was heterogeneous. Across feeding systems, the USHP and USHD strains showed a greater loss of BCS in early lactation (0.27 and 0.29 units, respectively) compared with the NZHF strain (0.21 units). The USHP strain failed to gain BCS over the entire lactation. These results concur with those of Roche et al. (2006). Both studies demonstrate that LW or body condition change is a product of environmental and physiological effects and is driven by an individual cow's ability to partition energy for milk production potential, particularly in the immediate postpartum period.

2.1.1 The relationship between dry matter intake, liveweight and productivity

The level of production achieved by a grazing dairy cow is an indirect measure of the feeding value of the forage that has been consumed. By definition, feeding value is the quantity of food eaten (voluntary feed intake; VFI) and the nutritive value of the feed that is consumed (Holmes et al. 2002). VFI determines DMI. VFI is influenced by factors (Figure 2.1) that compromise an animal's ability to actually harvest and consume feed, such as gastrointestinal fill or the ability of an animal to accommodate and digest available feed (Allen 1996), the animal's requirement for nutrients and the ability to metabolise nutrients that are absorbed (Forbes 1995, Hodgson 1990, Holmes et al. 2002).

In a literature review of the physiological regulation of feed intake in farmed animals, Roche et al. (2008) stated that factors influencing VFI can be related to the interaction of factors determined by the animal (e.g. gut fill and physiological energy demands) and those determined by herd management (e.g. pasture allowance or feed supplementation). These interactions are a product of physical effects on the organs of the gut (e.g. rumeno-reticulum distension) combined with metabolic feedback from the pituitary gland, adipose tissue, abomasum, intestine, pancreas and other organs. They trigger a chain of orchestrated signals that control an animal's appetite and feed intake. VFI and its physiological link to DMI has received considerable research attention in recent years due to its influence on animal productivity (van Soest 1994, Roche et al. 2008).

Understanding the physiological relationships between DMI, VFI and LW or BCS change is of great importance for understanding factors that influence BCS and/or LW which I term $\triangle$BCS.LW in the reminder of this chapter. During the past three decades, a large body of evidence regarding the physiology of lipid mobilisation and endocrinology of the dairy cow has accumulated (Allen et al. 2009, Bewley et al. 2008, Roche, Friggens, Kay, Fisher, Stafford & Berry 2009). It is beyond the scope of this review to go into detail of the physiology of lipid mobilisation. This section provides a brief background in order to provide the reader with sufficient information to facilitate understanding of the material presented later in the review.

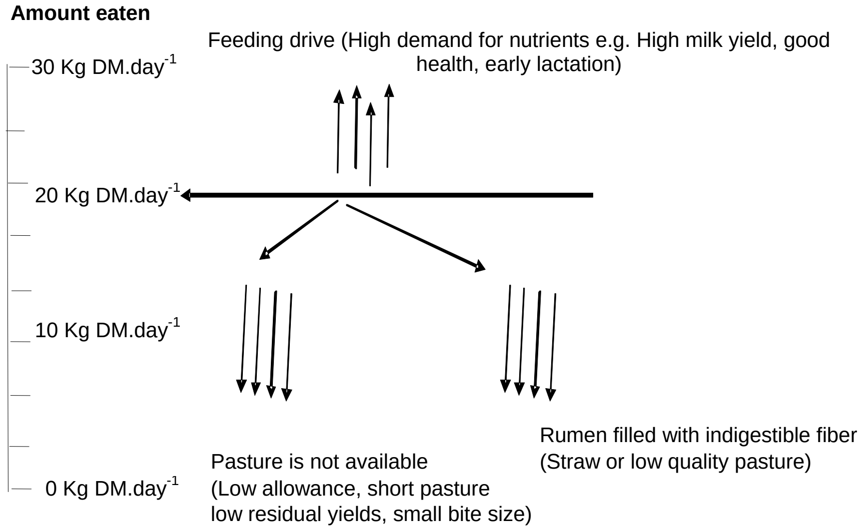

Figure 2.1: The balancing act between the three main factors which determine the actual feed intake by the cow (redrawn from Hodgson (1990) and Holmes et al. (2002), page. 263).

Endocrine responses to negative energy status and their effect on liveweight

Prolonged energy deficit triggers a cascade of hormonal expressions that alter body tissue responsiveness, resulting in increased lipid mobilisation to maintain energy homeostasis. This involves mobilisation of adipose tissue (lipolysis) to maintain physiological equilibrium (Bauman & Currie 1980, Roche, Friggens, Kay, Fisher, Stafford & Berry 2009). This process is phenotypically manifest as ΔBCS.LW.

Although homeostatic control implies that if DMI was adequate to meet a lactating cow's energy requirements then tissue mobilisation will be minimised, several studies have shown that during a lactation, other mechanisms such as a cow's genetic merit for milk production (homeorhetic process) influence the capacity to mobilise body reserves (McNamara & Hillers 1986, Roche et al. 2006). In the immediate postpartum period, mobilisation of body reserves and subsequent LW loss still occurs independent of a cow's energy inputs and outputs (Friggens 2003). For all cows, including those that are not nutritionally compromised, (Gagliostro & Chilliard 1991, Andersen et al. 2004, Roche et al. 2006, Pedernera et al. 2008, Delaby et al. 2009) or on severe feed restrictions (Roche 2007), mobilisation of body reserves occurs in a cyclical fashion to meet other physiological requirements such as the resumption of sexual activity (Friggens 2003, Friggens et al. 2004). This demonstrates that the dairy cow has a genetic drive to safeguard important biological functions that can only be fulfilled if the necessary resources are partitioned to them (Bauman & Currie 1980).

Adipose tissue represents the body's predominant energy supply through two continuously occurring metabolic processes, lipolysis and lipogenesis (Bell 1995). The major aspects of lipid metabolism are involved with fatty acid oxidation to produce energy (lipolysis) or the synthesis of lipids (lipogenesis). Lipid metabolism is closely connected to the metabolism of carbohydrates (in the form of acetate derived from rumen fermentation) which may then be converted to fats.

Physiological factors that influence lipid metabolism include growth hormone (GH or somatotropin), insulin-like (IGF-I) growth factor-I (Lucy 2008), insulin, leptin, and catecholamines (Roche, Friggens, Kay, Fisher, Stafford & Berry 2009). GH, a protein hormone released from the anterior pituitary, facilitates energy release from adipose stores (Liesman et al. 1995) particularly during the prepartum period. IGF-I is released from the liver in response to GH to control growth and lactation (Renaville et al. 2002, Bartke et al. 2004). GH and IGF-I reach maximum concentrations prepartum if energy intake restrictions occur (Lucy 2008). GH directly regulates ruminant adipose tissue stores by enhancing the response to lipolytic stimuli, attenuating the lipogenic response to insulin, and inhibiting the insulin-mediated uptake of glucose by adipocytes. The net effect is the partitioning of nutrients away from adipocytes (Roche, Friggens, Kay, Fisher, Stafford & Berry 2009).

Insulin has an antagonist effect on the lipolytic actions of GH through its positive effect on hepatic and adipocyte GH receptor availability (Rhoads et al. 2004). Reduction in plasma isulin concentration and a reduction in insulin sensitivity of adipose tissue occur simultaneously in early lactation (Doepel et al. 2002). This increases glucose uptake by the mammary gland and promotes greater mobilisation of tissue reserves (Roche, Friggens, Kay, Fisher, Stafford & Berry 2009). Dairy cows selected for high milk yields have a greater level of insulin resistance (Chagas et al. 2009), which is associated with greater body lipid mobilisation postpartum (Smith & McNamara 1990, Roche et al. 2006, Kay et al. 2009). Leptin, a protein hormone, serves as an intake satiety signal by acting predominantly on regions of the brain involved in regulation of energy metabolism (Roche et al. 2008). The plasma leptin response to insulin is approximately six times greater during late pregnancy than during lactation (Leury et al. 2003) and low plasma leptin levels are consistent with reduced adipose tissue glucose uptake in early lactation (Roche, Friggens, Kay, Fisher, Stafford & Berry 2009).

Catecholamines, such as adrenalin and noradrenalin, secreted by the sympathetic nerve endings in adipocytes and the adrenal medulla, respectively, act as potent lipolytic stimulators (Bauman & Currie 1980). These act via specific proteins to increase adenyl cyclase production which in turn activates the regulatory subunits of both hormone-sensitive lipase and perilipin proteins, thereby increasing lipolysis (Stipanuk 1999) particularly in early lactation (McNamara 1988).

In summary, mobilisation of body energy reserves from body tissues occurs via homeostatic and homeorhetic mechanisms. Nutrient quality and availability (predominantly dependent on factors operating at the herd level) initiate homeostatic utilisation and mobilisation of energy stores, while homeorhetic mechanisms (particularly in the early postpartum period) are dependent on a cow's genetic merit for milk production and physiological state (cow-level factors) that temporarily override homeostatic mechanisms. The GH and IGF-I axis uncouples due to a down-regulation in liver GH receptors which is associated with a reduction in circulating IGF-I and elevated GH concentrations (Lucy 2006, 2008). This, combined with the hypoinsulinaemia and higher than normal leptin levels, provides an endocrine environment that promotes the direct action of GH on lipolysis and gluconeogenesis in early lactation, influencing the degree of adaptation of the postpartum cow to NEB (Jorritsma et al. 2003, Wathes et al. 2007, Roche, Friggens, Kay, Fisher, Stafford & Berry 2009). Normally, NEB continues for around to 2 to 4 months following calving or until a cow's DMI increases to a point where energy input is greater than energy output, resulting in positive energy balance thereafter.

Assessing body fat reserve and energy status

Managing body fat reserve and energy status at the herd and cow level has been cited by some authors as a means to optimise production and reproductive performance (Heuer et al. 1999, Berry et al. 2003, Banos et al. 2005, Auldist et al. 2007). Experimental methods exist that can accurately detect the amount of body fat in dairy cows and how it changes over time. High accuracy can be obtained using post-slaughter chemical analysis of the entire body with contents of the digestive and urinary tracts removed (Otto et al. 1991). A high correlation is found between entire body fat content and the fat content of the ninth through eleventh rib (Otto et al. 1991). However, such methods are either too invasive or impractical for field application.

Assessment of BCS and LW provide alternative tools to assess body fat reserves and energy status of dairy cows. Body condition scoring is widely regarded as a quick, non-invasive metric (Wildman et al. 1982, Butler & Smith 1989, Domecq et al. 1997*a*,*b*, Berry, Buckley & Dillon 2007). However, the inter-assessor variability that arises from the subjective nature of BCS recording (Ferguson et al. 1994, Kristensen et al. 2006) makes the use of more objective methods such as measuring LW appealing. In addition, automation of body condition scoring has, to date, been unsuccessful. Automatic daily weighing of cows is possible and facilitates the monitoring of ΔLW which has been associated with fertility (Buckley et al. 2003) and, more recently, with milk production (Bossen et al. 2009). Also, several studies have shown that the genes influencing BCS and LW are closely linked. These studies reported moderate (0.34 – 0.55) phenotypic (Enevoldsen & Kristensen 1997, Berry et al. 2002) and genetic (Berry et al. 2002) correlation between BCS and LW in dairy cattle. Using LW as a tool to assess an animal's energy status has been discouraged due to the potential confounding effects of parity, stage of lactation, frame size, stage of gestation and breed. It has been concluded that measurement of LW postpartum does not 'necessarily' provide a reflection of an individual cow's true energy status (Roche, Friggens, Kay, Fisher, Stafford & Berry 2009). This is true, particularly if LW is being measured on cross-sectional basis (i.e. at certain key points in a cow's production cycle), however, continuous monitoring of LW presents a much different scenario.

Continuous monitoring of LW on a daily or weekly basis allows identification of cows that continue to lose or gain LW over time. A cow that continues to lose LW over time is in a state of negative energy (NE), and a cow that gains weight over time has overcome NE (Jorritsma et al. 2003). ΔLW can be used to classify an individual cow's energy balance and divide individual lactations into the physiological stages of tissue mobilisation and deposition (Maltz et al. 1997). Also, because LW data can be measured objectively, when combined with other parameters such as milk yield it can be used to derive important information about an individual animal's energy status and handling of body reserves. This, in turn, allows sound managerial decisions to be made (Maltz et al. 1997).

Use of ΔLW as a management tool to monitor energy balance has been demonstrated recently. A four-year Danish study of 115 cows managed as a single herd was conducted to investigate the effect of feeding each cow according to her energy status (Bossen et al. 2009). Automatic LW recording was useful in this study to monitor the degree and duration of tissue mobilisation. Although these workers concluded that feeding according to ΔLW can be used to manipulate the transition from LW loss to LW gain in the post-partum cow and potentially enhance a cow's ability to maintain high milk production throughout a lactation, the study was conducted under controlled experimental conditions and involved only a small number of animals. Thus the conclusions drawn from this study should be interpreted with caution due to the inherent limitations imposed by the chosen study design.

Due to the overlap between BCS and ΔLW (Enevoldsen & Kristensen 1997, Berry et al. 2002) and the paucity of experiments using LW as a primary management parameter, the following sections evaluate the BCS and LW literature to help illustrate the effect of breed, heredity, parity, calving body condition and milk yield on ΔLW. Two selection criteria were used for studies included in this part of the review.

Changes in BCS are related to both LW and body composition and can influence the health and productivity of dairy cows. The subjective nature of BCS in different studies has made quantifying the effects of BCS change or agreement between condition score and liveweight and interactions with cow health and production controversial. Therefore, only those studies that clearly stated how and when BCS was conducted, and by whom, are included in this review. Secondly, the number of animals in a study and the number of animals per treatment group are important when assessing the effect of BCS or ΔLW on subsequent animal performance (Broster & Broster 1998). While small numbers per treatment group influences external validity (that is, the ability to extrapolate findings to target populations), it can also impact on internal validity. Internal validity can be compromised when information on extreme values of ΔBCS.LW is limited to a small number of experimental units or not provided, or information on potential confounders and their method of control is not provided. In this review, within study comparisons are only reported when the previous criteria were satisfied, otherwise the focus is on comparisons between studies.

Table 2.1: Comparisons between North American Holstein and New Zealand Holstein-Friesian cows for milk production traits and liveweight expressed as the North American Holstein minus New Zealand Holstein-Friesian means.

Study	Milk fat (kg)	Milk protein (kg)	Milk volume (L)	Liveweight (kg)	Source
CANZ trial (1987)	0.8 [c]	4.1 [c]	238 [c]	15 [a,c]	Peterson (1988)
LW trial (1999)	2.0	1.0	106	36 [b,c]	Rameriz (2000)
SPS study	1.9	7.7 [c]	389 [c]	43 [c]	Harris & Winkelman (2000)
DRC comparison trial (1998)	-14.9 [c]	5.3	280 [c]	62 [b,c]	Kolver et al. (2000)
DRC comparison trial (1999)	-26.4 [c]	0.9	197	70 [b,c]	Harris & Kolver (2001) [d]
DNZ comparison trial (2004)	-114 [c]	-17 [c]	Not reported	16 [c]	Macdonald et al. (2008) [e]

[a] Liveweight at 30 month of age.

[b] Liveweight after calving.

[c] Means differ ($P < 0.05$).

[d] Secondary citation from unpublished source.

[e] Comparisons reported in this study were between NZ90 (a 1990s high Breeding Worth Holstein-Friesian of New Zealand origin) and NA90 (a 1990s high Breeding Worth Holstein-Friesian of North American origin).

2.1.2 Breed and heredity

Low cost farming systems have necessitated matching the right type of cow to a given production system. This has introduced many differences between cows in their genetic capacity for milk production (Harris & Kolver 2001). Phenotypically this is reflected as differences in mature LW between cow strains. In New Zealand, breeding objectives to increase milk production has led to increased proportions of imported Holstein-Friesian genetics (Table 2.1). Recent New Zealand studies have cited the steady increase in average LW (Harris & Kolver 2001) to be a likely reason for the reduction in herd reproductive performance (Garcia-Muniz 1998, Thiengtham 2003, Macdonald et al. 2008). Hence, the suitability of larger framed cows in pasture based dairying systems has been questioned because of their inability to walk long distances (Harris & Kolver 2001) and harvest sufficient pasture to maintain LW compared with smaller framed animals (Macdonald et al. 2008).

In New Zealand Bryant et al. (2007) studied 184,288 milk yield records from first lactation cows from multiple herds from 1989 to 2002. These authors demonstrated that due to heterosis, crossbred Jersey-Holsteins had superior performance compared with purebred Holsteins for milk yield, fat and protein (average heterosis 7.3%; $P < 0.05$; Bryant et al.

2007). Similar results were reported from a smaller North American study in Minnesota conducted on 76 Jersey-Holstein and 73 Holstein dairy cows (Heins et al. 2008). These authors concluded that Jersey-Holstein cows maintained BCS and hence had lower levels of LW loss after calving (Heins et al. 2008). These findings, particularly those related to the rate of ΔLW within and between breeds, were in subsequent research attributed to differences in grazing behaviour. VFI and appetite (van Soest 1994), as a driver of grazing behaviour, limits the amount of DMI sufficient for maintenance and production (Roche, Friggens, Kay, Fisher, Stafford & Berry 2009, Prendiville et al. 2010).

Jersey (JE) and Jersey × Holstein-Friesian crosses (F1) are an example of where breed and heredity influence ΔBCS.LW. The aggressive grazing ability of JE and F1 cows results in a higher DM intake per unit of LW and therefore less energy is expended per unit of production (Lopez-Villalobos, Garrick, Holmes, Blair & Spelman 2000*b*, Prendiville et al. 2010). A recent longitudinal study of 108 mixed age and breed (Holstein-Friesian [HF], JE, and F1) cows in Ireland investigated the association between grazing behaviour, intake capacity and production efficiency under grazing conditions (Prendiville et al. 2010). Prendiville et al. (2010) showed that, compared with HF cows, JE and F1 cows spent, on average, more time grazing (129 min.100 kg^{-1} of LW *versus* 171 min.100 kg^{-1}, 149 min.100 kg^{-1} of LW; respectively; $P < 0.001$) and harvested dry matter at a higher rate (5.3 $g.min^{-1}$ *versus* 6.2 $g.min^{-1}$ and 5.6 $g.min^{-1}$, respectively; $P < 0.001$). The net effect was that JE and F1 cows in the Prendiville et al. study had a mean BCS greater than that of HF (2.91 *versus* 2.75, respectively; $P < 0.05$). F1 cows produced more milk and maintained their LW and body condition throughout the lactation compared with their parents (i.e. purebred JEs and HFs). This corresponded to hybrid vigor estimates of +14 kg (+3.1%) and +0.17 units (+5.7%) for LW and BCS, respectively. This accords with the findings of Lopez-Villalobos, Garrick, Blair & Holmes (2000) who reported hybrid vigor estimates for LW of +7.7 kg for F1 cows in New Zealand.

Dillon et al. (2003) evaluated the effect of breed on milk production throughout a lactation. The breeds were Dutch Holstein-Friesian (DHF), upgraded Irish Holstein-Friesian (CL), French Montbeliarde (MB) and French Normande (NR) cows. NR had significantly higher LW at all stages of lactation compared with DHF and CL. MB had significantly higher LWs in early lactation. ΔLW was similar for all four breeds in weeks 1 to 8 and weeks 8 to 12 of lactation. From weeks 12 to 40 LW gain for the DHFs was significantly lower (+0.28 kg.day^{-1}) than CL (+0.37 kg.day^{-1}), MB (+0.36 kg.day^{-1}), and NR (+0.38 kg.day^{-1}). In a small factorial design study conducted in New Zealand Roche et al. (2006) reported similar findings when they evaluated the effect of HF strain and concentrate supplementation on milk production, LW, and BCS. The Roche et al. (2006) study comprised LW records for 113 lactations across 76 cows between 2002 and 2004. Although no significant effect of the interaction between strain and diet on milk yield was found, New Zealand cows reached nadir BCS 14 days earlier and lost 22 kg LW less than the North American HF group. Veerkamp et al. (2001) reported that increases in the percentage of the Holstein gene in dairy cows had a positive effect on milk yield and a negative effect on LW and fertility. Compared with 50% Holstein cows, 100% Holstein cows produced 231 kg more milk and took 7.2 days longer to conceive (Veerkamp et al. 2001). These findings were supported when Toshniwal et al. (2008) analysed LW, milk yield, DMI and BCS records between 2002 and 2007 from 660 dairy cows in North America. Toshniwal et al. concluded that ΔLW in early and mid lactation are under genetic control and that there are genetic differences among cows for the amount of daily ΔLW that occurs in the first 100 days in milk. Also, these authors further reported a high heritability estimate for daily ΔLW and hypothesised that reasonably accurate genetic evaluations for ΔLW could be generated if automated daily LW were available from progeny test herds (Toshniwal et al. 2008). Hence, it was recommended to include other highly heritable variables in the genetic selection criteria (such as ΔBCS.LW) to act as indirect traits that influence individual cow energy status (Coffey et al. 2001). This has the potential to select animals capable of achieving higher DMI during lactation while at the same time minimising the extent and/or the duration of NEB postpartum (Berry, Macdonald, Penno & Roche 2006, Roche, Lee, Macdonald & Berry 2007).

In pasture based production systems, the LW of a cow selected for higher milk production and the antagonistic effect of milk production on ΔLW is a controversial topic. Attempts to maximise farm profitability through breeding for cows of high genetic merit has resulted in cows with higher mature LW (Lopez-Villalobos, Garrick, Holmes, Blair & Spelman 2000*a*,*b*). This necessitates a reduction in farm stocking rate and requires more DM for maintenance and milk production with marginal milk yield advantage (Holmes et al. 2002, Macdonald et al. 2008). In a completely randomised trial conducted in New Zealand, Macdonald et al. (2008) compared three strains of HF (NZHF70, high genetic merits for 1975; NZHF90, high genetic merits for 1998 and USHP90, North American with high Breeding Worth 1998) in 156 cows (n = 45, 60 and 60 for NZHF70, NZHF90 and USHP90, respectively) managed under different pasture allowance between 2004 and 2007. The NZHF90 cows produced greater yields of fat ($P < 0.01$), protein ($P < 0.01$), and lactose ($P < 0.01$) than the USHP90 and NZHF70 cows. Dry matter intakes were the same for the 2 NZHF strains (286 DMI), both of which were greater ($P < 0.01$) than the USHP90 cows (252 DMI). The NZHF90 producing 52 kg milksolids.cow^{-1} more than the USHP90 at all feeding levels ($P < 0.01$). On a scale from 1 to 10, the NZHF70 strain had the highest seasonal average BCS (5.06), followed by the NZHF90 (4.51) and the USHP90 (4.13) strains. BCS increased with higher feeding levels in the 2 NZHF strains, but not in the USHP strain. The 2 NZHF strains had similar 6 week in-calf rates (69%), which were higher than those achieved by USHP90 cows (54%, $P < 0.01$). The Macdonald et al. (2008) study demonstrated that compared with NZHF strains the USHP90 cows required large amounts of feed for body maintenance and milk production. These findings, combined with their lower reproductive performance questions the benefit of these breeds as being suitable seasonally calving, pasture fed systems with low levels of supplementation. The results of the Macdonald et al. (2008) study are supported by the economic impact LW as measured by the New Zealand breeding evaluation index (Breeding Worth; BW) that was introduced in 1995 (Harris et al. 1996). The BW index includes breeding values for milk, fat and protein production, LW, fertility, somatic cell count and residual survival weighted by their relative economic weight selection index (Spelman & Garrick 1997). Currently, every one kilogram increase in LW reduces farm profitability by NZD 1.24 (Anonymous 2010). This is mainly related to low beef returns from culled animals and the high cost of feed supplements. These findings demonstrate the potential benefits from including some measure of genetic ability to manage ΔBCS.LW in genetic analyses.

2.1.3 Parity and body condition at calving

In preparation for lactation, cattle have evolved a strategy to build up lipid reserves until a certain target is met (Ingvartsen et al. 2003). As mentioned in Section 2.1, LW increase in cattle continues until mature LW is reached. This increase has previously been estimated to be between 14% and 19% of LW at the time an animal calves for the first time

(Berry et al. 2005). This growth, coupled with the change in an animal's physiological status during lactation, increases the energy required to meet the demands for growth and lactation Berry, Veerkamp & Dillon (2006).

Although herd managers can address this issue directly through preferential feeding of first parity cows (Berry, Veerkamp & Dillon 2006, Roche, Berry, Lee, Macdonald & Boston 2007, Roche, Friggens, Kay, Fisher, Stafford & Berry 2009), failure to maintain or regain lost BCS or LW throughout a lactation, especially in the early postpartum period, is a well recognised challenge, particularly those operating under pasture based systems (Roche, Friggens, Kay, Fisher, Stafford & Berry 2009).

Koenen et al. (1999) estimated the effect of growth throughout a lactation from a dataset comprised of weekly averaged LW records from 452 lactations of 239 Dutch Holstein-Friesian cows. An estimated average growth of 46 kg was reported for first parity cows compared with 52 kg and 23 kg ($P < 0.05$) for second and third parities, respectively. Further, maximum LW loss ($P < 0.05$) was observed for first parity cows over a shorter period of time (26 kg over the first 7 weeks of lactation) compared with later parities (22 kg over the first 13 weeks of lactation). The effect of parity on LW and BCS change throughout the lactation has been documented in a large Irish field study conducted over a seven year period. Berry, Veerkamp & Dillon (2006) analysed 27,126 LW and 8,212 BCS records from 838 lactations that took place between 1995 and 2002. These authors found that first parity cows were lighter ($P < 0.01$), lost more BCS ($P < 0.01$) in early lactation, and were in NEB ($P < 0.01$) for longer, compared with older cows.

Similarly, van Straten et al. (2008) assessed daily LWs over the first 120 days of lactation in a longitudinal study of 2,167 high producing Israeli Holstein dairy cattle on 7 commercial farms. These authors found that average days from calving to nadir LW and LW loss to nadir were positively associated with parity. Older cows lost more weight than first parity cows (78 kg *versus* 56 kg) and had a longer period of negative energy balance. However, the association between parity and ΔLW has been inconsistent (Roche, Lee, Macdonald & Berry 2007). van Straten et al. (2008) concluded that differences in the study population (high producing, zero grazing Holstein cows *versus* average producing mixed breed, pasture-fed cows) and the frequency of weighing (daily *versus* fortnightly weighing, respectively) were the most likely factors leading to the reported discrepancies.

Body condition at the time of calving has been reported to be negatively associated with

DMI (Broster & Broster 1998) and therefore positively associated with the rate of LW loss after calving in favour of milk production (Section 2.1.1). Broster & Broster (1998) reported that VFI per litre of milk decreased by 1.3 kg.day^{-1} for unit increases in BCS. Stockdale (2008) reported similar findings recently from a smaller randomised factorial trial using 72 Holstein-Friesian multiparous cows in Australia. In this study fatter cows lost more condition and more LW postpartum (1.5 difference in BCS on a scale 1 to 8 and 81 kg LW, respectively). The period over which this loss of condition and weight occurred was longer than that for thinner herd mates. Thin cows maintained similar levels of milk production during lactation compared with fatter cows.

Many studies have shown that over conditioned dairy cows undergo a higher rate of BCS and LW loss after calving (Grainger et al. 1982, Ruegg & Milton 1995, Suriyasathaporn et al. 1998, Stockdale 2001, Berry, Lee, Macdonald, Stafford, Matthews & Roche 2007, Roche, Lee, Macdonald & Berry 2007, Stockdale 2007). Higher rates of BCS and LW loss after calving have been shown to have detrimental effect on health and reproductive performance (Section 2.1.5). These associations have been thought to be due to the physiological need for animals to maintain a certain level of condition relative to their physiological state (Oldham & Emmans 1989). For example, in sheep, body fatness was reported to be negatively associated with VFI (Mccann et al. 1992, Tolkamp et al. 2006). Mccann et al. (1992) and Caldeira et al. (2007) in two independent studies reported a rapid rise in VFI in lean sheep fed *ad libitum* until they reached a BCS of 3.7 – 4.0, at which point VFI declined rapidly to a constant lower level such that LW was maintained. In a literature review on the preparation of dairy cows for a lactation, Friggens et al. (2004) reported that body condition change during pregnancy and early lactation is genetically driven to safeguard reproductive success or to modify fat stores appropriately for their physiological state throughout the lactation.

2.1.4 Milk production

While in Section 2.1.1 a negative correlation between ΔLW and milk production was described, several studies have implicated positive ΔBCS.LW with higher milk production. In the United Kingdom two factorial design trials were conducted to evaluate the association between BCS and milk production. Three groups of eight Holstein dairy cows were fed for two months before calving to achieve a BCS at calving of 1.5 to 2.0 , 2.5 to 3.0 and 3.5 to 4.0 and the milk production from each group was compared (Garnsworthy & Topps 1982). The two groups were then followed for four months after calving and were fed a diet with an energy content of 12.25 MJ ME.kg^{-1} and 12.35 MJ ME.kg^{-1} DM in trials 1 and 2 respectively. Daily milk yields were then recorded and compared. These authors reported that cows with a BCS of 1.5 to 2.0 produced more milk, and started to regain BCS losses sooner than the BCS 3.5 to 4.0 BCS group ($P < 0.05$). Similar results have been reported elsewhere (see, for example, Treacher et al. 1986, Jones & Garnsworthy 1988, Fulkerson et al. 2008) with the consensus of opinion being that thin cows have an ability to match or exceed the milk yield of fatter cows if access to high quality feed was not limited. These conclusions were further supported in a longitudinal study of 350 high producing North American Holstein dairy cows by Waltner et al. (1993). The Waltner et al. study showed that BCS at calving was related ($P < 0.05$) quadratically to milk production. Waltner et al. reported that although an increase in BCS at calving from 2 to 3 increased milk production by 322 kg over the first 90 DIM, a similar increase from a BCS of 3 increased milk production by only 33 kg over the same period. Similar findings were reported by Berry, Buckley & Dillon (2007). While these authors reported that optimum BCS for milk yield at calving was 4.25, BCS and the effect of ΔLW at different stages of lactation had a non-linear relationship with milk production throughout the lactation. Although milk yield increased with loss of BCS postpartum, the marginal effect decreased as thinner cows lost in excess of 1.5 BCS gained weight (Berry, Buckley & Dillon 2007). Cows calving at a BCS of 3.50 units produced 68 kg less milk than cows calving at a BCS of 4.25 units while cows calving at 3.25 or 3.00 BCS units produced 118 and 182 kg less (Berry, Buckley & Dillon 2007), respectively, than cows calving at BCS of 3.50.

In New Zealand, a longitudinal trial of 259 Holstein-Friesian and 430 Jersey cows was conducted between 1991 and 1994 (Macdonald et al. 2005). Macdonald et al. showed up to 7% increase in milk yield in cows that maintained BCS compared with herd mates that lost condition. A positive correlation was also reported by Stockdale (2004*a*,*b*, 2005) and Stockdale et al. (2005) between LW and milk production. Berry, Buckley & Dillon (2007) reported a positive effect of BCS and ΔLW on milk production after controlling for the confounding effect of breed.

The studies presented in Sections 2.1.4 and 2.1.1 illustrate the complex nature of the relationship between $\triangle$BCS.LW, breed, parity and milk yield. Only recently have researchers in this area used analytical techniques to control for the confounding effects of frame size, age or breed on $\triangle$LW and milk production. Further, because many studies have used relatively small numbers of animals, inadequate statistical power is likely to have limited the ability to identify some of the more subtle influences on milk production. There is a need for further longitudinal studies involving larger numbers of animals to further clarify the nature of the relationship between $\triangle$BCS.LW and milk production.

2.1.5 Health and pregnancy

Management of dairy cows from dry off to calving, particularly in the last 4 weeks of pregnancy (termed the transition period), is an important determinant of health and productive performance throughout the subsequent lactation. During this period, cows experience substantial physiological changes and high metabolic demands (Section 2.1.1). Excessive LW loss or increased mobilisation of body reserves during the transition period has been associated with increased morbidity (Ingvartsen et al. 2003) and/or subfertility (Diskin et al. 2003). It has been hypothesised that cows that mobilise lipid excessively during the transition period have a pronounced peroxidative damage of lipids (Smith et al. 1984, Bernabucci et al. 2005, Sordillo & Aitken 2009) that alters the cell membranes and macromolecule cellular components, reducing immune function, particularly through negative effects on neutrophils (Kehrli et al. 1989, Kimura et al. 1999, 2002, Goff & Horst 1997, Lucy 2008, Rinaldi et al. 2008). It is thought that these effects increase an individual's susceptibility to metabolic disorders (Higdon & Frei 2003, Morrow 2003, Bernabucci et al. 2005) and postpartum reproductive complications (Markusfeld 1985, Suriyasathaporn et al. 1998, Diskin et al. 2003, Berry, Lee, Macdonald, Stafford, Matthews & Roche 2007, Roche, Macdonald, Burke, Lee & Berry 2007, Roche, Friggens, Kay, Fisher, Stafford & Berry 2009, Leblanc 2010). Therefore, management of LW and BCS of the transition cow has the potential to improve health and productivity throughout the subsequent lactation (Lean et al. 2008).

Liveweight change and health

Gearhart et al. (1990) studied LW and BCS change throughout the lactation in 561 North American Holstein cows in nine herds in New York, USA. These authors found that over conditioned cows (BCS $>$ 3) that lost greater BCS (-0.90) in the first 90 days after calving were 4.1 times (OR 4.1, 95% CI 1.2 to 13.8; P = 0.022) more likely to develop cystic ovarian disease and 2.8 times (95% CI 1.3 to 6.1; P $<$ 0.01) times more likely to develop reproductive problems (metritis, dystocia, retain foetal membranes, and/or pyometra) compared with herd mates. Similarly, cows over conditioned at dry off had 7.0 (95% CI 0.9 to 54.8; P = 0.06) times the risk of developing foot problems after calving. Although this study provided preliminary insights into optimal body condition for dairy cows in various stages of lactation, it had limitations. A major limitation was the lack of clear case definition for each of the health disorders that were investigated: the authors relied on farm staff to identify and diagnose problem animals. It was not clear from the study details whether farm workers adhered to a set of criteria to define cases, nor whether the authors had ascertained health status at the start of the observation period. Therefore it is not clear if the change observed in a cow's BCS resulted in health complications or *vice versa*. The direction of this bias is most likely to be away from the null and may have resulted in overestimation of the strength of association between changes in BCS and animal health status.

In another study of 1,335 lactations of dairy cows in 16 commercial dairy herds in The Netherlands, Heuer et al. (1999) reported a 50% increase in the risk of lameness (OR 1.5, P $<$ 0.05) and 3.3-fold (P $<$ 0.05) increase in the risk of milk fever in cows that lost excessive body condition during the first 20 DIM and 100 DIM, respectively, compared with herd mates that lost moderate body condition. Data from 732 moderate yielding, dual-purpose Norwegian cows (Gillund et al. 2001) showed that over conditioned cows at calving (BCS $>$ 3.75) lost greater amounts of condition postpartum and were at least 2.4 (95% CI 1.3 to 4.6; P $<$ 0.01) times more likely to suffer from ketosis in the first 190 days of lactation.

Berry, Lee, Macdonald, Stafford, Matthews & Roche (2007) reported that LW and BCS pre-calving, at calving, at 60 days in milk (DIM), and at nadir (minimum recorded LW or BCS) was associated with clinical mastitis in the early lactation period (first 60 DIM) and affected ($P < 0.05$) the odds of a clinical mastitis occurring throughout the lactation. For each standard deviation increase in LW loss at these time points, the odds of clinical mastitis increased by 23% (Berry, Lee, Macdonald, Stafford, Matthews & Roche 2007). Also, the probability of clinical mastitis followed a curvilinear relationship with LW loss and BCS change. The probability of clinical mastitis increased as the duration of LW loss increased to a maximum probability of 9% at 17 days postpartum and declined thereafter (Berry, Lee, Macdonald, Stafford, Matthews & Roche 2007). Care is needed when interpreting these results. Although BCS and LW were measured every two weeks, only BCS and BW at key points throughout the lactation were used in the analysis. The rate of change in BCS and LW used was the difference in LW and BCS measurements on the specified dates, divided by the interval length. It was not clear, nor did the authors justify why BCS and LW recorded at specific stages of the lactation were used to calculate the rate of change for these two measures. Also, the approach that was used has the potential to miss the impact of short-term BCS and LW change on udder health. Also, BCS or LW records within 6 to 10 weeks precalving were used to determine precalving BCS or LW. It was not clear from this study whether all the study animals were free from mastitis precalving. Once again, the bias in this study most likely affected the estimation of the strength of association between exposure to ∆BCS.LW and udder health. It is not possible to speculate on the direction of this bias from the details presented in the study.

Other studies have found less consistent associations between ∆BCS.LW and health (Markusfeld 1985, Domecq et al. 1997*a*,*b*, Suriyasathaporn et al. 1998, Heuer et al. 1999, Gillund et al. 2001, Lopez-Gatius et al. 2003, Drennan & Berry 2006, Berry, Lee, Macdonald & Roche 2007). For example, although Berry, Lee, Macdonald & Roche (2007) showed that calving difficulties were found to impact negatively on ∆LW postpartum, ∆BCS.LW in the transition period was not found to be a risk factor for dystocia or ill-health (Drennan & Berry 2006, Berry, Lee, Macdonald & Roche 2007). It was hypothesised that a cow that experienced a calving disorder may have higher than normal plasma cortisol levels compared with herd mates that calved normally (Drennan & Berry 2006, Berry, Lee, Macdonald & Roche 2007). Elevated cortisol concentration may affect metabolic functions and reduce appetite (Heuwieser et al. 1987, Nakao & Grunert 1990, Berry, Lee, Macdonald & Roche 2007), increasing the risk of NEB (Ingvartsen et al. 2003). A small observational study in New Zealand was conducted to identify the relationship between endometritis, serum non-esterified fatty acid (NEFA) and glucose concentrations during early lactation (Burke, Meier, McDougall, Compton, Mitchell & Roche 2010). These authors showed that negative ΔBCS.LW postpartum, as indicated by serum NEFA and glucose profiles, was not a risk factor for endometritis.

Liveweight change and pregnancy

The relationship between a cow's BCS and LW at calving on reproductive performance is well established and consistent results have been reported in the literature. In brief, heavier and/or over conditioned cows at calving have been shown to experience higher rates of BCS and LW loss in early lacation and poorer reproductive performance (Grainger et al. 1982, Garcia-Muniz 1998, Stockdale 2001, Dechow et al. 2002, Buckley et al. 2003, Morton 2004, Burke & Roche 2007, Roche, Macdonald, Burke, Lee & Berry 2007, Stockdale 2007, Burke, Williams, Hofmann, Kay, Phyn & Meier 2010). The association between excessive postpartum negative ΔLW on reproductive performance has been hypothesised to be due to either poor uterine conditions and/or impaired folliculogenesis (Britt 1992). Britt (1992) hypothesised that early postpartum NEB has a negative effect on follicular development. Weaker follicles are incapable of producing or sustaining a plasma concentration of progesterone sufficient to support the maintenance of pregnancy (Diskin et al. 2003).

2.1.6 Summary

There is a consistent relationship between ΔBCS.LW during the transition period and early lactation and animal health and fertility (Ingvartsen et al. 2003) which potentially has a substantial effect on productivity. This being the case, monitoring ΔLW after calving at the herd or individual cow level should prove useful for herd managers. For example, monitoring animals at the herd level provides an opportunity to evaluate and change current herd feeding programmes. Also it provides valuable inputs for informing herd culling and breeding decisions. For example, should culling a heavier non-pregnant cow take priority over culling a smaller herd mate if differences in milk production were marginal? Heavier cows impact negatively on stocking rate and require more feed, therefore culling them makes economic sense. Monitoring ΔLW at the individual animal level provides an opportunity for early identification of cows losing more LW than others, allowing preferential feeding to be applied to reduce the risk of negative effects on health, production and reproductive performance.

2.2 Animal welfare

Modern livestock farming systems aim to increase yield while continuing to ensure consumer safety. To do this it is necessary to minimise the impact of poor health on productive performance. Drug use, feed type and feed supplements are regulated to ensure that yields are not increased at the expense of consumer safety, animal health and welfare. However, the conditions that animals are kept in have raised a number of consumer concerns about animal welfare (Fraser et al. 1997, Fraser 2008, Rushen et al. 2008, von Keyserlingk et al. 2009). Although animal welfare *per se* is beyond the scope of this review, this section provides a brief summary of consumer concerns about animal welfare and how monitoring ΔLW might be used to partly address these concerns.

Fraser et al. (1997) summarised public concerns about farm animal welfare in terms of the 'five freedoms' (freedom from hunger and thirst, discomfort, pain, fear, and freedom to express normal behaviour; FAWC 1997). These welfare concerns fell into three main overlapping categories: (1) biological functioning (e.g. disease); (2) affective state (e.g. pain), and (3) being able to live reasonably a natural life. As a general premise, managers of livestock and their veterinarians are concerned about animal welfare, however as discussed in Section 2.1.5 only a very crude assessment of animal welfare is provided by objective measures such as the frequency of disease events, reproductive and productive performance (von Keyserlingk et al. 2009).

If consumer, herd manager, and veterinarian views about welfare are taken into account, better monitoring of individual animals should provide better underpinning for animal welfare (Frost et al. 1997). For example, monitoring individual dairy cow status for health disorders (biological functioning), oestrus detection (biological functioning, natural living) through sensors (Thysen 1993, de Mol & Ouweltjes 2001) that measure milk yield, temperature, and electrical conductivity, as well as the animal's activity with pedometers successfully identified diseased cows (affective state) and those in oestrus (Frost et al.

1997). Similarly, automated systems to monitor health and stress for other farmed animals such as pigs (Madeson et al. 2005, Moura et al. 2008) and broiler chickens (Mertens et al. 2009) also exist and were able to identify individual animals in distress, based on unusual vocalisation (Moura et al. 2008) or weight loss (Chedad et al. 2003).

2.3 Automated animal monitoring systems

Automation means the control of processes, data collection and analysis into information that can be used to assist management (Frost et al. 1997). The evolution of automation and technology for farmed animals aims to maximise production, milk yield, reduce expenses (mainly labour costs) or compensate for labour shortages or inexperience, enhance herd management and to provide accurate guidelines for managerial decision making (Spahr 1993). Dairy herd managers can maximise the efficiency of a production system by monitoring all its critical components, ensuring that each are kept close to optimum.

On-farm automated systems are available for feed (McAllister et al. 2000)(Growsafe, Growsafe Systems Ltd., Airdrie, Alberta, Canada; DeLaval feeding stations, DeLaval, Tumba, Sweden) and milking (DeLaval Parallel Rotary, DeLava International, Sweden). Automatic systems have the potential to allow staff to spend more time with their animals by reducing the amount of time required to carry out repetitive and laborious operations. In theory, this should improve the human-animal relationship and provide greater opportunity for staff to detect unusual conditions or activities in their stock.

For example, deviations in milk production, excessive LW loss or prolonged times to conception in individual animals are likely to be related to an underlying disorder such as parturient paresis, ketosis, or delayed onset of cyclicity. In this situation, once an abnormality is detected, interventions need to be applied to correct the problem or prevent further negative impacts. For this approach to work, farm staff need to have a good understanding of normal animal condition and performance. Thus, if automatic monitoring of herds or animals is used it should be aimed at augmenting the skill of farm workers or veterinarians at detecting abnormal deviations in performance rather than replacing their skills or diagnostic abilities (Mottram 1997). Early identification of deviations from normal determine the success of treatments or management changes that might be applied to rectify a problem. In this way automatic monitoring can be seen as a tool that promotes animal health and welfare.

Early identification of health problems in dairy cows is influenced by farm size, the ratio of the number of labour units to the number of animals and the experience of farm staff (Gonzalez et al. 2008). Subclinical disease can escape early diagnosis and lead to serious problems later (Gonzalez et al. 2008). Increases in the size of dairy herds coupled with the declining numbers of experienced farm workers is a trend that is likely to continue into the future. This makes automated monitoring of herd performance an attractive and viable means for maintaining productivity and welfare (Fraser et al. 1997, von Keyserlingk et al. 2009). In addition to the benefits outlined above, automated monitoring systems have the capacity to make routine tasks (milking, and animal handling) less stressful for both animals and farm staff. The data recorded by such systems is uniform in quality, thus avoiding variations in data recording quality that might occur when multiple individuals are involved in recording information.

Weights recorded while animals are inside a milking robot provide a reliable means for detecting lameness in dairy cattle (Pastell et al. 2006). Image analysis has been used a method for assessing the bodyweight of pigs. This involves a machine vision-based system comprised of a video camera for image capture and a computer for image acquisition and image processing. Pigs are guided to walk from one pen to another through a passage approximately one metre wide where imaging takes place. This technique is non-intrusive, fast and a relatively accurate tool that has the capacity to reduce stress on animals and farm workers during weighing (Wang et al. 2008). Image analysis techniques and automatic weighing has also been used in broilers and is promising in terms of being able to provide flock managers with uniform data on growth, feed conversion efficiency and the occurrence of disease problems (Chedad et al. 2003).

While LW recording has long been used as a tool in beef cattle production, only recently has it become commonplace in dairy production systems (Maltz et al. 1991, 1992, Spahr & Maltz 1997, Robinson 2005). Before the widespread availability of walkover weighing systems, LW measurements were recorded at critical times during the production cycle (Berry, Buckley & Dillon 2007). Changes in individual cow LWs from one measurement to the next provided a crude measure of energy balance (as discussed in Section 2.1). As discussed in Section 2.1.5, ΔLW throughout the lactation has been shown to be an important determinant of animal health, fertility and milk yield.

Intermittent LW recording using conventional static weighing systems is time consuming and labour intensive. This can influence the accuracy of the data being collected and interferes with the behaviour of animals being investigated (Charmley et al. 2006). To reduce stress, several methods have been developed to measure or estimate LW directly or indirectly. Weighing dairy cattle after milking as they exit the milking parlour using walkover or walk-through technology (Peiper et al. 1993) has the advantage of minimal disturbance of the milking process. Peiper et al. (1993) showed that LWs recorded using automated weighing systems should be within $\pm 1\%$ of a cow's true LW (measured statically). This means for a cow of 400 kg LW, an average LW fluctuation of 396 to 404 kg reflects an acceptable LW measure (Peiper et al. 1993).

Automated systems for monitoring cow health using automatically recorded LWs require the development of analytical techniques to relate variation in LW to the probability that an animal is ill. This requires prior knowledge of individual cow LWs within known limits. This can be achieved by fixing weighing times and consistent herd management. Weight variation can be between 5 – 10 kg around the daily mean LW measurements (Mottram 1997).

A number of automatic weighing methods for dairy cattle have been investigated. Automation of LW measurement is now generally achieved using walkover or walk-through technology (Filby et al. 1979, Peiper et al. 1993). Systems use electronic circuits involving a continuous averaging technique and peak hold facilities to obtain dynamic LW estimates from a specially designed weigh crate or platform. The performance of such a system is affected by cow flow and behaviour, for example, whether cows walk at a steady pace, with close succession or crowd over the weigh platform. Also, care is necessary to ensure that a cow does not exert downward force (which may occur with head and neck rubbing) which may result in a false reading (Filby et al. 1979). Cveticanin (2003) used a fuzzy logic approach to overcome a crowding problem when weighing livestock with a single scale platform. Using this approach Cveticanin achieved an average error (when estimated weight was compared with true one) of 1.5% in the case of a single crossing and 2% when crowding occurred.

Automatic weighing systems made from four strain gauge balance devices have been used in combination with milking robots (Pastell et al. 2006). These systems have been shown to measure average LW and weight variation of each limb giving a error rate of 10% (Pastell et al. 2006).

Other methods developed for beef cattle such as assessing LW remotely using loading scales and ‘off the shelf’ technology components allow automatic weighing of cattle at pasture (Charmley et al. 2006). Charmley et al. found that relatively large numbers of weights per animal were required to provide a sufficiently accurate assessement of LW using this method. Furthermore, ‘sensible’ LWs recorded using this method were found to be around 20 kg greater than static weights measured on the same animals within the same week. Charmley et al. provided no details about what constituted a ‘sensible’ LW measurement, nor details on the validity of LW measurement comparisons using the remote weighing unit and those measured statically.

A number of indirect methods for measuring weight in dairy cattle have been described. Heart girth measurement, wither height, body length (Heinrichs & Hargrove 1987, Heinrichs et al. 1992, Dingwell et al. 2006) and hip width measurement (Dingwell et al. 2006) are the most common indirect methods that have been used. Heinrichs et al. (1992) showed that heart girth has the highest association with LW measured statically. The difficulty performing such measurements uniformly on large numbers of cows limits the usefulness of these approaches for routine herd management. Image analysis and thermography have been studied in pigs and cattle for estimation of LW through determination of body dimensions. These methods have successfully estimated LW after adjusting for age (Stajnko et al. 2008). Such a system requires precise, breed-specific prediction functions to establish the relationship between body dimensions from acquired images and LW. Since the image is only a two dimensional plane projection of the animal, the loss of one dimension limits the application of this system (Stajnko et al. 2008). Image analysis has been used to automatically estimate BCS in dairy cattle (Leroy et al. 2005, Bewley et al. 2008, Bewley & Schutz 2009). Although automation has not been achieved, preliminary results are promising because the error of the prediction of BCS using image analysis methods, is on average, of the same order of magnitude as the error of experienced human experts (Leroy et al. 2005, Bewley et al. 2008, Bewley & Schutz 2009).

A dairy cow in mid lactation consumes just over 100 kg of feed and water per day (Devir et al. 1995, Maltz et al. 1997). This means that the gastrointestinal tract accounts for approximately 25% of LW (Woodford et al. 1984). Fluctuations in LW are normal and, as discussed in Section 2.1, can be influenced by herd management and an animal's physiological state. Maltz et al. (1997) used the average daily value of many measurements to overcome the natural fluctuation in LW. Averaged daily values can be used to detect temporary changes in LW which can be used diagnostically to indicate changes in physiological status associated with disease or oestrous events. Furthermore, daily LW values can be pooled to create weekly averages that can be used for decision making at the herd level (Maltz et al. 1997).

Therefore, any reduction in dry matter intake due to physiological disorders (particularly in the period around calving where DMI can be reduced by 30%) requires a recovery period of several days (Greenough & Vermunt 1991, Gonzalez et al. 2008). When this occurs, metabolic and endocrine changes cause body fat reserves to be mobilised to provide energy for maintenance and production (Section 2.1.1). Other physiological disorders result in brief changes in LW and this can be useful for diagnostic purposes. For example, a 1 – 2 day reduction of DM intake is characteristic of extended periods of activity such as oestrus (Maltz et al. 1997). Maltz et al. (1997) in a small study of 24 Dutch Holstein cows showed that 68% of detected oestrus events were associated with a significant temporary decrease in LW. The duration of LW change was limited to 1 – 3 days (Maltz et al. 1997). Records of daily LW, if consistently recorded and analysed appropriately, have the potential to be used as a tool to improve oestrus detection in commercial dairy herds. Improved oestrus detection means better reproductive outcomes with positive effects on herd profitability.

The managerial feature where LW measurements associated with physiological disorders can be utilised is influenced by two factors: BCS and DMI. Measured changes in LW result from the interaction between these two factors. These dictate the rate at which ΔLW occurs at any stage of lactation (see Section 2.1.1 for details). Further details are presented in Chapter 3.

2.4 Conclusions

A large volume of research has quantified the association between ΔBCS.LW and dairy cow health and fertility. The interval between LW measurements or BCS in published studies varies from daily (van Straten et al. 2008, 2009), to weekly (Domecq et al. 1997*a*,*b*) to every other week (Roche et al. 2006, Roche, Macdonald, Burke, Lee & Berry 2007). Irregularity in measurement intervals, the subjective nature of body condition scoring and the relatively large increments in which BCS change is scored makes quantifying the effect of BCS on cow health and production subject to controversy.

Excessive LW and/or BCS loss during early lactation has been attributed mainly to increased selection for high milk production (Veerkamp et al. 2000, Ingvartsen et al. 2003). The point at which selection for high milk production and the inherited increase in LW loss act as stessors predisposing animals to disease or reduced reproductive performance is not clear (van Dorp et al. 1998, Toshniwal et al. 2008).

This review has shown that ΔBCS.LW throughout a lactation can have an impact on dairy cow health, reproductive performance, milk yield and animal welfare. The subjective nature of BCS recording and the amount of time it reqires makes the automatic daily weighing of cows appealing. Automatic weighing facilitates the monitoring of ΔLW which has been associated with fertility and more recently with milk production. However, little is known about how it compares with conventional methods to measure LW or the frequency of weighing required before a significant change in LW is observed in pasture fed dairy herds. Additional research is needed to better quantify the real impact of ΔLW on animal health and productivity. The development of reliable automated monitoring technologies to provide frequent and repeated LW measurements may facilitate the practice of on-farm monitoring of ΔLW in pasture fed dairy herds. This is an area of research that needs attention and will form the basis of the studies presented in this thesis.

CHAPTER 3

Automatic recording of liveweight of dairy cattle at pasture in the first one hundred days in milk

Abstract – Daily walkover liveweight (WoW) records (n = 79,697) from 463 cows from a single dairy herd in the lower North Island of New Zealand were recorded over the first 100 days of lactation. The aims of this study were to: (1) describe LW records retrieved by a standalone automatic walkover daily weighing system; (2) describe the frequency and nature of outlier LW records measured by the system and develop an approach for excluding identified outlier LW records; (3) quantify the agreement between cow LWs measured using the walkover system and those measured statically; and (4) describe the autocorrelation between LW measurements in order to provide recommendations around how frequently dairy cows need to be weighed to detect LW change in the early lactation period.

The standard deviation of daily LW measurements across parities was 17 kg on average. A near perfect agreement between liveweights measured statically and WoWs (concordance correlation coefficient 0.99, 95% CI 0.99 to 1.0) was observed. After controlling for the effect of liveweight at calving and long term liveweight change using a mixed-effects linear regression model, the autocorrelation between WoWs recorded on successive days was 0.21, decaying to zero by eight days.

This study shows that by using a standalone automatic walkover weighing system positioned in the exit race of a rotary milking parlour, it was possible to record LWs of individual cows on a daily basis and, with controlled cow flow over the weighing platform (allowing for sufficient succession distance to prevent congestion), results were similar to those recorded using conventional, static weighing techniques using the same scales. Based on the autocorrelation analyses, we recommend that LWs are recorded on a daily basis to allow changes in physiological status such as the onset of acute illness or oestrus to be detected. For managerial purposes, such as using LW change as a guide for adjusting the herd feeding programme, we recommend a seven-day decision interval where LW measurements on day 1 are compared with LW measurements on day 7.

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3.1 Introduction

Economic drivers of milk production in New Zealand have resulted in an increase in the national median herd size and a decrease in the number of labour units per cow. In 2008 – 2009 the median milking herd size was 300 cows and the average number head of cattle managed per labor unit was 150 (Anonymous 2010). Under these conditions, successful dairy farming is less dependent on the husbandry of individual animals and more dependent on the ability of farm staff to manage large numbers of animals at the population or group level (Ott et al. 1995).

A number of technologies are now available to assist dairy herd staff to manage large numbers of stock. Automated systems are available to manage feed (McAllister et al. 2000) (Growsafe®, Growsafe Systems Ltd., Airdrie, Alberta, Canada; DeLaval^{TM} feeding stations, DeLaval, Tumba, Sweden), milking (DeLaval^{TM} parallel rotary, DeLaval International, Sweden) and oestrus detection (HeatWatch®, DDx Inc., Denver, Colorado, USA). These technologies have the potential to enhance herd profitability by identifying shortfalls in performance or impending problems without requiring a herd manager to scrutinise herd data in detail at regular intervals. They also allow problems to be detected promptly which means that corrective action can be taken in a timely manner (Cveticanin & Wendl 2004, Peiper et al. 1993, Spahr & Maltz 1997).

Measurement of liveweight (LW) is an established method for monitoring the performance of intensive and extensively managed beef cattle (Clanton et al. 1983). Individual animal LWs and estimates of LW change have relatively recently been used as tools to aid in the management of dairy herds (Robinson 2005, Spahr & Maltz 1997). Changes in body composition and LW have been associated with dairy cow health (Berry, Lee, Macdonald, Stafford, Matthews & Roche 2007), fertility (Buckley et al. 2000, 2003), milk yield and milk composition (Berry, Buckley & Dillon 2007, Maltz et al. 1997, Roche, Lee, Macdonald & Berry 2007). Berry, Lee, Macdonald, Stafford, Matthews & Roche (2007) studied LW and LW change and its association with clinical mastitis in 2,600 lactations in 897 New Zealand dairy cows and reported a negative association between LW change and clinical mastitis. These authors found that cows that lost a greater amount of weight postpartum (one standard deviation below mean LW loss across the entire lactation) had a 1.29 (95% CI 1.02 to 1.64) times increase in the odds of clinical mastitis occurring throughout the lactation. Roche, Lee, Macdonald & Berry (2007) used the same data to identify and quantify relationships between LW change and reproductive performance. They reported that the odds of detecting an oestrus after the Planned Start of Mating date (PSM) was positively associated with LW change and cows that lost more weight from calving to nadir (minimum LW recorded for each cow) or PSM were less likely to be detected in oestrus and be submitted for artificial insemination in the first 21 days following PSM.

Liveweight measurements in dairy cattle are typically obtained using conventional static weighing systems which require cattle to be individually walked onto a set of scales and a measurement recorded when the system comes to equilibrium. This process is time consuming, labour intensive and places stress on both the animals being weighed and the operator carrying out the procedure (Charmley et al. 2006). Walkover weighing systems require cattle to pass through a specially designed crate which allows body mass to be estimated using continuous averaging techniques (Long et al. 1991, Peiper et al. 1993, Ren et al. 1992). In commercial dairies walkover scales provide a number of advantages over static methods since LWs can be measured frequently (e.g. at the end of each milking) without the stress associated with conventional weighing procedures. Such measurements can then be used as a proxy to assess the physiological well-being of individual herd members. Little appears to be known about how walkover LW (WoW) measurements agree with static LW measurements under commercial dairy farm conditions and how frequently WoW measurements need to be recorded to produce information that can be used for diagnostic (e.g. detecting temporary states or disorders such as oestrus, or disease) or managerial purposes (e.g. feeding cows according to performance, or to prevent undesired LW loss or gain).

Although WoW facilities show great promise in providing information that can be used for tactical and strategic herd management, poor cow flow over the scale platform (resulting in more than one cow simultaneously being present on the scale platform, or a cow standing partially on the scale platform at a given time) can result in erroneous LW measurements manifest as outliers in the data presented for analysis (Filby et al. 1979). A critical issue when analysing data collected using these systems relates to the decision rules around how far an animal's recorded weight needs to change from previous values before it should be regarded as erroneous. Outlier detection in this situation consists of two sub-problems: firstly, defining which data are exceptionally distant from other values in a given dataset and, secondly, finding an efficient algorithm to deal with such data (Han et al. 2005). The majority of WoW studies in dairy cattle contain few details about the methodology used to detect and deal with outlying observations and simply refer to these observations as 'biologically implausible' (Kujala et al. 2008, Pastell et al. 2006, Ren et al. 1992). A small number of studies have addressed the problem in detail. van Straten et al. (2008) used a technique involving penalised cubic spline regression methods and time series analyses to avoid outlying LW measurements from 3,295 zero-grazing, high producing Israeli Holsteins. Onyiro et al. (2008) studied 14,026 LW records from 248 Holstein-Friesian cows in Scotland and used observation distance (expressed in terms of the number of standard deviations from a cow's mean LW) to identify and remove LW records that were considered biologically implausible.

The objectives of this study were to evaluate a WoW system on a commercial New Zealand dairy farm. Specifically, our aims were to: (1) describe LW records retrieved by a standalone automatic walkover daily weighing system over the first 100 days of milk; (2) describe the frequency and nature of outlier LW records measured by the system and develop an approach for excluding identified outlier LW records; (3) quantify the agreement between cow LWs measured using the walkover system and those measured statically; and (4) describe the autocorrelation between LW measurements in order to provide recommendations on the frequency that dairy cows need to be weighed to detected LW change in the early lactation period.

3.2 Materials and methods

Study animals

This was a prospective cohort study of 463 mixed aged and breed (Holstein-Friesian, Jersey, and Holstein-Friesian × Jersey) dairy cows that calved between 15 July and 24 October 2008 in a seasonally calving, pasture fed dairy herd in Palmerston North in the lower North Island of New Zealand (longitude 175° , latitude -40°). Cows grazed as a single herd and had free access to water. The herd was managed so that the pasture allowance (14 – 16 kg DM.cow^{-1}.day^{-1}) and access to supplementation after the morning milking (palm kernel meal to a maximum of 2 kg DM.cow^{-1}.day^{-1} and maize silage to a maximum of 2 kg DM.cow^{-1}.day^{-1}) was sufficient for maintenance and production requirements of a 400 kg cow producing 2.0 kg milksolids.day^{-1}. The pasture was dominated by ryegrass (*Lolium perene*) throughout the year. White clover (*Trifolium repens*) contributed up to 20% of pasture dry matter. Cows were milked twice daily, starting at 0530 and 1500 hrs, in a rotary platform milking parlour (DeLaval^{TM} parallel rotary, DeLava International, Sweden).

Cows were identified using a radio frequency electronic identification system. This was comprised of low frequency (134.2 kHz), high performance, non-reusable half duplex ear tags fitted to each cow and an antenna (Allflex^{TM} New Zealand Limited, Palmerston North, New Zealand). The antenna was connected via a serial connection cable (9 pin universal RS232 connector cable) to an electronic walkover scale system (Figure 3.1) comprised of an aluminum walkover platform, two electronic loadbars and a scale indicator (WOW! XR-3000®,Tru-Test, Auckland, New Zealand). The antenna and walkover scale system were installed in the exit race, 10 metres from the exit point of the milking platform. LWs were recorded as each cow walked away from the milking platform at the end of each milking. Since this was an observational study, and one of our objectives was to determine the proportion of outlier records, no direct interventions were applied throughout the study period to interfere with, or modify cow flow over the scale platform. The walkover scale system was calibrated (as per manufacturer instructions) to have an accuracy of ± 2 kg. The study period was from 15 July 2008 to 1 February 2009 (100 days after the last cow in the herd calved for the 2008 – 2009 milking season).

Throughout the study period LW data were downloaded from the scale indicator to a portable personal computer twice weekly. Data that were downloaded included each cow's electronic identifier, the date and time of each weigh event, and the LW measurement (in kilograms) as estimated by the scales. Data were transferred to a dairy herd management software package (DairyWIN v99.91.148; Massey University, Palmerston North, New Zealand) allowing LW data to be matched with each cow's biographical and lactation event details (e.g. calving date, insemination date(s), diagnosis and treatment details and dates).

To quantify the agreement between LWs measured using the walkover system with those measured statically, three groups of animals were weighed on 4 August 2008, 1 September

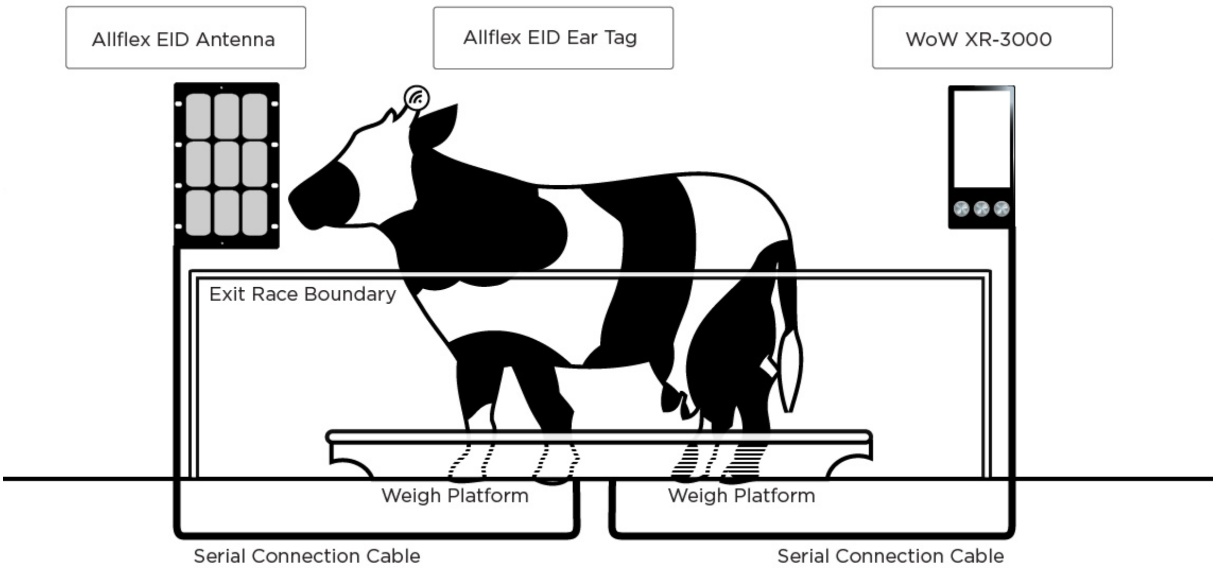

Figure 3.1: Diagram showing the hardware configuration used in this study.

2008, and 6 October 2008. On each of these dates, the last 50 cows milked at the morning milking were allowed to walk freely (allowing for sufficient succession distance to prevent congestion) over the scale platform and then immediately re-drafted for static liveweight measurement. For the static weights the same set of scales was used with the walkover weigh function disabled. The time period when this subgroup was held and re-weighed was kept to a maximum of one hour.

Data management

Prior to analysis a series of data cleaning procedures were carried out. Firstly, outlier individual daily LW records were considered to fall into one of two categories: (1) those that were biologically implausible and (2) those, while biologically plausible, were extreme for a given animal (termed potentially erroneous records in the remainder of this paper).

Secondly, we generated a smoothed LW curve using a nonparametric cubic spline regression model for each cow (Figure 3.2). This approach used days in milk (DIM) as a single smoothing variable. The smoothed value for a given DIM was calculated by minimising the following quantity:

$$Q(\alpha) = \sum_{i=1}^{n}[y_i - \mu(t_i)]^2 + \alpha \int_{-\infty}^{\infty} [\mu''(t)]^2 dt \qquad (3.1)$$

In Equation 3.1 y_i is the individual LW record on DIM$_i$, $\mu(t_i)$ is a cubic function of DIM$_i$, and α is a term to define the trade-off between the closeness of fit to the data as measured by the residual sum of squares and smoothness of $\mu(t)$ as measured by the integral term (the squared second derivative of the cubic function, Diggle 1990, p27). The trade-off between goodness of fit and smoothness (α) that minimised the predictive residual sum of squares on the fitted data was determined using a generalised cross-validation procedure (Green, 1994) implemented using the smooth spline function within R version 2.10.0 (R Development Core Team 2010). Individual LW record on DIM$_i$ were identified as biologically implausible from a cow's set of individual LW records if they varied by more than 3 standard deviations (calculated using each cow's individual LW records between 0 – 100 DIM) above or below the estimated LW at DIM$_i$ (Figure 3.2). This approach identified those individual LW records where there was less than a 1% chance that they were plausible values for that day in milk. Finally, an individual LW record on DIM$_i$ was then identified as potentially erroneous if it was above or below the boundaries of the 95% prediction intervals calculated around the estimated smooth daily LW curve (Figure 3.2). To minimise the variation of LWs that could arise from differences in daily gut fill effects, feed management or availability and milk volume between milking sessions, the two individual LW records for each cow for each day were averaged to provide a single daily measurement. If one record was missing (11% of total records) the remaining record was used. In the remainder of this paper we use the term 'daily LW measurement' to refer to the averaged daily individual LW records.

Individual cow liveweight at calving was quantified by averaging daily LW measurements during the first 7 days after the date of parturition. This was done to enhance the precision of the estimate of LW at calving, since erratic cow flow over the scale platform was more common early in the season when there were large numbers of freshly calved cows joined the milking herd. Day of nadir LW for each member of the herd was defined as the DIM when minimum LW was recorded and was identified using a two step process. Firstly, the daily recorded LWs for each cow were converted into weekly averages and records were screened to determine the week in milk with the minimum average LW. Secondly, the day in milk within the selected week with the lowest LW was taken as the nadir LW day. LW change from calving to nadir was derived by subtracting the LW recorded at nadir DIM from the recorded LW at calving (positive values representing losses and negative values representing gains). Also, the LW change from calving to 100 DIM (the end of the study observation period) was calculated by subtracting the LW recorded at 100 DIM from the recorded LW at calving (again, positive values representing losses and negative values representing gains).

Statistical analyses

Differences in mean LW at calving, mean LW loss to nadir and mean days to nadir LW across different parities (parities 1 – 2, 3 – 4 and 5+) and adjusted for breed were evaluated by analysis of variance (ANOVA) within the structure of a general linear model. The significance of the source of variation was determined using the F-test for type III sum of squares. This approach was used due to the unbalanced nature of the data.

An evaluation of the level of agreement between WoWs and LWs measured statically was made using Lin's concordance correlation coefficient (Lin 1989, 2000). The concordance correlation coefficient combines measures of both precision and accuracy to determine how far the observed data deviate from perfect concordance (a concordance correlation coefficient of 1.0). A limit of agreement plot (Bland & Altman 1995) was used to directly compare walk-over and static LW measurements.

Because LW measurements can be used in a number of different ways (e.g. for monitoring responses to feeding programmes versus detecting adverse health events in individual cows) it follows that the frequency of recording and analysing weigh events might need to vary depending on specific management objectives. For this reason, it was of interest to determine the number of days that must elapse between weigh events for a change in LW to be detected. To address this objective we developed a linear mixed model that accounted for individual cow-level effects (that is, LW at calving and change in LW post calving) using the following model:

$$y_{ij} = \beta_0 + \beta_1 t_{ij} + \beta_2 t_{ij}^2 + \alpha_{0j} + \alpha_{1j} t_j + \alpha_{2j} t_j^2 + \epsilon_{ij} \qquad (3.2)$$

In Equation 3.2 y_{ij} is the LW of cow j at DIM$_i$, β_0, β_1, β_2 are regression coefficients to estimate LW as a function of days in milk, α_{j0}, α_{1j} and α_{2j} are random intercept and slope terms to describe the deviation of cow j's LW from that of the herd average. Finally,

ϵ_{ij} represent the model residuals, the difference between LW predicted from the fixed-and random regression coefficients and the LW actually recorded for cow j at DIM$_i$.

An autocorrelation function (ACF) plot was constructed to show the correlation between the model residuals after adjusting for the covariates presented in Equation 3.2 at each distinct time separation or lag | DIM$_k$ - DIM$_l$ | where $k < 1$ (Diggle 2002). By doing this we were able to quantify the similarity in LW measurements at given time separations after controlling for the size of the cow (through the random intercept term) and long term weight change that might occur after calving (through the random slopes). These analyses were performed using the REML procedure implemented within the nlme package (Pinheiro et al. 2011) in R.

3.3 Results

There were 79,697 individual LW records available for analysis. Of these, 7,728 (10%) LW records were defined as outliers (Table 3.1). Daily individual liveweight records that were above and below the 95% prediction intervals calculated around the estimated smooth daily LW curve using the cubic spline method ranged from 0 to 465 kg. Outliers were excluded from the dataset before further analysis. A summary of the individual LW records and daily LW measurements data are shown in Table 3.1.

The distribution of daily LW measurements was consistent with the normal distribution (Kolmogorov-Smirnoff test of normality P $<$ 0.05). LW at calving differed significantly across parities (P $<$ 0.05). The standard deviation of daily LW measurements across parities were 17 kg (the ratio of the standard deviation to the mean; [17/395] $\times$ 100 = 4.3%), 16 kg ([16/440] $\times$ 100 = 3.6%) and 17 kg ([17/526] $\times$ 100 = 3.2%), for 1, 2, 3 – 4 and 5+ parities, respectively. 1^{st} and 2^{nd} parity LW loss at nadir (44 kg) and 100 DIM (13 kg) compared with LWs at calving were significantly lower (P $<$ 0.05) than those recorded for the parities 3 – 4 (52 kg, 26 kg), and 5+ parities (62 kg, 30 kg).

Figure 3.3 and Figure 3.4 show the concordance and the agreement between walk over and statically recorded LW measurements for three subgroups (n = 50) of cows weighed in August, September, and October of 2008. As shown in Figure 3.3, the best linear fit was y = 1.005x, where y is the measured WoW and x is the statically measured LW (r^2

0.9982). The concordance correlation coefficient was 0.99 (95% CI 0.99 to 1.00). Figure 3.4 shows that the errors were randomly scattered around the mean throughout the entire weight range, and overall, the mean difference between walkover and static LWs was -2.3 kg (SD 3.2 kg). The 95% lower and upper limits of agreement were -8.8 kg and +4.2 kg, respectively.

The ACF plot (Figure 3.5) showed a moderately high autocorrelation of 0.21 at lag (day) 1 that decayed to zero by lag 8. This means that, after controlling for individual cow-level effects (including LW at calving and LW change after calving) LWs measured on a given day were unlikely to be correlated with LW measurements taken up to 7 days previously.

Table 3.1: Descriptive statistics of individual liveweight records and daily liveweight measurements of dairy cattle, 15 July 2008 to 24 October 2008, stratified by parity groups.

Variable	Cows n	LW n	Mean (SD)	Median (Q1, Q3)	Min, max
Parities 1 – 2:	111	15009 [a]			
LW at calving (kg)*			404 (38)	403 (373, 430)	320, 490
Daily LW measurement (kg)			395 (17)	392 (372, 418)	261, 550
Days from calving to nadir LW [b]			47 (23)	43 (30, 64)	5, 93
LW loss from calving to nadir (kg) [c]*			44 (19)	42 (33, 55)	1, 79
LW loss from calving to 100 DIM (kg) *			13 (17)	6 (2, 8)	1, 47
Parities 3 – 4:	179	22548 [a]			
LW at calving (kg)*			461 (50)	462 (427, 487)	332, 622
Daily LW measurement (kg)			440 (16)	435 (406, 470)	265, 588
Days from calving to nadir LW [b]			53 (20)	54 (36, 67)	1, 100
LW loss from calving to nadir (kg) [c]*			52 (19)	52 (38, 64)	1, 114
LW loss from calving to 100 DIM (kg) *			26 (15)	23 (14, 34)	1, 61
Parities 5+:	173	34412 [a]			
LW at calving (kg) *			545 (45)	542 (515, 576)	434, 670
Daily LW measurement (kg)			526 (17)	527 (494, 553)	303, 661
Days from calving to nadir LW [b]			55 (24)	57 (30, 66)	5, 99
LW loss from calving to nadir (kg) [c]*			62 (26)	59 (41, 79)	2, 161
LW loss from calving to 100 DIM (kg) *			30 (22)	28 (18, 40)	1, 84
Total [d]	463	71969 [a]	478 (69)	475 (372, 553)	261, 661
Outliers [e]		7728			
Potentially erroneous		5939	33 (46)	9 (3, 47)	0, 148
Biologically implausible		1789	174 (47)	169 (142, 202)	66, 465

Key: SD standard deviation; Q1 25^{th} percentile; Q3 75^{th} percentile; LW liveweight; DIM days in milk.
* $P < 0.05$ across the three parity groupings.
[a] The number of individual liveweight records (am and pm) excluding outliers. Summary statistics were calculated after outliers were excluded.
[b] Day in milk when minimum daily LW measurement was recorded.
[c] LW at calving minus daily LW measurement at nadir. Positive values represent LW loss and negative values represent LW gain.
[d] Summary statistics for all parities.
[e] All individual LW records identified as biologically implausible and potentially erroneous outliers (am and pm) as described in the text.

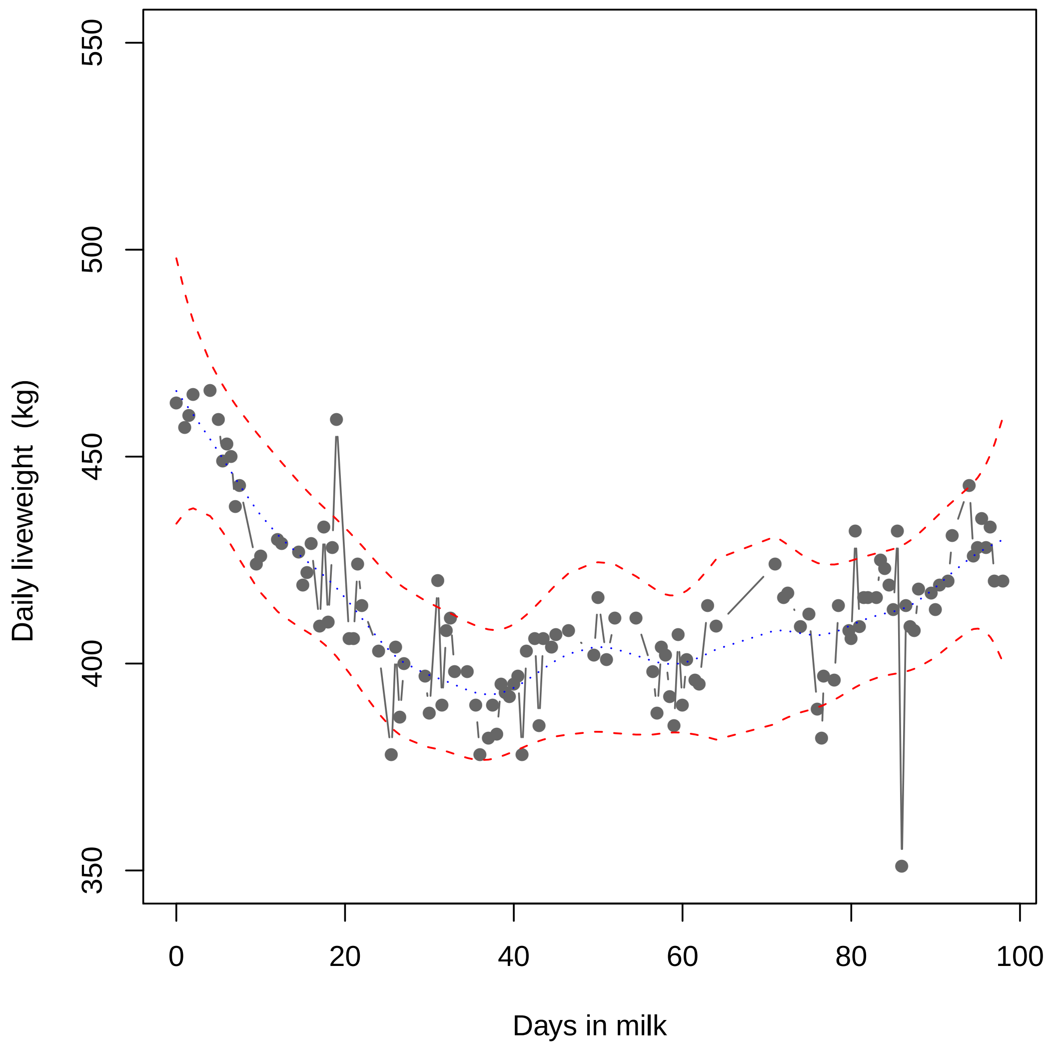

Figure 3.2: Daily individual liveweight records for a single cow shown as points (●) as a function of days in milk. The dotted line shows a penalised cubic regression line fitted to the liveweight records. The dashed lines represent the lower and upper 95% prediction intervals around the penalised cubic regression line. Six potentially erroneous individal LW records and one biologically implausible liveweight records are identified at 20, 25, 30, 40, 75, 79 and 85 days in milk. For this cow the standard deviation of LW records from 0 to 100 DIM was 15 kg.

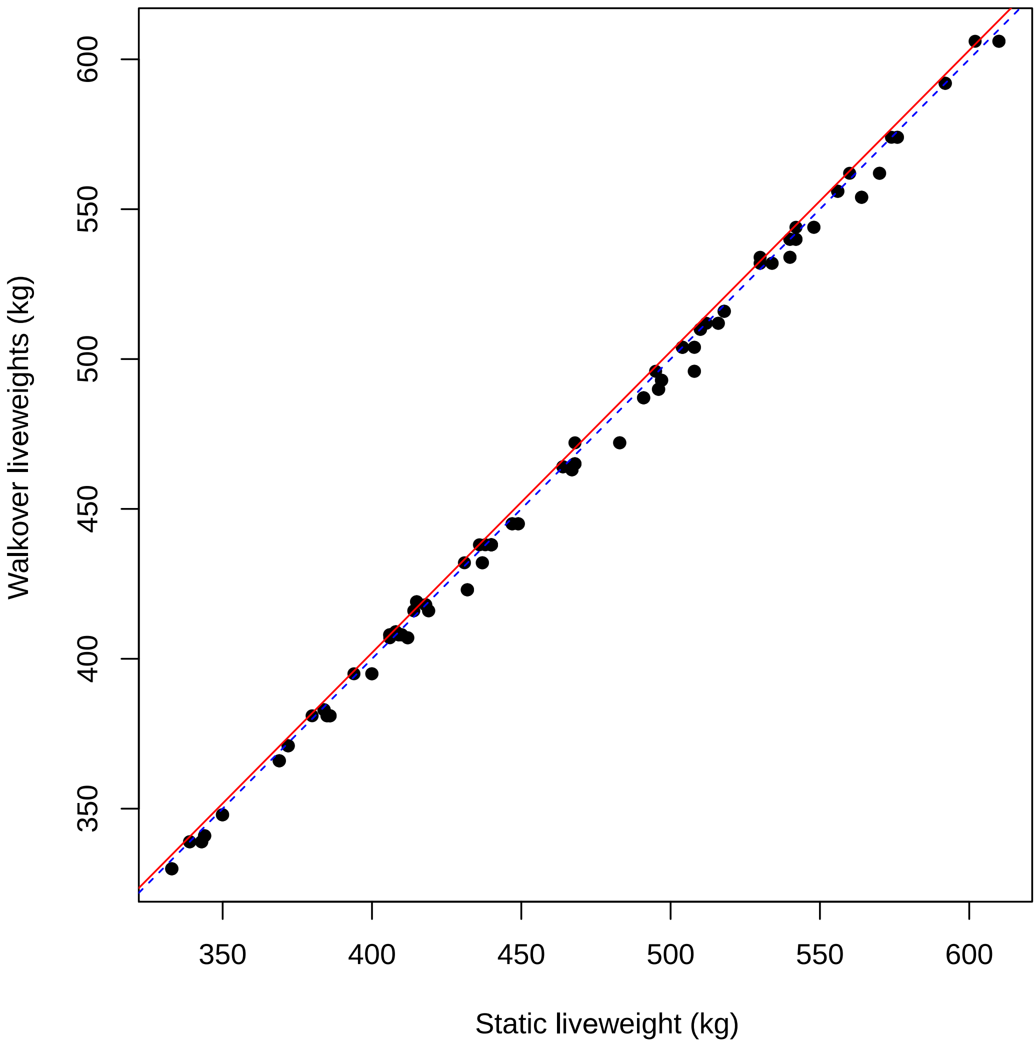

Figure 3.3: Scatterplot showing walkover liveweight measurements as a function of static liveweight measurements for three groups of 50 cows weighed on August, September and October of 2008. The broken line indicates the line of perfect concordance. The solid line is the best linear fit, y = 1.005x. The concordance correlation coefficient for these data was 0.99 (95% CI 0.99 to 1.00).

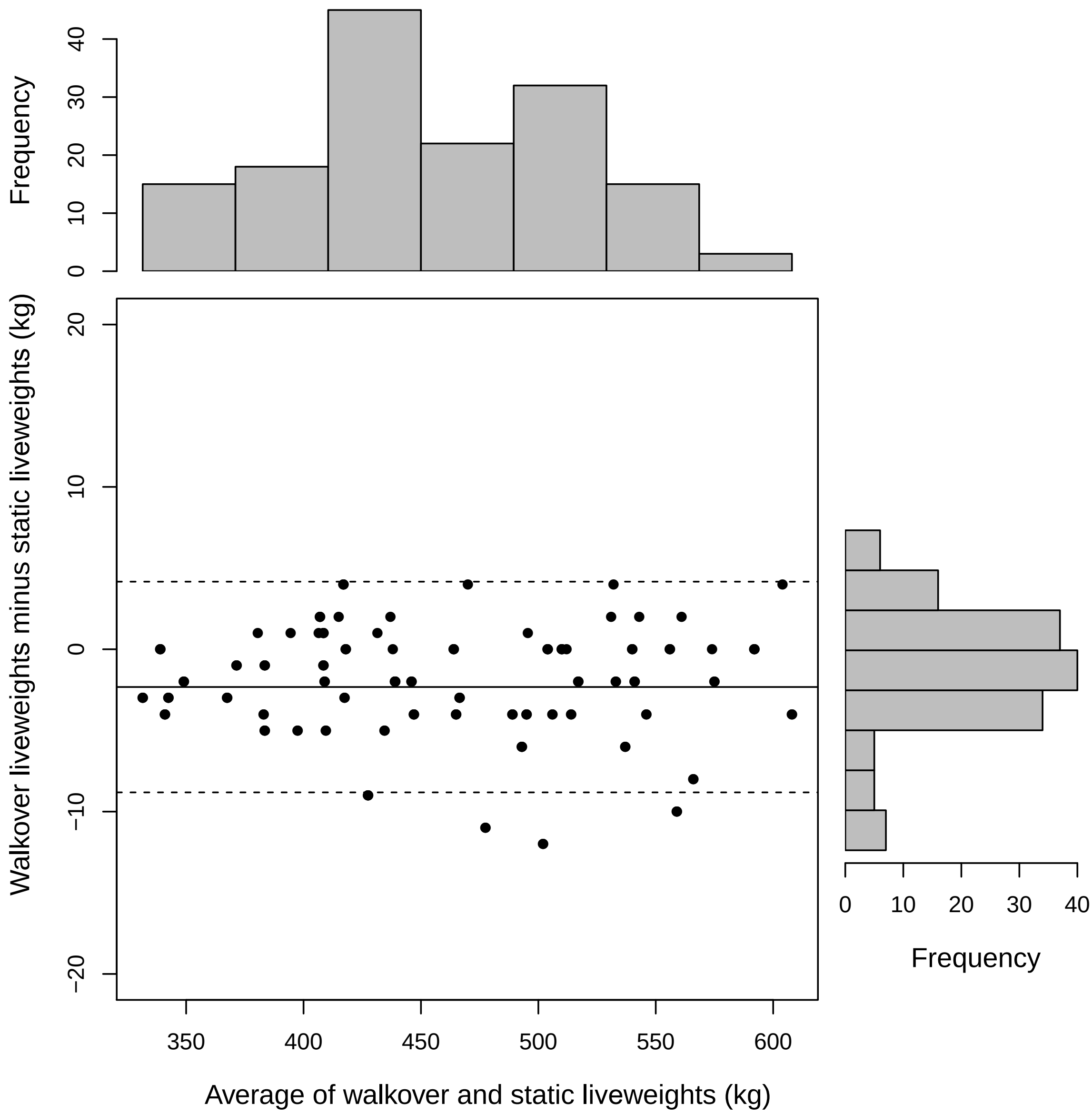

Figure 3.4: Scatterplot showing the observed difference between walkover and static liveweights (•) as a function of the average of walkover and static liveweights. Also shown are the 95% limits of agreement (-8.8 kg to 4.2 kg) at two standard deviations (dashed lines) from the average (solid line) of walkover liveweights minus static liveweights.

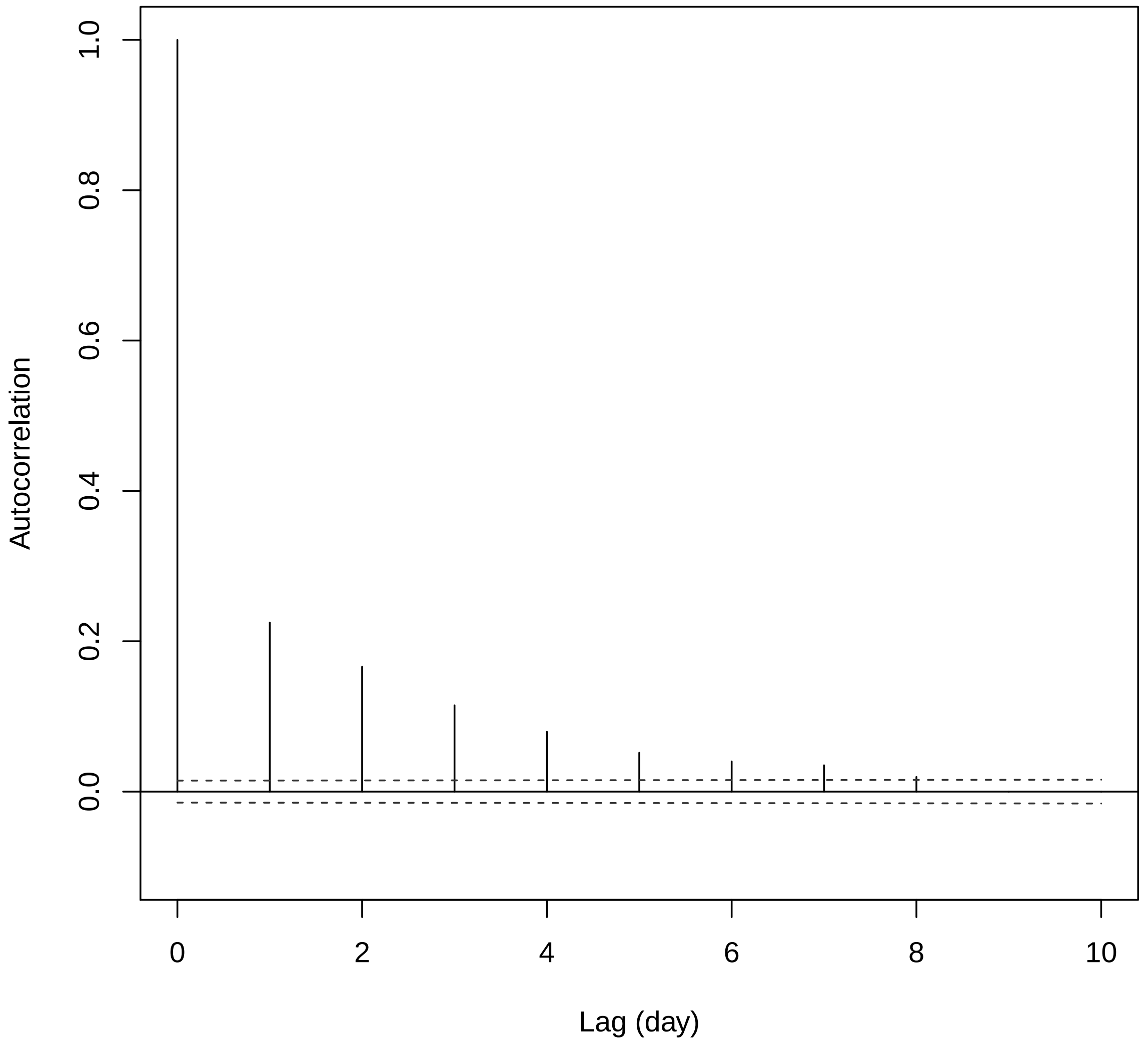

Figure 3.5: Autocorrelation function showing the correlation in the raw residuals (ϵ_{ij}) from Equation 3.2 as a function of number of days between successive daily LW measurements. The dashed grey lines represent approximate two sided critical bounds for the autocorrelation function at α = 0.01.

3.4 Discussion

Our estimates of average LW at calving and LW loss from calving to nadir were in agreement with those reported by Roche, Macdonald, Burke, Lee & Berry (2007) in a study of 2,600 lactations in 897 New Zealand dairy cows. Roche and co-workers reported a shorter number of days to nadir LW (30, 26, 29 days for parity 1, 2 and 2+ cows, respectively) than seen in this study (Table 3.1). Our results show that the magnitude of weight loss, and therefore degree of negative energy balance was less in 1^{st} and 2^{nd} parity cows compared with cows of parity 3 or greater, a conclusion cited by other authors (de Vries & Veerkamp 2000, van Straten et al. 2008).

Across parities, daily LW standard deviation represented 3.2% to 4.3% of mean daily LW measurement. This reported daily variation is greater than that previously reported in the literature. Maltz et al. (1997) used similar weighing technology to obtain daily LWs for 24 Holstein dairy cows in The Netherlands. These authors reported that within-cow daily LW variation (the ratio of the standard deviation to the mean) was 1% to 2.4%. Peiper et al. (1993), in an earlier study, reported a 1.5% within-cow daily variation in a 3-year study to determine the efficacy of recording LWs using a walkthrough weighing system in 85 Israeli Holsteins. The variability observed in our study can be explained by the difference in weighing frequency in these studies (24 animals weighed 20 times per day and 85 animals weighed 3 times daily, respectively). Furthermore, variability can also be explained by differences in management and feeding systems; a zero grazing and free stall system in the first and second study respectively, versus the free range, pasture based system in our study. In dairy systems where cows are permitted to freely graze at pasture the greater variability in daily LW measurements is likely to be a consequence of a range of factors including individual animal eating behavior, the quantity and quality of available forages, water availability and the distance to and from paddocks for grazing (Maltz et al. 1997, Maltz 1997).

We identified a near perfect agreement between LWs measured using the WoW system and those measured statically when cow flow over the platform was controlled (Figure 3.3; r^2 = 0.998). The 95% limits of agreement show that LWs measured using WoW may be 4.2 kg (60% of recorded WoWs) above or 8.8 kg (40% of recorded WoWs) below those recorded statically. Care is required when interpreting these results as although statically recorded LWs are thought to be the best weighing method it is neither an absolute or definitive measure of actual LW. Faecal and urinary losses which occurred between each weigh event may partly explain why the WoWs differed from those recorded statically (in all cases in this study WoWs were recorded first, then static LWs). Another explanation could be linked directly to the time and speed of a cow crossing over the scale platform (Cveticanin 2003, Cveticanin & Wendl 2004). WoW uses a continuous averaging technique to estimate LW, thus, if a cow crosses the scale platform at high speed (in less than 2 seconds) this will result in less data on which to base a LW estimate, with consequent effects on system accuracy.

The outlier detection method used in this study was a distance-based approach and relied on the absolute difference between an observed LW on DIM_i and the estimated LW based on the regression analyses described earlier. Once an outlier (i.e. biologically implausible or potentially erroneous) was identified the absolute difference between the outlier at DIM_i and the boundary of the 95% prediction interval at DIM_i (Figure 3.2) was calculated to provide insight into the likely reason for the outlier's presence. Twenty three *percent* (1,789 of 7,728) were classified as biologically implausible LW records. These observations were believed (based upon frequent observations of cow behaviour in the exit race) to be associated mainly with congestion in the exit race, typically caused by first parity heifers that had not fully adjusted to the routine of entering and exiting the milking platform. The majority of WoW outliers (77%, 5,939 of 7,728) were potentially erroneous and ranged between 0 and 148 kg above or below the prediction interval boundary. Those were thought to be (again, based upon frequent observations of cows behaviour at the exit race) related to rapid cow flow over the weigh platform or due to a successor cow placing her forefeet on the platform while a leading cow was crossing over the platform, resulting in overestimation of the LW for the leading cow. Direct comparison of the outlier (i.e. biologically implausible and potentially erroneous) results reported here with findings from other studies was not possible due to the lack of information about the magnitude and frequency of outliers in the cited literature. To facilitate such comparisons, documenting the effect of animal behavior and/or management on the frequency of outliers would be encouraged in future studies.

The ACF plot shown in Figure 3.5 is based on the residuals from the model presented in Equation 3.2 and thus represents the autocorrelation in daily LW measurements after controlling for the effect of size of the cow and long-term weight change that occurred after calving. The ACF plot (Figure 3.5) shows a progressive decay in the correlation between successive residual LW estimates over a period of 8 days. The irregularity particularly beyond the 3^{rd} lag reflects short term fluctuation in LW as a function of the number of days between LW measurements thought to be due to a combination of a gut fill effects, cow milking order, or changes in animal physiologic status such as changes in physical activity associated with oestrus or disease (Halachmi et al. 1997, Maltz et al. 1997, van Straten et al. 2009).

We propose that ACF plots have the potential to provide useful information for detecting abnormal weight change at the individual animal level. Based on these findings, we recommend that for identification of acutely ill cows, LWs should be recorded and analysed on a daily basis. For example, if an individual's residual LW at lag 1 or 2 differs excessively from that experienced by the remainder of the herd then that cow should be investigated immediately, as it could be indicative of a severe physiological disorder (e.g. systemic illness or acute lameness). On the other hand, when using WoWs to aid decision making (for example, when adjusting the herd feeding programme) our analyses show that (at least) a seven-day decision interval should be applied to monitor significant changes in cows recorded daily LW measurements.

It is important that these findings are interpreted with caution since they are only applicable for this herd. Similar to milk production, LW change is affected by management decisions that influence the animal and the environment. Replication of this study in a larger number of herds would be important to establish the external validity of the findings reported here. Of interest would be to establish if the observed residual autocorrelation estimates vary between and within-herds over time (in response to, for example, herd size, feed management and stocking rate). Also it is worth noting that the number of outlying LW records was sensitive only to the cut off point used for Equation 3.1. For example, a cut of point of 2 SD yielded approximately 27% of all LW measurements to be classified as outliers (results not shown) compared with the 10% reported here. The number of outliers decreased as the value of the cut off point increased (SD = 2.5, 3.0, 4.0). Our objective was to identify those LW records where there was less than a 1% chance that they were plausible values for that day in milk, therefore a 3 SD cut off value was used. If lower cut off values such as 2 SD were used, the method described in Equation 1 would be too sensitive and our ability to detect short-term changes in LW could be compromised.

3.5 Conclusions

This study addresses several issues that could potentially be an obstacle to more widespread uptake of WoW technology in commercial, pasture based dairy herds. Firstly, we have shown that with appropriate equipment and technology it is possible to record dairy cow LWs on a daily basis throughout the early lactation period. Our findings show that with controlled cow flow over the weighing platform there was a high level of agreement between LWs measured using walkover scales and those measured statically. Secondly, we have provided an algorithm to identify and eliminate outlier LW records, making it easier for herd managers to draw inferences from LW records gathered in real time. Finally, we quantified the residual temporal autocorrelation in daily LW measurements, providing a more objective basis for defining decision intervals when using daily LW measurements for diagnostic and managerial purposes.

CHAPTER 4

The effects of liveweight loss and milk production on the risk of lameness in a seasonally calving, pasture fed dairy herd

Abstract – The aims of this study were to: (1) determine if excessive liveweight (LW) loss and milk yield in the first 50 days postpartum was associated with the development of lameness after 50 days in milk, and (2) estimate the incidence risk of lameness in this herd attributable to excessive liveweight loss. The dataset comprised details from 564 mixed age cows from a seasonally calving, pasture fed dairy herd in New Zealand.

After adjusting for the confounding effects of parity, LW at calving, breed, the presence of specified disease events in the first 50 days of lactation and milk yield, LW loss in the first 50 days postpartum increased the risk of lameness after 50 days by a factor of 1.80 (95% CI 1.00 to 3.17). Based on data accumulated during the study period we estimate that for this herd, there would be a 4% (95% CI 2% to 10%) reduction in the risk of lameness if excessive LW loss was prevented. Thirty *percent* of the incidence of lameness in this herd was attributable to excessive LW loss.

We conclude that polices and interventions to reduce both the rate and the amount of LW loss in the immediate postpartum period will have a non-negligible impact on the incidence risk of lameness in this herd. An additional benefit of managing LW change in this period is the positive effects on reproductive and productive performance.

4.1 Introduction

As a general trend, dairy herd managers have attempted to increase and maintain profits by selectively breeding for high producing dairy cattle (Shook 2006). Selecting cows on milk yield alone has resulted in progeny that are prone to increased metabolic demands and prolonged periods of negative energy balance which are manifest as excess liveweight (LW) loss, mainly due to inadequate dry matter intake relative to milk yield (Veerkamp et al. 2000).

In the early postpartum period mobilisation of body reserves is required to meet a cow's physiological priorities and lactation demands. For example, across all cows, including those that are not nutritionally compromised, mobilisation of body reserves occurs in a cyclical fashion to ensure resumption of sexual activity (Friggens et al. 1993, Grummer et al. 1995, Ingvartsen et al. 2003). Although selection for milk production may have resulted in a greater tendency for LW loss postpartum (Ingvartsen & Andersen 2000, Veerkamp et al. 2000), the point at which selection for milk production and the associated increased tendency for LW loss act as stressors predisposing animals to disease is not clear (Ingvartsen et al. 2003). Consequently, the relationships between LW loss (a proxy indicator of body reserve mobilisation), selection for milk yield and disease risk has been difficult to clarify (Toshniwal et al. 2008, van Dorp et al. 1998). In addition, the situation is further complicated due to the confounding that occurs between milk production, metabolic stress and disease (Ingvartsen et al. 2003).

In New Zealand the most prevalent animal health problem in dairy cattle is mastitis (Harris 2005). New Zealand data (up to 2005) shows that mastitis accounted for more than 50% of recorded animal health problems in dairy herds that used herd testing facilities provided by Livestock Improvement Corporation (Harris 2005, Xu & Burton 2000). The same data showed that foot and leg problems followed mastitis and accounted for approximately 20% of all recorded health disorders (Harris 2005, Xu & Burton 2000).

The aims of this study were to: (1) determine if excessive liveweight (LW) loss and milk yield in the first 50 days postpartum was associated with the development of lameness after 50 days in milk, and (2) estimate the number of lameness cases in this herd attributable to excessive liveweight loss. This study provides useful information for dairy herd managers and their consultants concerning the potential role of managing LW change in the postpartum cow as an additional strategy to further optimise herd health and productivity.

4.2 Materials and methods

Study animals

This was a prospective cohort study of 828 lactations in 564 mixed aged and breed (Holstein-Friesian, Jersey, and Holstein-Friesian $\times$ Jersey) dairy cows that calved between 1 July and 24 October of 2008 and 1 July and 24 October 2009 in a university owned, seasonally calving, pasture fed dairy herd in Palmerston North in the lower North Island of New Zealand. Cows grazed as a single group at pasture and had free access to water. The herd was managed so that the pasture allowance (14 – 16 kg DM.cow^{-1}.day^{-1}) and access to supplementation after the morning milking (palm kernel meal to a maximum of 2 kg DM.cow^{-1}.day^{-1} and maize silage to a maximum of 2 kg DM.cow^{-1}.day^{-1}) was sufficient for maintenance and production requirements of a 400 kg cow producing 2.0 kg milksolids.day^{-1}. The pasture was dominated by ryegrass (*Lolium perene*) throughout the year. White clover (*Trifolium repens*) contributed up to 20% of pasture dry matter. Cows were milked twice daily, starting at 0530 and 1500 hrs through a 50 bale rotary-platform milking parlour (DeLaval^{TM} Parallel Rotary, DeLaval International, Sweden).

Walkover LWs were recorded for each cow from when it joined the milking herd after calving. LWs for each cow were measured using an automatic walkover weighing system comprised of: (1) an electronic identification system (Allflex^{TM} New Zealand Limited, Palmerston North, New Zealand) and (2) a calibrated electronic walkover scale system (WOW! XR-3000®, Tru-Test, Auckland, New Zealand). See Chapter 3 for further details.

The volume of milk produced by each cow throughout the lactation was estimated monthly (once within the first week of each calendar month) from the Planned Start of Calving date. A consistent fraction of milk was collected from a sequential evening and morning milking, the samples were weighed, and a subset of the combined evening and morning milking taken for infrared analysis of milk fat and protein concentration and somatic cell count.

Data were evaluated to determine the frequency of risk factors between lame (n = 105) and non-lame lactations (n = 723) using a logistic regression model. Risk factors for lameness included various measures of milk yield (volume, milksolids, milk protein and milk fat) per day as estimated from the herd test carried out immediately before 50 days in milk. If there was no herd test data available before 50 days in milk, the herd test that occurred immediately after 50 days was used. The choice of 50 days was a semi-arbitrary based on the assumption that by this time a cow would have reached the period of maximum nutrient demand coinciding with peak milk production.

Clinical lameness cases were identified and managed according to normal farm practice. At the start of the study the farm manager received detailed instructions from the herd veterinarian to clarify issues around detection of lameness and treatment of identified cases. The farm manager then trained all staff members to ensure consistent identification and management of lame cows. The following protocol was applied: any cow which was observed by the farm staff as having a persistent gait abnormality was drafted for further investigation. If the diagnosis was footrot cows were treated with a broad spectrum antibiotic by farm staff, otherwise they were held for veterinary examination. After treatment, which usually comprised combinations of corrective hoof trimming, antibiotics, and/or analgesics lame cows were placed on a once-daily milking regime and kept separate from the main herd in paddocks near to the milking parlour, until farm staff considered that they had recovered sufficient to be returned to the milking herd.

Data management

Throughout the study period LW data were downloaded from the scale indicator to a portable personal computer twice weekly. Downloaded data included each cow's electronic identifier, the date and time of each weigh event, and the LW record (kg) as estimated by the scales. Data were transferred to a dairy herd management software package (DairyWIN v99.91.148; Massey University, Palmerston North, New Zealand) allowing LW data to be matched with each cow's biographical and lactation event details (e.g. calving date, insemination date(s), herd test details and treatment dates and details).

Data cleaning procedures were carried out before analysis. A lameness event identified within 14 days of a prior lameness diagnosis was considered to be the same event unless it occurred in another foot. The two LW records for each cow for each day were averaged to provide a single daily measurement. If one LW record was missing the remaining record was used as the LW for that day (see Chapter 3 for further details). In the remainder of this paper we use the term 'daily LW measurement' to refer to the averaged daily LW records. LW at calving for each cow was defined as the average LW in the first seven days in milk (DIM_{1-7}). The main reason for this was freshly calved cows had never been exposed to the scale and as soon as they joined the milking herd they cautiously approached the scale platform. Irregular cow flow over the scale platform increased the number of potentially erroneous records during this period. Averaging all of the LW records captured during the first 7 days in milk was thought to provide a more stable estimate of cow LW change in the immediate postpartum period.

LW change (ΔLW) was calculated for each cow as the difference between LW recorded at DIM_{50} and that recorded at DIM_{1-7} divided by LW recorded at DIM_{1-7} and expressed as a percentage (negative values representing LW loss and positive values representing LW gains). ΔLW estimates were then allocated to quartiles and categorised as less than first quartile (cows that lost excessive LW in the DIM_{1-50} period) and greater than or equal to first quartile (moderate LW loss or LW gain in the DIM_{1-50} period). In the remainder of this paper these are termed LW loss and LW gain, respectively. Total milk yield, milk fat and protein and their percentages were allocated to quartiles and categorised as less than third quartile and greater than or equal to third quartile. Again, these are termed low and high yields for each production outcome. A disease variable was created for each cow and coded 1 if a cow was treated for a metabolic, mastitis, infectious, or reproductive disorder in the first 50 days in milk and 0 otherwise. Parity was categorised as less than or equal to second parity and greater than second parity.

Statistical analyses

A cow's lactation records were excluded from the analyses if DIM at observed lameness was less than 50. The incidence risk of lameness in the period after the first 50 days in milk was defined as the total number of cows experiencing at least one lameness event from 50 days in milk to the end of lactation divided by the number of cows present in the herd throughout the same period. Descriptive statistics (mean, median, first and third quartiles, minimum and maximum values, where applicable) were generated for each continuous variable.

The association between candidate explanatory variables and lameness was assessed using bivariate logistic regression models. The nature of the association between each candidate explanatory variable and the outcome was assessed graphically (Dohoo et al. 2009). Here the log odds of the outcome was plotted as a function of each of the levels of a categorical variable. Explanatory variables expressed on a continuous scale were categorised into quartiles and subject to the same procedure. A likelihood ratio test P value ≤ 0.25 was used as a criterion for entry of an explanatory variable into the multivariable logistic regression model. Model parameters were estimated by backward stepwise elimination. Variables were retained in the multivariable model if the likelihood ratio test P values were <0.05 when establishing the model involving main effects (Hosmer & Lemeshow

2000). Production season (a categorical variable with two levels, 2008 and 2009; termed season in the remainder of this paper) was included as a fixed effect in the final model to control for the possible confounding effect that farm management, weather, and other seasonal variations may have had on the outcome. To determine the effect of individual lactations within cows in the final model, the amount of over-dispersion in the data was assessed by calculating the variance inflation factor (the ratio of the Pearson chi-square goodness of fit statistic to its degrees of freedom). Over-dispersion was declared to be present if the chi-squared p-value was less than than or equal to 0.05. Crude and adjusted ORs were converted to crude or adjusted risk ratios (RR) using the technique of Beaudeau & Fourichon (1998). The logistic regression analyses were performed using the glmmML procedure implemented within the glmmML package (Broström 2009) in R (R Development Core Team 2010).

In the literature many terms are used to refer to interaction, for example joint or combined effects, heterogeneity of effects or effect modification. In principle they all mean the same thing. That is, the strength of the association between one explanatory variable and the outcome is modified by the presence of another explanatory variable. In the biomedical literature there are two concepts of interaction: (1) additive interaction, defined as a deviation from additivity of the absolute effects of two explanatory variables Rothman & Greenland (1998), and (2) multiplicative interaction, arising from the inclusion of a product term for two explanatory variables in a statistical model. Statistical interactions in the multivariate model were tested on the additive scale using the techniques of Rothman & Greenland (1998) and Hosmer & Lemeshow (1992). Use of the additive scale was preferred since most interactions in biological systems are additive (as opposed to multiplicative). Using this approach, the risk ratio for a given pair of explanatory variables, for example, was represented by RR_{ij}, with i indexing exposure to the first explanatory variable and j indexing exposure to the second. The subscripts i and j take values of 0 or 1 in the absence or presence of exposure respectively. Interaction on the additive scale was said to be present if the observed influence of explanatory variable i and explanatory variable j on lameness risk was not equal to the sum of their individual absolute effects.

To estimate the proportion of lameness risk in the total population associated with exposure to ΔLW, the population attributable fraction (PAF) was calculated as follows (Szklo & Nieto 2007):

$$\text{PAF} = \left(\frac{\text{P}_e[\text{RR}_e - 1]}{\text{P}_e[\text{RR}_e - 1] + 1} \right) \times 100 \tag{4.1}$$

In Equation 4.1 P_e equals the proportion of the population exposed to the explanatory variable of interest and RR_e equals the lameness risk in those exposed divided by the lameness risk in the unexposed. The population attributable fraction estimates the proportional reduction in average disease risk that would be achieved by eliminating the exposure of interest (Szklo & Nieto 2007). To estimate the incidence risk of lameness ($\geq$ 50 DIM) in this herd that was attributable to ΔLW $<$ 50 DIM, the population attributable risk (PAR) was calculated as the incidence risk of lameness in those exposed to the explanatory variable of interest minus the incidence risk in those unexposed. PAR, in this context, quantifies the expected decrease in lameness incidence if exposure to ΔLW was removed (Dohoo et al. 2009). Although interpretation of PAF and PAR requires an assumption of a causal relationship between exposure and the outcome variable, they also have application when causation is uncertain (Benichou et al. 1998, Morton 2004). For exposure variables where a causal link has not been established, PAFs and PARs can be used to speculate on the importance of a given set of exposure variables as a disease determinant until causality is established.

4.3 Results

Complete lactation records from 542 cows were used in these analyses. Twenty-two cows were excluded due to either incomplete production records (culled n = 8 or died n = 6 within the first 50 days postpartum) or they were observed lame in the first 50 days in milk (n = 8). There were 105 observed lameness events with 59 and 46 cases for the 2008 and 2009 seasons, respectively. Over the two seasons the incidence risk of lameness was 13 cases per 100 cows (95% CI 10% to 15%). Descriptive statistics of the herd and variables assessed in the bivariate analyses are presented in Tables 4.1 and 4.2, respectively.

In the bivariate analyses the risk of lameness in cows with LW loss was 2.37 times higher compared with cows with LW gain throughout the lactation (RR 2.37, 95% CI 1.47 to 3.50, P <0.01). High yielding cows had an increased risk of lameness compared with low yielding cows (RR 1.75, 95% CI 1.10 to 2.80, P = 0.01). Of the eight potential explanatory variables screened at the bivariate level, six were selected for inclusion in the final logistic regression model.

Estimated regression coefficients for the final logistic regression model are shown in Table 4.3. After adjusting for the effect of parity, LW at calving, breed, the presence of disease and season, the individual effect of LW loss in low yielding cows relative to LW gain in low yielding cows increased the risk of lameness (RR 1.80, 95% CI 1.00 to 3.17, P = 0.05). High yielding cows that lost LW were at greater risk of lameness compared with low yielding cows with no LW loss (RR 4.36, 95% CI 4.21 to 8.19, P $<$0.01). The sum of the individual effects attributable to LW loss and high milk yield was less than their observed joint effect providing evidence of strong positive interaction (Table 4.4). Figure 4.1 shows this graphically.

Estimated population attributable fractions (PAFs) and risks (PARs) for LW loss (in low and high yielding cows) are shown in Table 4.4. PAFs ranged from 13 (95% CI 0 to 29) cases per 100 cows at risk to 17 (95% CI 16 to 31) cases per 100 cows at risk for LW loss in low and high yielding cows, respectively. That is, assuming a causal relationship between LW loss and lameness, a reduction of between 13 and 17 new lameness cases per 100 cows at risk would be expected if exposure to LW loss was prevented in low and high yielding cows. PARs for LW loss were 2 (95% CI 0 to 4) and 2 (95% CI 2 to 4) cases of lameness per 100 cows at risk in low and high yielding cows, respectively.

Table 4.1: Descriptive statistics of parity, liveweight at calving, relative liveweight change in the first 50 days in milk, milk production, breed and disease records for the study herd for the 2008 and 2009 milking seasons.

Variable	Cows n	Mean (SD)	Median (Q1, Q3)	Min, max
Parity	542	4 (2)	4 (3,5)	1, 14
LW at calving (kg)	542	470 (65)	466 (415, 525)	304, 638
Relative LW change (%)	542	-4 (3)	-4 (-5, -3)	-23, 20
Milk yield (L.cow^{-1}.day^{-1})	542	21 (5)	21, (17, 25)	3, 44
Protein (%)	542	3.4 (0.3)	3.4,(3.2, 3.7)	2.0, 4.6
Fat (%)	542	5.3 (1.0)	5.2,(4.6, 6.3)	1.7, 11.0
Breed:				
Holstein-Friesian	333			
Crossbred	209			
Disease records [a]	179			

Key: n Number of cows; SD standard deviation; Q1 25th percentile; Q3 75th percentile; LW liveweight.
[a] Presence of a disease event in the first 50 days of lactation: metabolic disorders (n = 20), clinical mastitis (n = 153), infectious disease (n = 1), reproductive disorders (n = 5).

Table 4.2: Variables screened for inclusion in a multivariate logistic regression model of risk factors for lameness (after 50 days in milk) in dairy cattle.

Variable	Cases (n = 105)	Non-cases (n = 723)	Coefficient (SE)	P	RR	95% CI
Parity:						
≤ 2	25	247	-	-	1.00	Reference
>2	80	476	0.5096 (0.2784)	0.06	1.56	0.97 to 2.57
Liveweight at calving (kg):						
<525	44	422	-	-	1.00	Reference
$\geq$525	61	301	0.7812 (0.2732)	<0.01	1.97	1.23 to 3.16
ΔLW(%) :						
Gain	62	559	-	-	1.00	Reference
Loss	43	164	1.0200 (0.2919)	<0.01	2.37 [a]	1.47 to 3.50
Milk yield (L.cow^{-1}.day^{-1}):						
<Q3	67	552	-	-	1.00	Reference
$\geq$Q3	38	171	0.6459 (0.2720)	0.01	1.75	1.10 to 2.80
Protein (%):						
<Q3	77	518	-	-	1.00	Reference
$\geq$Q3	28	205	-0.1201 (0.3024)	0.69	0.92	0.54 to 1.48
Fat (%):						
<Q3	80	540	-	-	1.00	Reference
$\geq$Q3	25	183	-0.1365 (0.3015)	0.65	0.9	0.53 to 1.49
Breed:						
Holstein-Friesian	65	434	-	-	1.00	Reference
Crossbred	40	289	-0.1146 (0.2756)	0.61	0.91	0.56 to 1.45
Disease record: [b]						
Absent	76	581	-	-	1.00	Reference
Present	29	142	0.3952 (0.3103)	0.20	1.41	0.83 to 2.32
Production season:						
2009	46	344	-	-	1.00	Reference
2008	59	379	-0.7320 (0.3053)	0.01	0.69	0.50 to 0.93

Key: n Number of lactations; SE standard error; RR risk ratio; CI confidence interval; Q3 75th percentile; LW liveweight.

[a] Interpretation: The risk of lameness for cows classified as ΔLW negative was (as defined in the text) was 2.37 (95% CI 1.47 to 3.50) times that of cows classified as ΔLW positive.

[b] Presence of a disease event in the first 50 days of lactation: metabolic disorders (n = 20), clinical mastitis (n = 153), infectious disease (n = 1), reproductive disorders (n = 5).

Table 4.3: Estimated regression coefficients and their standard errors from a multivariate logistic regression model of risk factors for lameness (after 50 days in milk) in dairy cattle.

Variable	Cases (n = 105)	Non-cases (n = 723)	Coefficient (SE)	P	RR	95% CI
Intercept			-3.2270 (0.5614)	$<$0.01		
Parity:						
$\leq$2	25	247	-	-	1.00	Reference
$>$2	80	476	0.5819 (0.3675)	0.11	1.67	0.88 to 3.24
Liveweight at calving (kg):						
$<$525	44	422	-	-	1.00	Reference
$\geq$525	61	301	0.5827 (0.3480)	0.09	1.66 [a]	0.91 to 3.03
ΔLW$\times$ milk yield:						
Gain $\times$ $<$Q3	43	421	-	-	1.00	Reference
Loss $\times$ $<$Q3	24	131	0.6697 (0.3390)	0.05	1.80	1.00 to 3.17
Gain $\times$ $\geq$Q3	19	138	0.2065 (0.3674)	0.60	1.20	0.62 to 2.30
Loss $\times$ $\geq$Q3	19	33	1.8776 (0.5053)	$<$0.01	4.36	4.21 to 8.19
Breed:						
Holstein-Friesian	65	434	-	-	1.00	Reference
Crossbred	40	289	-0.5762 (0.3119)	0.06	0.6	0.35 to 1.03
Disease record: [b]						
Absent	76	581	-	-	1.00	Reference
Present	29	142	0.3952 (0.3103)	0.20	1.41	0.83 to 2.32
Production season:						
2009	46	344	-	-	1.00	Reference
2008	59	379	-0.7320 (0.3053)	0.01	0.69	0.50 to 0.93

Key: n Number of lactations; SE standard error, RR risk ratio; Q3 75th percentile; CI confidence interval.
[a] Interpretation: The risk of lameness for cows equal to or greater than 525 kg at calving was 1.66 (95% CI 0.91 to 3.03) times that of cows that were less than 525 kg at calving.
[b] Presence of a disease event in the first 50 days of lactation: metabolic disorders (n = 20), clinical mastitis (n = 153), infectious disease (n = 1), reproductive disorders (n = 5).

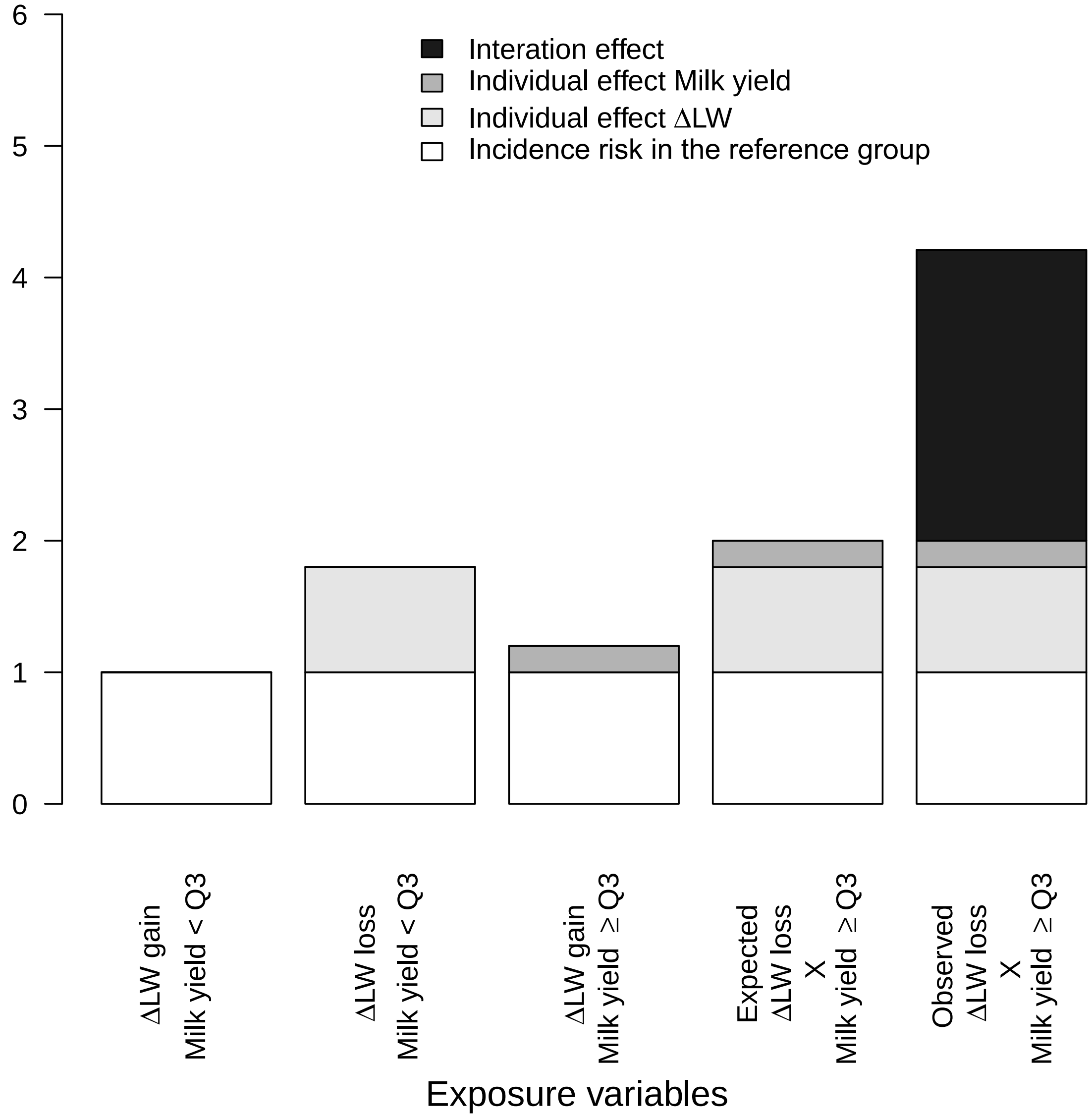

Figure 4.1: Risk ratios for lameness in the first 50 days of lactation for: (1) cows with ΔLW gain and milk yield <3Q (the reference category), (2) cows with ΔLW loss and milk yield <3Q, (3) cows with ΔLW gain and milk yield $\geq$ 3Q, (4) the expected risk ratio for cows with ΔLW loss and milk yield $\geq$ 3Q (assuming no interaction), and (5) the observed risk ratio for cows with ΔLW loss and milk yield $\geq$ 3Q.

Table 4.4: Incidence risk, population attributable fraction and population attributable risk of lameness (after 50 days in milk) for low and high yield cows gaining and losing liveweight in the first 50 days of lactation based on the estimated regression coefficients from the multivariable logistic regression model shown in Table 4.3.

ΔLW	Milk yield	Cases n	Exposed n	IR [a]	95% CI	PAF [b] (95% CI)	PAR [c] (95% CI)
Gain	<Q3	43	464	9	7 to 12	Reference	-
Loss	<Q3	24	155	15	11 to 22	13 (0 to 29)	2 (0 to 4)
Gain	≥Q3	19	157	12	8 to 18	4 (-7 to 20)	1 (-1 to 3)
Loss	≥Q3	19	52	37	25 to 50	17 (16 to 31)	2 (2 to 4)

Key: CI confidence interval.

[a] Incidence risk of lameness from 50 days in milk until the end of lactation, expressed as the number of cases per 100 cows at risk.

[b] Population attributable fraction (cases per 100 cows at risk) calculated using Equation 4.1.

[c] Population attributable risk (cases per 100 cows at risk) calculated as PAF $\times$ LIR (as estimated in this study, 13%).

See Rothman 2002, pp. 130 – 143 for details on calculation of 95% CIs.

4.4 Discussion

It has been proposed that cows with a higher genetic merit for milk production experience an excessive amount of LW loss during the early lactation and this increases their risk of diseases such as mastitis (Gröhn et al. 1995), reproductive disorders (Heuer et al. 1999) and lameness (Archer et al. 2010, Pryce et al. 1998). These observations provided the hypothesis for this study, that LW loss and higher milk yields were positively associated with lameness risk after 50 days in milk.

Liveweight loss, as defined in this study, significantly increased the risk of lameness, irrespective of milk yield. For high yielding cows with LW loss the risk of lameness was 4.4 (95% CI 4.2 to 8.2) times greater than low yielding cows that gained weight (Table 4.3). Table 4.4 shows that the incidence risk of lameness for the reference group (low yielding cows that gained weight) was 9 (95% CI 7 to 12) cases per 100 cows at risk. This increased to 15 (95% CI 11 to 22) cases per 100 cows at risk in low yielding cows with LW loss. This equates to a risk difference of 6 cases of lameness per 100 cows that may be attributed to exposure to LW loss. Similarly, the risk difference for high yielding cows with LW gain was 3 cases per 100 cows at risk (i.e. 12 - 9 cases per 100 cows, Table 4.4). If no interaction between LW change and milk yield was present, the expected incidence risk would equal the risk of lameness in the reference group plus the risk attributed to exposure to LW loss and high milk yield, that is (9 + 6 + 3) = 18 (95% CI 11 to 27) cases per 100 cows. The observed joint effect was (37 - 9) = 28 (95% CI 20 to 39) cases of lameness per 100 cows. Thus, due to the interaction between LW loss and milk yield 10 (95% CI 5 to 18) additional cases of lameness per 100 cows were observed, indicating that the interaction of liveweight change and milk yield was beyond additive. The risk difference remained the highest for LW loss across low and high yielding cows. This highlights the role that controlling LW loss might have on lameness prevention. In this study herd, we estimate a reduction in lameness incidence risk by around 4 (95% CI 2% to 10%) cases per 100 cows at risk (Table 4.4) if LW loss was prevented. This represents 30% of the lameness incidence attributable to exposure to LW loss.

Factors associated with LW loss may have directly influenced the pathways through which the risk of lameness was increased, for example due to increased level of haemorrhages in the sole and a decline in horn quality, as a result of laminitis (Westwood & Lean 2001, Vermunt & Parkinson 2002), or increased levels of fatty acids circulating in the body postpartum (Allen et al. 2009). Although possible, it is unlikely that such haemorrhages in high producing cows (as defined in this study) were associated with subclinical laminitis because concentrate feeds were not used in this herd. However, the continuous flux of circulating fatty acids stresses an animal physiologically, potentially compromising the immune system (Sinclair et al. 1999). This increases the risk of clinical and subclinical metabolic disorders leading to reduced hoof horn quality. It is plausible that changes in hoof horn quality could have increased the risk of lameness in this herd (Mulling et al. 1999, Westwood et al. 2003).

In addition to the physiological mechanisms outlined above, genetic selection of cows for high milk yield may impair the ability to utilise dietary nutrients efficiently (Bauman et al. 1985, Ingvartsen et al. 2003, Veerkamp & Brotherstone 1997), which potentially increases the risk of diseases such as lameness. Green et al. (2002) analysed 8,000 test-day milk yields of 900 cows over an 18 month period from 1997 to 1999 and showed that higher yielding cows had, on average, a greater risk of becoming lame. Similar findings were reported in a study of 1,335 lactations in 16 commercial dairy herds in The Netherlands (Heuer et al. 1999). In that study, Heuer et al. (1999) reported a 50% increase in the risk of lameness (OR 1.5, $P < 0.05$) in cows that lost excessive body condition compared with herdmates that lost moderate amounts of body condition during the early postpartum period. The association between high milk yield and undesirable claw conformation indicates that breeding solely for production carries with it an increased risk of lameness (Archer et al. 2010, Ingvartsen et al. 2003, Pryce et al. 1998, van Dorp et al. 1998).

Further possible explanations for the association between LW loss and lameness could be related to dominance hierarchies within the herd. Cows losing LW at a higher rate compared with those losing moderate amounts or gaining LW could simply be more socially active, spend more time interacting with other cows than feeding and resting. Barker et al. (2009) studied data from 3,074 dairy cows in 27 dairy farms in England and Wales. These authors reported that cows kept on pasture were at least 1.48 times more likely to be observed lame than cows kept in tie stalls (the odds ratios reported ranged from 1.48 to 2.08; 95% CI 0.73 to 2.99, 0.65 to 6.67; for white line disease and solar bruising, respectively). The findings reported by Barker et al. (2009) indirectly agree with earlier New Zealand studies that pointed to dominance hierarchies as a factor partly responsible for lameness in pasture fed herds, either by increasing movement or evasive movements on hard surfaces (Chesterton 2004, Chesterton et al. 1989).

One of the strengths of this study is the analysis of the association between lameness, LW loss and milk yield under the same farm and management conditions. The use of a single herd, on the other hand, means that these results are valid only for this particular farm. Selection bias may have been introduced when cows were omitted from the analyses due to incomplete records (culled n = 8 or died n = 6). Although this bias is differential with the outcome as none of the cows omitted were observed lame and non-differential with the exposure (three cows lost LW excessively, one died and two culled) during the observation period, its overall effect on our results is believed to be small. The magnitude of the risk ratios and the population attributable fraction were sensitive to the choice of cutpoint used to classify cows according to milk yield and our results should be interpreted bearing this in mind. Although it could be argued that the selection of $\geq$ 3 quartile as cutpoints for milk yield may have introduced analytical bias, it is not believed that this affects the internal validity of this study. Similar results would still be reproduced if the same cutpoints were used in similarly managed herds. Furthermore, as mentioned earlier, the point at which selection for higher milk production acts as a stressor predisposing for disease is not clear and the international literature definition of a high yielding cow does not apply under New Zealand management conditions. Nevertheless, if the cutpoint used to classify cows based on their milk yield was too high, then the direction of this bias is likely to be away from the null, overestimating the strength of association between milk yield and lameness. On the other hand, if the cutpoint used too conservative, the direction of bias is likely to be towards the null therefore underestimating the strength of association reported in this study.

Information bias in this study was unlikely, as farm managers and workers received on-going veterinary training to identify and manage lameness in the herd. Furthermore, data collection and verification was carried out regularly by the first author throughout the two milking seasons. If information bias existed, it would have been associated with the identification and assignment of lame and non-lame cows by farm staff. It is likely, given previous research that indicates that herd managers are not able to detect all cases of lameness (Whay 2002), that some cows were not treated. The direction of this bias is therefore likely to be towards the null meaning that the results presented here are likely to be an underestimate of the true strength of association between LW loss, milk production and lameness.

Lack of regular screening of the herd using a validated lameness scoring system may have introduced information bias in this study. If such a method was used it would have provided lameness frequency estimates incomparable with other observational studies which comprise the bulk of published literature on lameness incidence. This being the case, the estimated measures of association would be of little use to commercial farmers since only statements about the effect of weight change and production on lameness risk in those herds where trained investigators were able assess lameness on a regular basis would be possible. Although farmer detection of disease events was likely to be less than perfect it was uniform in terms of the intensity of detection throughout the entire season and the frequency of lameness identified in this study was consistent with that observed on commercial dairy herds in this area of New Zealand (Tranter & Morris 1991, Chesterton et al. 2008). Given confidence in the validity of the outcome measure, we have confidence in the direction of the associations identified in this study. It is now important to replicate this study design on a larger number of herds to provide further confidence of the external validity of the findings reported here.

4.5 Conclusions

After adjusting for the confounding effect of parity, LW at calving, breed, the presence of specified disease events in the first 50 days of lactation and milk yield, LW loss in the first 50 days postpartum increased the risk of lameness after 50 days by a factor of 1.80 (95% CI 1.00 to 3.17). Based on data accumulated during the study period we estimate that for this herd, there would be a 4% (95% CI 2% to 10%) reduction in the risk of lameness if excessive LW loss was prevented. We conclude that polices and interventions to reduce both the rate and the amount of LW loss in the immediate postpartum period will have a non-negligible impact on the incidence risk of lameness in this herd. An additional benefit of managing LW change in this period is the positive effects on reproductive and productive performance.

CHAPTER 5

The use of liveweight change as an indicator of oestrus in a seasonally calving, pasture fed dairy herd

Abstract – This was an observational study of 828 lactations in 542 mixed aged dairy cows that calved in 2008 and 2009 in a seasonally calving, pasture fed herd in New Zealand. Our objectives were to: (1) document daily liveweight change (ΔLW) before and after observed oestrus for cows subsequently diagnosed pregnant and non-pregnant, and (2) quantify the sensitivity and specificity of ΔLW as a test for oestrus. The sensitivity and specificity of ΔLW combined with other commonly used oestrus detection methods was also evaluated.

In cows that conceived as a result of service events applied in response to a detected oestrus event, liveweight loss began one day before the day of detection and was lowest on the day of detection (-9.6 kg, 95% CI -11.3 kg to -7.8 kg; $P < 0.01$) compared with LW recorded at two days before the day of detection. In non-pregnant cows the lowest liveweights were recorded one day before the day oestrus was detected (-4.3 kg, 95% CI -7.7 to -0.8 kg; $P = 0.02$) compared with LW recorded at four days before the day of detection. The sensitivity and specificity of ΔLW as a means of oestrus detection was 0.42 (95% CI 0.40 to 0.45) and 0.96 (95% CI 0.95 to 0.97), respectively. When ΔLW was combined with tail paint and visual observation (TPVO), oestrus detection sensitivity and specificity were 0.86 and 0.94, respectively. In herds where TPVO performance lower than ΔLW and TPVO are combined, LW measured on daily basis has the potential to increase both the sensitivity and specificity of oestrus detection.

5.1 Introduction

In seasonally calving dairy herds, where animals graze pasture year round, a high pregnancy rate over a restricted period is necessary to ensure compact calving in the following season. A compact calving pattern facilitates maximum utilisation of pasture (Macmillan & Asher 1990, Holmes et al. 2002). In New Zealand, cows are managed to calve in early spring so that their highest feed demand matches the period of greatest pasture growth. Pasture is minimally supplemented with conserved feed, with the amount fed being influenced by seasonal pasture growth, herd composition and stocking rate. Effective management is required to ensure that cows resume cyclicity post calving, cows are detected in oestrus and receive service events at an appropriate time post detection, and artificial or natural service events are managed to optimise conception rates (Cutullic et al. 2009). In seasonally calving herds oestrus detection and the time of calving relative to the Planned Start of Mating (PSM) have a major influence on reproductive success. The shorter the interval from calving to PSM, the less chance there is for a cow to resume cyclicity and to conceive, when she is served. Independent of conception rate, errors in oestrus detection negatively impacts on herd in-calf rate. Oestrus and its detection are critical components of reproductive management in seasonally calving dairy herds.

Correct identification of oestrus requires that cows express characteristic signs and that a herdsman observes and interprets the signs of oestrus activity appropriately. Hormonal actions lead to physiological changes that result in the expression of oestrus (i.e. behavioural changes such as mounting and increased activity). Monitoring progesterone profiles (Bulman et al. 1978) has been proposed as one approach to enhance oestrus detection (Friggens et al. 2008). Progesterone profiling is accurate but its cost and restricted availability on farm limit widespread application. Tools such as heat mount detectors (At-Taras & Spahr 2001) and tail paint (Williamson 1980) have been devised to detect behaviour that accompanies oestrus. Other tools detect increased walking activity (Liu & Spahr 1993, Lovendahl & Chagunda 2010) or physiological events such as changes in vaginal mucous conductivity (Carter & Dufty 1980, Wehner et al. 1997). These tools have been used individually or jointly to significantly improve oestrus detection sensitivity and submission rates for artificial inseminationed diry herds (Palmera et al. 2010).

The growing use of automation and computerised dairy management systems provides an opportunity to develop new and novel ways to monitor dairy cow behaviour. Recently published studies have emphasised the potential of monitoring changes in liveweight (van Straten et al. 2008), dry matter (DM) and water intake to detect changes in reproductive status (Meyer et al. 2004, Lukas et al. 2008). Few studies have investigated the relationship between daily changes in liveweight (ΔLW) and oestrus in pasture fed dairy herds. The aim of this study was to document ΔLW around the time of oestrus in two groups of cows: those that conceived as a result of a service event applied in response to a detected oestrus event (termed pregnant cows), and those that did not conceive (termed non-pregnant cows). A secondary aim was to quantify the sensitivity and specificity of ΔLW as a test for oestrus.

5.2 Materials and methods

Study animals

This was an observational study of 828 lactations in 542 mixed aged and breed (Holstein-Friesian, Jersey, and Holstein-Friesian $\times$ Jersey) cows that calved during the 2008 and 2009 seasons and were present at PSM in a university owned, seasonally calving, pasture fed dairy herd. The herd was located in Palmerston North in the lower North Island of New Zealand. Cows grazed as a single group at pasture and had free access to water. The herd was managed so that the pasture allowance (14 – 16 kg DM.cow^{-1}.day^{-1}) and access to supplementation after the morning milking (palm kernel meal to a maximum of 2 kg DM.cow^{-1}.day^{-1} and maize silage to a maximum of 2 kg DM.cow^{-1}.day^{-1}) was sufficient for maintenance and production requirements of a 400 kg cow producing 2.0 kg milksolids.day^{-1}. The pasture was dominated by ryegrass (*Lolium perene*) throughout the year. White clover (*Trifolium repens*) contributed up to 20% of pasture dry matter. Cows were milked twice daily, starting at 0530 and 1500 hrs through a 50 bale rotary-platform milking parlour (DeLaval^{TM} Parallel Rotary, DeLaval International, Sweden).

Liveweights were measured for each cow from the time it joined the milking herd after calving using an automatic walkover weighing system comprised of an electronic identification system (Allflex^{TM} New Zealand Limited, Palmerston North, New Zealand) and a calibrated electronic walkover scale system (WoW! XR-3000®, Tru-Test, Auckland, New Zealand). See Chapter 3 for further details.

Premating oestrus events were recorded by farm staff one month before PSM for the herd which was 24 October for both the 2008 and 2009 milking seasons. Cows that were detected in oestrus (pm previous day and am same day) from PSM to 6 December (2008 and 2009) were artificially inseminated by a contract inseminator that visited the farm once daily after the morning milking. For the seven-week period from 7 December 2008 and 2009 to 25 January 2009 and 2010, 8 bulls were run with the milking herd at any one time (three groups of four bulls were rotated with one group resting weekly).

Oestrus detection was carried out by farm staff using direct observation and tail paint (FIL oil based tail paints, fluorescent oestrus detection tail paint, Tell Tail). Cows were observed by staff in the paddock for 30 to 45 minutes before milking, while they traveled from the paddocks to the milking parlour and throughout each milking (3 hours each milking). A cow was considered to be in oestrus if more than 50% of her tail paint was removed or it showed typical oestrus behaviour (standing to be mounted, mounting other cows and head mounting). True oestrus was confirmed (for pregnant cows) using the calculation calving dates minus gestation length (282 days) or the date of last service (for non-pregnant cows) as described under data management, below.

Cows not observed to be in oestrus by one week before PSM (17 October) were treated with an intravaginal progesterone releasing device (eight day CIDR Programme; Pfizer Animal Health, Auckland, New Zealand) without veterinary examination on 17 October (100 and 73 cows in 2008 and 2009, respectively). A further 58 cows (30 cows in 2008 and 28 cows in 2009) that had been detected in oestrus before PSM and were not re-observed in oestrus by 21 days after PSM were treated with prostaglandin F2α (2 mL; Estroplan, Parnell, Auckland, New Zealand) on 14 November.

Data management

Throughout the 2008 and 2009 milking seasons LW data were downloaded from the scale indicator to a portable personal computer twice weekly. Downloaded data included each cow's electronic identifier, the time and date of each weigh event, and the LW record (kg) as estimated by the scales. Data were transferred to a dairy herd management software package (DairyWIN v99.91.148; Massey University, Palmerston North, New Zealand) allowing LW data to be matched with each cow's biographical and lactation event details (e.g. calving date, insemination date(s), natural mating date(s), herd test details and treatment dates and details).

A series of data cleaning procedures were carried out before analysis. The two LW records for each cow for each day were averaged to provide a single daily measurement. If one record was missing the remaining record was used as the LW measurement for that day (see Chapter 3 for further details). In the remainder of this paper we use the term 'daily

LW measurement' to refer to the averaged daily LW records. Pregnancy was diagnosed by rectal examination by an experienced veterinarian and ultrasound examination 5 and 13 weeks after the end of the 12-week mating period. Calving records and the date of last service were used to determine the accuracy of oestrus detection by farm staff for pregnant and non-pregnant cows, respectively. For pregnant cows that were present in the herd at the 2008 and 2009 PSM dates, calving events that occurred in the subsequent milking season (i.e. the milking seasons starting in the spring of 2009 and 2010) were listed for each cow and 282 days (± 3 days) counted back from the date of calving to identify the ovulatory days and the service that resulted in conception, termed the confirmed conception date. From the confirmed conception date reverse counts (to PSM date) of 21 days (± 3 days) and 42 (± 3 days) were made to generate a series of ovulatory dates on which the animal was expected to have been in oestrus, termed oestrus in the rest of this chapter. If no oestrus event was recorded at calving minus 282 days (± 3) the date of conception was assumed to have occurred at the date coincided with calving date minus 282 days (± 3 days). In non-pregnant cows, only the date of last service was used and reverse counts of 21 days (± 3 days) and 42 (± 3 days) were made to generate a series of dates on which the animal was expected to have been in oestrus. A detailed description of this methodology is provided by Alawneh et al. (2006).

To account for the repeated measurement within cow in a given production year a unique identity was created for each cow before data analysis was conducted. This identity comprised a combination of a cow's unique lifetime identification number and production year. This allowed each cow in the data set to be unique and therefore captured repeated estrus events within cow in a given production year.

Statistical analyses

A total of 22,407 LW measurements and 1,611 services were recorded during the mating periods of the 2008 and 2009 seasons (Table 5.1). The data were arranged so that each DIM relative to the day of each oestrus event was regarded as a single observation. Each observation comprised details of the cow's identity as well as parity, breed, LW, the presence or absence of a detected oestrus event, the presence or absence of fertility treatment on that day and production year (as a categorical variable with two levels, 2008 and 2009).

Two sets of analyses were conducted using these data. The first quantified ΔLW that occurred around confirmed service events for pregnant and non-pregnant cows (pregnant and non-pregnant cows used for the analysis). The second evaluated the diagnostic test performance of ΔLW as a tool for oestrus detection (using only the pregnant cow data set) .

Liveweight change around service events

For the first set of analyses, LW records for pregnant and non-pregnant cows were analysed separately within a mixed linear model that included a random intercept and slope term for each cow. The mixed linear model was used to estimate LW on any given day relative to oestrus taking into account the confounding effect of parity, breed, presence of a fertility treatment and production year and also to account for the repeated LW measurements within cow.

A key assumption here was that services were administered in response to detected oestrus events. Our interest was to assess ΔLW for each of the eight days before and after a service events. In the data set for pregnant cows, this provided an estimate of LW change before and after the fertile oestrus that resulted in pregnancy (we knew this was a fertile oestrus because the service applied in response to that oestrus resulted in delivery of a calf 282 days later). ΔLW for the eight days before and after service events that occurred 21 days ($\pm$3 days) and 42 ($\pm$3 days) before the date of fertile oestrus (if present) were also included in this data set. For non-pregnant cows, the data set comprised the ΔLW for the eight days before and after service events that occurred 21 days ($\pm$3 days) and 42 ($\pm$3 days) before the date of the last recorded service event (if present) were included.

A derived variable of 17 levels termed OESTIDX: 8 levels for the 8 days prior to service (-8 to -1), 1 level for the day of service (0) and 8 levels for the 8 days after service (1 to 8) was developed. This allowed us to estimate the difference in LW at a given OESTIDX level compared with a specified reference OESTIDX level after adjusting for breed, parity, season and individual cow-level effects.

Breed, parity, and season were entered into the model *a priori* as fixed effects. OESTIDX was then entered and a Wald test performed to determine the significance of the regression coefficients for each level of OESTIDX. The levels of OESTIDX were then revised to include only those levels that were significant at the alpha level of 0.05. The structure of the model was as follows:

$$
\begin{aligned}
Y_{ijklnt} = \beta_0 \quad &+ \quad \text{parity}_i + \text{breed}_j + \text{season}_k + \text{OESTIDX}_l + \text{breed} \times \text{OESTIDX}_{jl} \\
&+ \quad \alpha_{0n} + \alpha_{1n}\text{OESTIDX}_{ln} + \epsilon_{ijklnt}
\end{aligned} \tag{5.1}
$$

In Equation 5.1 Y_{ijklnt} is the i^{th} LW measured at time t for cow n and β_0 is the intercept representing the average LW across all cows in the herd. The terms parity$_i$, breed$_j$, season$_k$ and OESTIDX$_l$ represent the effects of parity, breed, season, breed and OESTIDX on Y_{ijklnt}, respectively. The term breed $\times$ OESTIDX$_{jl}$ represents the interacting effect of breed on OESTIDX. The terms α_{0n} and α_{1n} are random intercept and slope terms (respectively) describing the deviation of cow n's LW from that of the rest of the herd. ϵ_{ijklnt} represents the random residual error.

Unstructured, compound symmetry and first-order autoregressive correlation patterns were investigated to adjust for the correlation in repeated LW measurements within cows (Diggle 2002). Raw and normalised residuals were evaluated graphically against predicted values to test the assumption of homogeneity of variance of the error terms. The effect of the different correlation structures on model fit was assessed using Akaike's Information Criterion (AIC) with a first-order autoregressive correlation pattern yielding the lowest AIC. The mixed model was fitted using the restricted maximum likelihood (REML) procedure within the nlme package (Pinheiro et al. 2011) in R (R Development Core Team 2010).

Liveweight change as a diagnostic test for oestrus

A 2 $\times$ 2 contingency table was constructed from the pregnant cow data set to evaluate ΔLW as a tool for oestrus detection (the non-pregnant cow data set was not used for these analyses). ΔLW as a diagnostic test for oestrus detection was evaluated by calculating sensitivity and specificity as follows. For each cow, ΔLW from PSM to the service resulting in conception was calculated and compared with predictions from the mixed model shown in Equation 5.1. ΔLW at a day$_i$ during the mating period was calculated as LW at day$_i$ minus LW at day$_{i-2}$. If LW at day$_{i-2}$ was not available (28 records) then LWs at day$_{i-3}$ or day$_{i-4}$ were used. ΔLW at PSM was compared with day$_{i-2}$ before PSM. A positive oestrus detection was credited for ΔLW when, for a given day in the mating period, the observed ΔLW was less than or equal to the lower 95% confidence limit of ΔLW estimated from the model on the day of oestrus (i.e. insemination day). Lower 95% confidence limit of ΔLW was used to minimise any potential effect of normal fluctuation in a cow's LW. ΔLW detected oestrus events were compared with the series of dates on which the animal was expected to have been in oestrus as confirmed by calving dates. The sensitivity of ΔLW for oestrus detection was then calculated as the proportion of true positive detections that were credited positive. Specificity was calculated as the proportion of true negative detections that were not credited positive by ΔLW.

Kappa (κ) and McNemar's χ^2 test statistic were used to assess the concordance and disagreement; respectively, of results (each method's proportion of positive detections) by ΔLW with the gold standard, as defined in this study. A κ value of 0 indicates no concordance and a value of 1 indicates a perfect concordance. For this study, a κ value between 0 and 0.4 was considered to indicate a fair level of concordance, a κ value between 0.4 and 0.6 a moderate level and a value greater than 0.6 a high level of concordance (Dohoo et al. 2009).

Parallel test combinations adjusting for two arbitrarily selected conditional dependence levels (Dohoo et al. 2009) of ΔLW with other oestrus detection methods were evaluated to identify those combinations with satisfactory sensitivity and specificity. Statistical analyses were performed using the nlme (Pinheiro et al. 2011) and epiR (Stevenson et al. 2011) packages within R (R Development Core Team 2010).

5.3 Results

Records from 49 cows (15 cows in 2008 and 34 cows in 2009 that either calved late in the season or were voluntarily culled) were excluded from these analyses due to incomplete breeding records. A similar profile was observed for ΔLW for pregnant and non-pregnant cows (Table 5.2, Figure 5.1). Liveweight loss for pregnant cows began at OESTIDX -1 (with LW at OESTIDX -2 used as the reference category), reaching the lowest level on OESTIDX 0 (-9.6 kg, 95% CI -11.3 to -7.8 kg; P <0.01). For non-pregnant cows (with LW at OESTIDX -4 used as the reference category) the lowest LW was recorded on OESTIDX -1 (-4.3 kg, 95% CI -7.7 to -0.8 kg; P = 0.02). From then ΔLW was negative until OESTIDX +6 in pregnant cows (0.1 kg, 95% CI -1.8 to 2.0 kg; P = 0.91) and OESTIDX +4 in non-pregnant cows (0.3, 95% CI -3.6 to 4.1; P = 0.89).

Holstein-Friesian cows had an OESTIDX profile that differed from crossbreds ($P < 0.05$). ΔLW for pregnant Holstein-Friesians was approximately 5 kg (95% CI 2.0 to 7.4 kg; $P < 0.01$) less than that of pregnant crossbred cows (Figure 5.2). The intraclass correlation coefficients for pregnant and non-pregnant cows were 79% and 64%, respectively. This indicates a relatively high correlation of LW measurements within individual cows.

The number of true oestrus events and the number of true and falsely predicted oestrus events on the basis of ΔLW are shown in Table 5.3. For pregnant cows there were 1,314 oestrus events signalled. Of these, 583 were true positives and 731 were true negatives. For pregnant cows there were 19,031 non-oestrus events signalled. Of these, 18,229 were true negatives and 802 were true positives. The sensitivity and specificity of ΔLW as a test for oestrus was 0.42 (95% CI 0.40 to 0.45) and 0.96 (95% CI 0.95 to 0.97), respectively.[1] There was little evidence of disagreement between positive detections by ΔLW with the gold standard (McNemar's χ^2 test = 3.28; P = 0.07), with a fair to moderate concordance between them (κ = 0.39, 95% CI 0.36 to 0.42).

Sensitivities and specificities from using ΔLW in combination with additional oestrus detection techniques, adjusted for conditional dependence, are shown in Table 5.4. A conditional dependence of 0.01 improved oestrus detection sensitivities for all techniques and on average, decreased oestrus detection specificities by 0.04. The highest positive difference in oestrus detection sensitivity was expected for those techniques with relatively low sensitivities such as visual observation (Se 0.61 *versus* Se 0.76) and tail paint (Se 0.69 *versus* Se 0.81, Table 5.4).

[1] See Rothman 2002, pp. 130 – 143 for details on calculation of 95% CIs.

Table 5.1: Numbers of cows, services, and liveweight records stratified by production season.

Season	Pregnant cows			Non-pregnant cows		
	Cows	Services	LW records	Cows	Services	LW records
	(n)	(n) [a]	(n)	(n)	(n) [a]	(n)
2008	331	647	8,342	119	120	1,095
2009	289	638	12,003	99	106	967
Total	620	1,385	20,345	218	226	2,062

Key: LW liveweight.

[a] Number of services based on calving records for pregnant cows and date of last service for non-pregnant cows.

Table 5.2: Estimated regression coefficients and their standard errors from a mixed-effects linear regression model of factors influencing liveweight in pregnant and non-pregnant dairy cattle.

Variable	Pregnant cows			Non-pregnant cows		
	Coefficient (SE)	95% CI	P	Coefficient (SE)	95% CI	P
Intercept	390.93 (3.51)	384.05 to 397.80	<0.01	381.19 (8.57)	364.37 to 398.02	<0.01
Parity:						
1	Reference	-	-	Reference	-	-
3 – 4	28.91 (1.80)	25.38 to 32.45	<0.01	50.05 (8.89)	31.39 to 68.71	<0.01
>4	53.05 (2.02)	49.08 to 57.03	<0.01	116.44 (8.06)	100.45 to 132.38	<0.01
Production season:						
2008	Reference	-	-	Reference	-	-
2009	-4.59 (0.82)	-6.18 to -2.95	<0.01	-7.19 (6.98)	-21.00 to 6.16	0.30
Breed:						
Holstein-Friesian	47.23 (4.97)	37.45 to 57.01	<0.01	32.34 (6.74)	18.87 to 45.13	<0.01
Crossbred	Reference	-	-	Reference	-	-
OESTIDX: [a]						
-4 days	-	-	-	Reference	-	-
-3 days	-	-	-	4.58 (1.59)	1.45 to 7.71	<0.01
-2 days	Reference	-	-	2.27 (1.71)	-1.10 to 5.64	0.20
-1 days	-6.72 (0.77)	-8.23 to -5.22	<0.01	-4.27 (1.74)	-7.70 to -0.85	0.02
0 days	-9.59 (0.88)	-11.30 to-7.83	<0.01	-3.17 (1.79)	-6.68 to 0.34	0.08
+1 days	-4.15 (0.94)	-5.95 to -2.10	<0.01	-0.95 (1.83)	-4.55 to 2.64	0.60
+2 days	-3.93 (0.95)	-5.82 to -2.10	<0.01	-1.02 (1.87)	-4.70 to 2.65	0.60
+3 days	-2.11 (0.97)	-4.00 to -0.22	0.02	-0.06 (1.94)	-3.87 to 3.74	0.97
+4 days	-2.74 (0.97)	-4.62 to -0.78	<0.01	0.27 (1.97)	-3.59 to 4.13	0.89
+5 days	-1.03 (0.97)	-2.89 to 0.92	0.31	1.91 (2.03)	-2.10 to 5.90	0.34
+6 days	0.10 (0.98)	-1.81 to 2.04	0.91	2.22 (2.09)	-1.87 to 6.32	0.28
+7 days	1.52 (0.96)	-0.36 to 3.41	0.11	2.77 (2.14)	-1.42 to 6.97	0.19
+8 days	0.53 (0.92)	-1.27 to 2.33	0.56	4.11 (2.20)	-0.21 to 8.43	0.06
OESTIDX × breed: [b]						
-4 days	-	-	-	Reference	-	-
-3 days	-	-	-	0.01 (3.23)	-6.35 to 6.35	0.99
-2 days	Reference	-	-	-0.36 (3.48)	-7.20 to 6.47	0.92
-1 days	3.10 (1.23)	0.68 to 5.53	0.01	0.99 (3.53)	-5.95 to 7.92	0.78
0 days	4.67 (1.39)	1.95 to 7.40	<0.01	2.91 (3.63)	-4.21 to 10.03	0.42
+1 days	3.25 (1.48)	0.34 to 6.15	0.03	0.32 (3.71)	-6.96 to 7.61	0.93
+2 days	3.92 (1.52)	0.93 to 6.93	0.01	-3.72 (3.82)	-11.22 to 3.78	0.47
+3 days	1.63 (1.54)	-1.39 to 4.65	0.29	-2.82 (3.94)	-10.56 to 4.91	0.31
+4 days	2.44 (1.57)	-0.64 to 5.52	0.12	-4.02 (4.00)	-11.88 to 3.82	0.09
+5 days	2.42 (1.59)	-0.71 to 5.54	0.13	-6.92 (4.12)	-15.01 to 1.17	0.93
+6 days	3.31 (1.60)	0.16 to 6.45	0.04	0.33 (4.25)	-8.01 to 8.67	0.69
+7 days	2.66 (1.59)	-0.47 to 5.80	0.09	-1.71 (4.34)	-10.22 to 6.81	0.83
+8 days	3.05 (1.55)	0.01 to 6.10	0.05	-0.92 (4.49)	-9.74 to 7.91	0.83
Random effects:						
Intercepts (SD)	47.22	43.47 to 51.30		37.17	32.55, 42.44	
OESTIDX within cow (SD)	0.43	0.25 to 0.79		0.98	0.78, 1.22	

Table 5.2 (continued)

Variable	Pregnant cows			Non-pregnant cows		
	Coefficient (SE)	95% CI	P	Coefficient (SE)	95% CI	P
Residuals (SD)	12.34	12.02 to 12.67		10.88	10.34, 11.45	

Key: SE standard error; CI confidence interval; SD standard deviation.

[a] Negative values indicate LW loss and positive values indicate LW gain.

[b] Results shown in Figure 5.2.

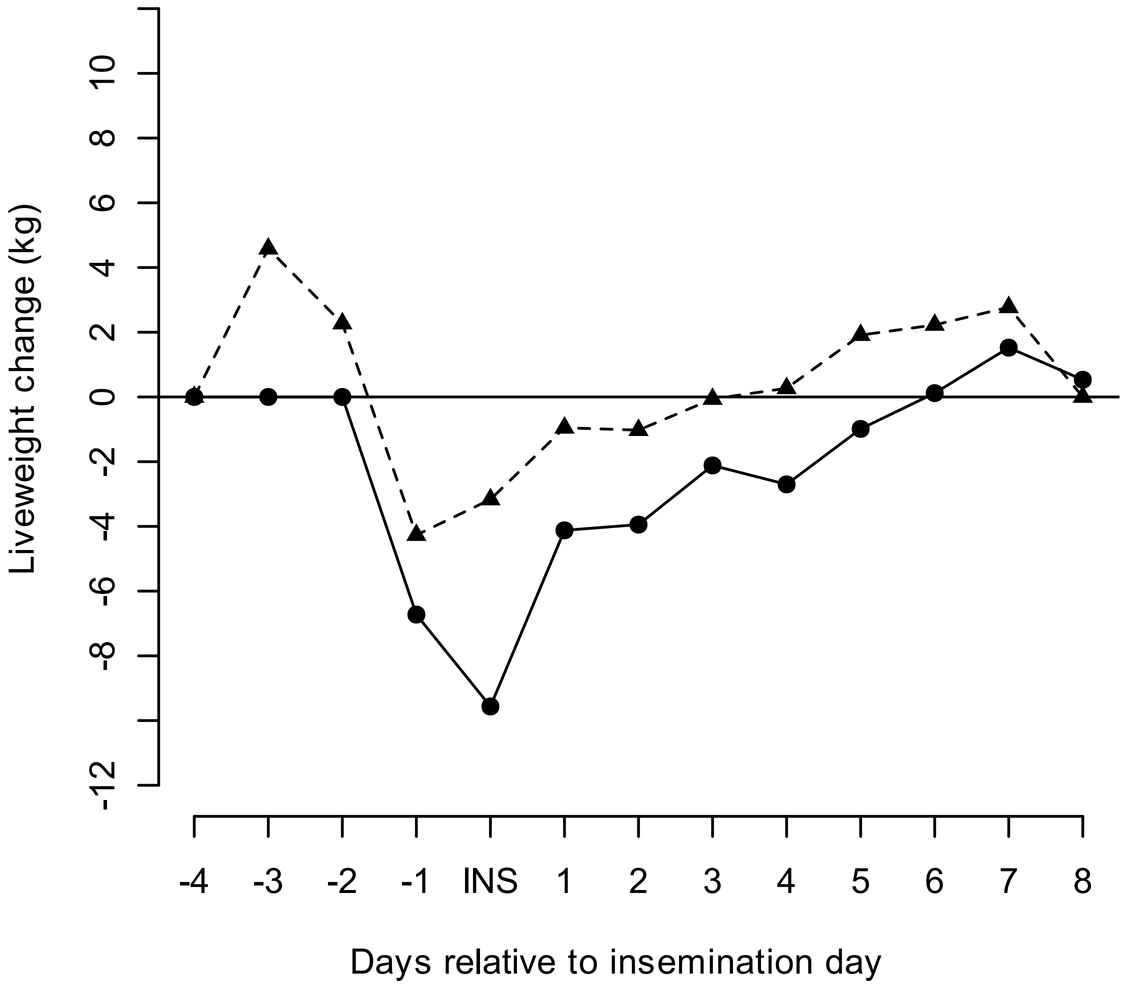

Figure 5.1: Lineplot showing estimated liveweight change as a function of the number of days relative to the day of insemination (INS) for pregnant (solid line; liveweight on day -2 used as a reference) and non-pregnant cows (dashed line; liveweight on day -4 used as a reference).

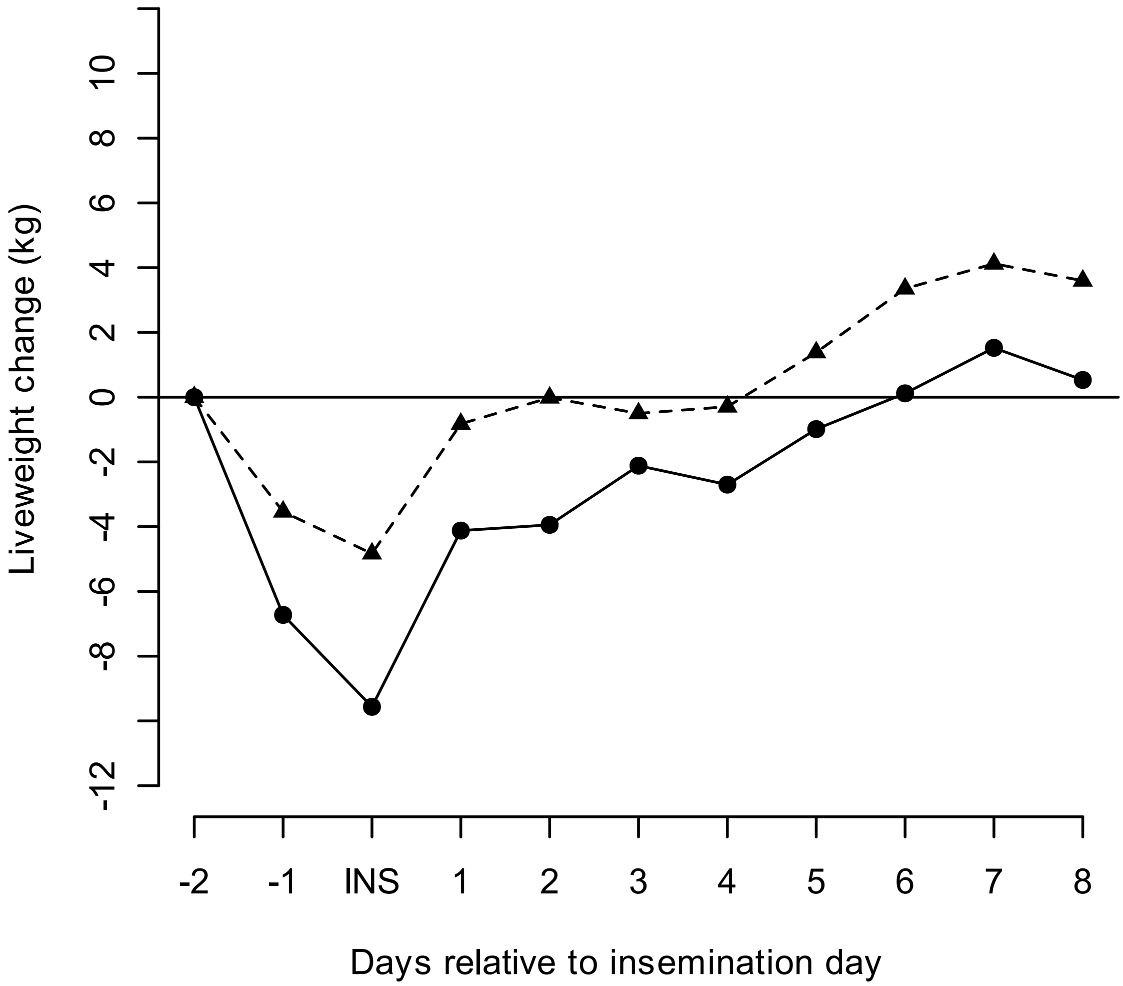

Figure 5.2: Lineplot showing estimated liveweight change as a function of the number of days relative to the day of insemination (INS) for Holstein-Friesian (dashed line; liveweight on day -2 used as a reference) and crossbred cows (solid line; liveweight on day -2 used as a reference).

Table 5.3: 2 $\times$ 2 contingency showing the total number of true positive and true negative oestrus events detected using liveweight change.

	Oestrus +	Oestrus -	Total
ΔLW +	583	731	1,314
ΔLW -	802	18,229	19,031
Total	1,385	18,960	20,345

Sensitivity: 0.42 (95% CI 0.40 to 0.45).

Specificity: 0.96 (95% CI 0.95 to 0.97).

Kappa: 0.39 (0.36 to 0.42).

Table 5.4: Sensitivities and specificities for a number of commercially available oestrus detection tools and the expected sensitivities and specificities where these tools are used in combination (interpreted in parallel) with liveweight change as an additional oestrus detection tool, stratified by fixed conditional dependence levels (0.01 and 0.1).

Method 1			Method 2			Combined		
	Se	Sp		Se	Sp	Covariance	Se	Sp
Visual observation [a]	0.61	1.00	LW change	0.42	0.96	0.01	0.76	0.96
Visual observation	0.61	1.00	LW change	0.42	0.96	0.10	0.67	1.00
Tail paint [b]	0.69	1.00	LW change	0.42	0.96	0.01	0.81	0.96
Tail paint	0.69	1.00	LW change	0.42	0.96	0.10	0.72	1.00
Tail paint-visual [c]	0.78	0.98	LW change	0.42	0.96	0.01	0.86	0.94
Tail paint-visual	0.78	0.98	LW change	0.42	0.96	0.10	0.77	1.00
Pedometer [d]	0.87	1.00	LW change	0.42	0.96	0.01	0.92	0.96
Pedometer	0.87	1.00	LW change	0.42	0.96	0.10	0.83	1.00
Oestrus mount [e]	0.92	1.00	LW change	0.42	0.96	0.01	0.94	0.96
Oestrus mount	0.92	1.00	LW change	0.42	0.96	0.10	0.85	1.00

Key: Se sensitivity; Sp specificity.

[a] Liu & Spahr (1993).

[b] Cavalieri et al. (2003).

[c] Tail paint and visual observation combined (Alawneh et al. 2006).

[d] At-Taras & Spahr (2001).

[e] Xu et al. (1998).

5.4 Discussion

This study describes ΔLW around the time of detected oestrus events in pasture fed dairy cattle and investigates how that information might be used to improve oestrus detection sensitivity and specificity. To the best of our knowledge, this relationship has not previously been investigated in seasonally calving, pasture fed dairy herds.

LW change in relation to the day of oestrus detection followed a similar profile in pregnant and non-pregnant cows (Figure 5.1). A difference was that the greatest negative ΔLW was recorded one day before insemination in non-pregnant cows whereas it occurred on the day of insemination in pregnant cows. This suggests that non-pregnant cows were actually in oestrus at the time of insemination but raises the following questions. Did these cows have reduced oestrus behaviour or expression and poor fertility related to poor oocyte quality or poor uterine environment (Cutullic et al. 2009, Diskin & Sreenan 2000) or was inappropriate timing of insemination the cause of insemination failure? The influence of oestrus expression and insemination time on the probability of conception is well documented (Dransfield et al. 1998, Diskin & Sreenan 2000, Saacke et al. 2000, Dalton et al. 2001, Morton 2004). Early insemination can result in reduced conception rates but high embryo quality, whereas late insemination (i.e. 24 hours after the onset of estrus signs) increases conception rates but reduces embryo quality (Dalton et al. 2001). Thus, an intermediate time of approximately 12 hours (6 to 16 hours) after the onset of oestrus has been cited as optimal when using a 'precise' method for estrus detection (Dransfield et al. 1998, Saacke et al. 2000).

The observed difference in ΔLW during oestrus for Holstein-Friesian and crossbred cows shows that oestrus behaviour varied with breed. This supports previous New Zealand studies that have reported differences in postpartum follicular and luteal function in heavy- and light-strain cows (Thiengtham 2003, Thiengtham et al. 2004, 2008) and the contention that breed, body fatness, and milk yield influence reproductive performance. The interaction between breed and yield (i.e. Holstein-Friesian cows producing more milk) can influence E2 concentration by increasing its metabolic clearance, resulting in shorter and less intense periods of oestrus activity (Friggens et al. 2007, Lovendahl & Chagunda 2010). The higher metabolic clearance of steroid hormones in high producing Holstein-Friesian cows has previously been reported by Lopez et al. (2004). These authors found that cows producing $\geq$39.5 kg milk per day had lower serum E2 concentrations on the day of oestrus and that the duration of oestrus was reduced compared with cows producing $<$ 39.5 kg milk per day. Lopez-Gatius et al. (2005) in a study of 5,883 oestrus events in a study of 350 dairy cows in northeastern Spain between 1998 and 2003 found that 1 kg increases in milk yield were associated with a 1.6% decrease in the level of walking activity at the time of oestrus. Although the findings presented in our study agree in principle to those reported in the literature, the differences in management and total lactation milk yields in our study herd limits the ability to make definitive conclusions about the relationship between breed and oestrus expression.

Forty four *per cent* of pregnant cows showed a significant decrease in LW on the day on which the successful insemination occurred. This finding agrees with previous reports in the literature. Maltz et al. (1997) studied liveweight change in 24 Dutch Holstein dairy cattle and reported a decrease in LW that occurred for 1 to 3 days prior to oestrus in 68% of the 65 oestrus events that were observed. A weakness of this study was the relatively small numbers of animals involved and it wasn't clear how cows were managed, nor were the criteria used to signal cows as in oestrus. van Straten et al. (2008) used approximately 255,000 daily LW records from 5,167 Israeli Holstein dairy cows from 7 herds to investigate the association between LW change and ovarian activity. van Straten et al. (2008) were able to confirm the presence of 21-day ovarian cycles in 33% of their study animals. Although van Straten and co-authors didn't directly conclude that ΔLW findings in their study could be used for oestrus detection, they highlighted the potential use of monitoring ΔLW as a tool for monitoring change in reproductive status. Meyer et al. (2004) monitored daily feed intake of 120 mixed age, Holstein dairy cows kept in a loose housing system for one lactation in Germany. In that study a decrease in intake of 1.8 kg DM on the day of oestrus was reported (mean daily feed intake was comprised of grass silage and corn silage; *ad libitum* access, reported was 20.5 kg; SD = 3.9 kg). Lukas et al. (2008) reported an increase of 0.61 kg DM per day (P $<$0.01) but a decrease in water intake (-1.13 L; SE = 0.63 L; P = 0.07) at the time of oestrus in 35 pairs of mixed age and breed, tie-stalled North American dairy cows that were monitored for 10 months. The small number of cows included in this study and (in the author's own words) the 'flawed' methodology used to estimate feed intake may have resulted in feed intakes being over estimated.

Based on the literature and the findings presented in this study we hypothesise that changes in LW around the time of oestrus are due to changes in physical activity during what has been described by Esslemont et al. (1980) as a 'period of intensified behaviour'. Behavioural changes such as standing to be mounted, excitement, restlessness and nervousness (Williamson 1980) are triggered by hormonal changes (progesterone and oestradiol-17β [E2]) that occur before ovulation. Oestrus behaviour in cattle is dependent on sufficient secretion of endogenous E2. In a study of oestrous activity of 195 Holstein and 4 Jersey cows in Virginia, USA associations between hormone concentrations and physical activity were reported (Desilva et al. 1981). Higher blood progesterone concentrations immediately prior to oestrus followed by higher E2 and lower progesterone at 12 hours after oestrus had a stimulatory effect on late oestrus behaviour expressed as increased activity (Desilva et al. 1981). A study of 23 primiparous Holsteins in Utah, USA reported that 22% of the study animals had elevated milk E2 concentrations ($>$3.5 pg.mL^{-1}) during five or more milkings around the time of oestrus (Lopez et al. 2002). Similar results have been reported elsewhere (MacDonald et al. 1982).

A number of oestrus detection tools attached or applied to animals have been tested and are commercially available. They can be used either individually or in combination to increase the probability of detecting cows in oestrus (i.e. increase detection sensitivity) thereby improving submission rates to artificial insemination. Parallel use of ΔLW with any of the oestrus detection aids (assuming low test dependence) increased sensitivity and therefore increased the predictive value of negative oestrus detection (detected negative cows are truly assigned as non-oestrus). This relationship may be better understood with a numerical example. Consider tail painting with visual observation (TPVO) combined (in parallel) with ΔLW, applied to a herd of 400 cows. Assume that, for a given day, the proportion of cows in oestrus (i.e. prevalence) is 5% (i.e. 20 cows). TPVO detects 78% (Table 5.4) leaving 22% undetected (16 cows and 4 cows in a 400 cow herd, respectively). ΔLW detects 42% of the remaining 22% which equates to approximately an additional 1.6 cows per day. Over a mating period of 42 days, the combined use of ΔLW and TPVO means that approximately an additional 67 cows in oestrus (17% of the herd) will be successfully identified as being in oestrus and submitted to AI. The lower specificity value does not undermine the performance of ΔLW in combination with TPVO, because prior to AI farm workers can reject any false positive cows. Using these values and Table

5.4, predictive values can be computed. Negative predictive value for TPVO alone was 0.988 *versus* 0.992 when TPVO was used with ΔLW. It is important to emphasise that the predictive value of any oestrus detection tool (or combination of tools) depends on the proportion (i.e. prevalence) of cows in oestrus. As the proportion of cows truly in oestrus decreases, exclusion of false positive cows is of little concern (i.e. tool specificity) and, most importantly, the probability of any cows in oestrus being missed (= 1 - test sensitivity) decreases.

The results presented are appropriate for this herd but extrapolation of the findings to other herds should be made with caution. It could be argued that selection bias may have been introduced when the analyses were restricted to pregnant cows, or when cull cows were excluded due to a lack of service records. This bias is likely to be minimal because LW curves for pregnant and non-pregnant cows followed the same profiles near oestrus. The decision to only include data from pregnant cows for the second set of analyses was made to avoid the likelihood of misclassification bias that could occur due to uncertainty in assigning oestrus dates. However, the lack of appropriate gold standard such as plasma progesterone levels doesn't rule out the likelihood of misclassification bias that could have been inherited from the methodology used to identify oestrus events. The direction of this bias on ΔLW oestrus detection sensitivity and specificity is difficult to predict. If misclassification of oestrus events was non-differential with respect to ΔLW (the most likely scenario) then sensitivity and specificity of ΔLW for detecting oestrus events would have been underestimated and *vice versa*. Further research is required to determine such effects on the sensitivity and specificity of ΔLW for detecting oestrus events. The small numbers of cows culled cows during the mating period (n = 49) makes it likely that the impact of this form of selection bias on our results was small. In addition, the number of oestrus events signaled by ΔLW was affected by the decision on the amount of daily LW change that had to occur in order to declare a day as oestrus positive. The cutpoint used in this study resulted in the highest number of signaled oestrus events but with a higher number of false positive oestruses compared with using 1 SD and 1.5 SD (derived from the raw data) as alternatives. Increasing the cutpoint to 1 SD and 1.5 SD reduced the number of true and false oestrus signals produced by ΔLW to 525, 447 and 103, 188, respectively, thus lowering ΔLW test sensitivity and specificity (results not shown). Of interest would be to evaluate the suitability of these cutpoints under experimental conditions where the true oestrus status of an animal could more firmly be established as described above. Also, replication of this study in a larger number of herds where different oestrus detection methods are being used would be important to establish the external validity of the findings reported here.

5.5 Conclusions

In pregnant cows that conceived to the service applied at a given oestrus, LW loss commenced one day before oestrus was detected and continued for a period of four days after. In non-pregnant cows, LW loss ended on the day of detected oestrus. Our analyses show that pregnant cows registered the greatest weight loss on the day of oestrus compared to the day before oestrus for non-pregnant cows. We propose that monitoring LW change holds promise as a cost-effective means to enhance oestrus detection in combination with other oestrus detection methods. The level of dependence can affect the efficacy of combinations of oestrus detection tools used. A combination with higher sensitivity and greater economic benefit might arise from choosing two independent oestrus detection tools with lower sensitivities (e.g. tail paint and ΔLW) than two dependent tools with higher sensitivities (e.g. restlessness and ΔLW).

CHAPTER 6

The effect of liveweight change on reproductive performance in a seasonally calving, pasture fed dairy herd

Abstract – This was a prospective cohort study of 930 lactations in 595 mixed aged dairy cows that calved between 1 July and 24 October of 2008 and 1 July and 24 October 2009 in a single dairy herd in the lower North Island of New Zealand. Parametric accelerated failure time models based on the log-normal distribution were used to identify and quantify the effect of factors influencing the length of time it took cows to conceive after the Planned Start of Mating (PSM) date. A focus of this study was to quantify the effect of liveweight change in the first four weeks after calving (ΔLW$_{long}$) and liveweight change in the period from PSM - 21 days to PSM (ΔLW$_{short}$) on PSM to conception intervals.

Parity, calving to PSM interval, ΔLW$_{short}$, milk protein percentage, breed, mastitis, the presence of a fertility treatment and season influenced PSM to conception intervals. PSM to conception intervals for cows with zero or positive LW change in ΔLW$_{short}$ were 74% of those for cows with negative LW change in ΔLW$_{short}$ (TR 0.74, 95% CI 0.48 to 1.00; P = 0.05).

The findings of this study are consistent with those that have been reported in the literature and better define the impact of long- and short-term liveweight change on reproductive performance, providing the opportunity to design feeding programmes in pasture fed dairy herds that have positive effects on fertility.

6.1 Introduction

New Zealand dairy farming is predominantly pasture based and a compact calving pattern is required to maintain high pasture utilisation (Macmillan & Asher 1990, Holmes et al. 2002). With the breeding period being typically restricted to four to eight weeks of artificial breeding (Macmillan & Asher 1990), followed by a period of natural mating, a dairy cow must have a calving interval of around 365 days. Within this period 282 days are required for pregnancy leaving around 83 days for an animal to resume normal cyclicity and to conceive (Macmillan & Asher 1990, Holmes et al. 2002). Cows not conceiving during a twelve-week breeding period cannot maintain an annual calving pattern and are usually culled.

After calving milk yields in dairy cattle reach their peak at the time when they should show oestrus and conceive (McDougall & Compton 2005). The period from calving to peak yield also coincides with the time when the incidence of many health problems, including mastitis, is high (McDougall & Compton 2005). Early in lactation, cows are usually in negative energy balance (NEB), requiring them to mobilise body reserves to support production (Pedernera et al. 2008). Britt (1992) hypothesised that early postpartum NEB has a negative effect on follicular development. Weaker follicles are incapable of producing or sustaining a plasma concentration of progesterone sufficient to support the maintenance of pregnancy (Diskin et al. 2003).

Almost all cows undergo a period of NEB in the early lactation period that is determined by biochemical, endocrine and clinical factors (Jorritsma et al. 2003). Many traits (e.g. milk composition, blood, and urine metabolic parameters and their ratios, body condition score [BCS], and unfasted liveweight) have been investigated as means to predict the degree and severity of NEB at the herd or individual cow level. The advantage that direct measurement of liveweight (LW) and BCS have over other traits for assessing NEB is that they can be measured for cows with relative ease, allowing the degree and severity of NEB and its impact on health and productivity to be quantified (Pedernera et al. 2008). BCS has been long regarded as a quick and non-invasive technique that allows herd managers to directly monitor and manage the nutritional status and health of dairy cows throughout the production cycle. Assessment of BCS at drying off, calving and the Planned Start of Mating (PSM) provides information that can be used as a basis for adjusting the herd feeding programme with positive effects on herd-level reproductive performance (Berry et al. 2002, Buckley et al. 2003). Automated systems that provide a direct measurement of cow LW have the potential to provide the same information without (Maltz et al. 1997, van Straten et al. 2008) the inherent problems with BCS measurement due to inter-observer variability and bias (Broster & Broster 1998).

Few studies have attempted to quantify the effect that LW and LW change (ΔLW) have on reproductive performance of pasture fed dairy cattle. Roche, Macdonald, Burke, Lee

& Berry (2007) measured the impact of ΔLW at key points throughout the production cycle and found that the likelihood of reproductive success was negatively influenced by increases in the amount and duration of LW loss. Further, Buckley et al. (2003) showed that cows that lost less weight and reached nadir LW before PSM were more likely to conceive to their first service and within the first 21 days following PSM. Cows that gained weight from PSM were more likely to be submitted in the first 21 days after PSM and conceive sooner than those that lost weight during the mating period. To the best of our knowledge few, if any, studies have assessed the effect of daily ΔLW on the reproductive performance of pasture based dairy systems operating commercially in New Zealand. The objective of this study was to quantify the association between a range of individual animal-level factors (including LW and ΔLW) and reproductive success of cows in a seasonally calving, pasture fed dairy herd. A better understanding of how ΔLW influence reproductive outcomes means that feeding programmes can be manipulated to minimise the effect of this source of variation on herd-level reproductive performance.

6.2 Materials and methods

Study animals

This was an observational study of 930 lactations in 595 mixed aged and breed (Holstein-Friesian, Jersey, and cross breed Holstein-Friesian × Jersey crossbreeds) dairy cows that calved during the 2008 and 2009 seasons and were present at PSM (24 October for 2008 and 2009; respectively) in a university owned, seasonally calving, pasture fed dairy herd in Palmerston North in the lower North Island of New Zealand. Cows grazed as a single group at pasture and had free access to water. The herd was managed so that the pasture allowance (14 – 16 kg DM.cow^{-1}.day^{-1}) and access to supplementation after the morning milking (palm kernel meal to a maximum of 2 kg DM.cow^{-1}.day^{-1} and maize silage to a maximum of 2 kg DM.cow^{-1}.day^{-1}) was sufficient for maintenance and production requirements of a 400 kg cow producing 2.0 kg milksolids.day^{-1}. The pasture was dominated by ryegrass (*Lolium perene*) throughout the year. White clover (*Trifolium repens*) contributed up to 20% of pasture dry matter. Cows were milked twice daily, starting at 0530 and 1500 hrs through a 50 bale rotary-platform milking parlour (DeLaval^{TM} Parallel

Rotary, DeLaval International, Sweden).

Cows were identified using a radio frequency electronic identification system. This comprised low frequency (134.2 kHz), high performance, non-reusable half duplex ear tags (transponders comply with ISO 11784 and ISO 11785 standards) fitted to each cow and an antenna (Allflex^{TM} New Zealand Limited, Palmerston North, New Zealand). The electronic identification system antenna was connected via a serial connection cable (9 pin universal RS232 connector cable) to an electronic walkover scale system which was comprised of an aluminum walkover platform, two electronic load bars and a scale indicator (WOW! XR-3000®, Tru-Test, Auckland, New Zealand). The electronic identification system antenna and walkover scale system were installed at the exit race of the milking parlour. LWs were recorded as each cow walked away from the milking platform at the end of each milking. The walkover scale system was calibrated to an accuracy of ± 2 kg. Throughout the study period LW data were downloaded from the scale indicator to a portable personal computer twice weekly. Downloaded data included each cow's electronic identifier, the date and time of each weigh event, and the LW measurement (kg) as estimated by the scales. Data were transferred to a dairy herd management software package (DairyWIN v99.91.148; Massey University, Palmerston North, New Zealand) allowing LW data to be matched with each cow's biographical and lactation event details (e.g. calving date, insemination date(s), diagnosis and treatment details and dates).

The volume of milk (milk yield) produced by each cow was estimated on a monthly basis (once within the first week of each calendar month) throughout the milking season. A consistent fraction of milk was collected from a sequential evening and morning milking, the samples weighed, and a subset of the combined evening and morning milking taken for the determination of milk fat and protein concentration and somatic cell count.

Premating oestrus events were recorded by farm staff one month before PSM date. Cows detected in oestrus from PSM until 6 December (2008 and 2009) were artificially inseminated by a contract inseminator that visited the farm once daily. For the seven-week period from 7 December (2008 and 2009) to 25 January (2009 and 2010), 8 bulls were run with the milking herd.

Oestrus detection was conducted by farm staff using direct observation and tail paint (FIL oil based tail paints, fluorescent oestrus detection tail paint, Tell Tail). Cows were observed by staff in the paddock for 30 – 45 minutes before each milking, while they traveled from the paddocks to the milking parlour and throughout each milking (3 hours each milking). A cow was considered to be in oestrus if more than 50% of her tail paint was removed or she showed typical oestrus behaviours (standing to be mounted, mounting other cows and head mounting).

Cows not observed to be in oestrus were treated with an intravaginal progesterone releasing device (eight day CIDR programme; Pfizer Animal Health, Auckland, New Zealand) without veterinary examination one week prior to PSM (100 and 73 cows in the 2008 and 2009 seasons, respectively). A further 58 cows (30 cows in 2008 and 28 cows in 2009) that had been detected in oestrus before PSM and were not re-observed in oestrus by 21 days after PSM were treated with prostaglandin F2α (2 mL Estroplan, Parnell, Auckland, New Zealand) on that day.

Pregnancy was diagnosed by rectal examination by an experienced veterinarian and ultrasound examination 5 and 13 weeks after the end of the 12-week mating period to identify the service (based on farm records and foetal ageing) that resulted in conception.

Data management

Data cleaning procedures were carried out before analysis. Erroneous LW records were identified and removed from the dataset. The two LW records for each cow for each day in milk were averaged to produce a single daily LW measurement. If one value was missing the present measurement was used as the daily LW measurement.

The dataset comprised details of the cow's identity, whether or not the outcome of interest occurred (1 if the cow conceived and 0 otherwise), and the number of days from PSM to conception (for cows that conceived) or the number of days from PSM to the end of the mating period (for cows that did not conceive) or the number of days from PSM to the date of removal from the herd if a cow was culled or died prior to the end of the mating period. Variables thought to influence the risk of pregnancy included: (1) parity, (2) the average LW recorded in the first week after calving, termed LW at calving, (3) calving to PSM interval, (4) LW change from calving to the 4^{th} week after calving (4^{th} week LW minus LW at calving divided by LW at calving, termed ΔLW$_{long}$), (5) LW change from PSM - 21 days to PSM (LW at PSM minus LW PSM - 21 days divided by LW at PSM - 21 days, termed ΔLW$_{short}$), (6) the presence or absence of a hormonal fertility treatment during the breeding period, (7) breed, (8) the presence or absence of a clinical lameness event between calving and PSM, (9) the presence or absence of a clinical mastitis event between calving and PSM, (10) the presence or absence of either a metabolic or reproductive disorder between calving and PSM, (11) mating season as a categorical variable with two levels (2008 and 2009), and (12) milk protein content (estimated from the herd milk test at or nearest to the herd PSM date).

Statistical analyses

The distribution of PSM to conception intervals was consistent with a log-normal distribution (Figure 6.1). Most conceptions occurred around 15 – 20 days after PSM with smaller numbers conceiving up to 70 days after PSM. Based on this distribution it was considered appropriate to develop a model of days open using a parametric approach. A parametric approach provided two key advantages for this study. Firstly, it provided greater analytical power. That is, for the given number of subjects in the study our ability to detect factors influencing time to event was greater than that if we used a non-parametric approach (such as Cox proportional hazards regression). The second advantage was that model outcomes were expressed in terms of time ratios which are more easily understood than metrics such as the hazard ratio (produced from a Cox proportional hazards model).

The association between each of the explanatory variables thought to influence PSM to conception interval was tested using the log rank test. Kaplan-Meier survival curves for each level of an explanatory variable were plotted and the homogeneity of the curves between levels tested using the log rank test statistic. Explanatory variables that showed an association with days open (that is, a difference in the Kaplan-Meier survival curves that was significant at P <0.20) were selected for inclusion in the multivariate analysis. An accelerated failure time (AFT) approach (Kleinbaum & Klein 2005) was then used to quantify the effect of each of the prescribed explanatory variables on days from PSM. The general form of the accelerated failure time model is:

$$log(t) = \alpha + \beta_1 x_{1i} + \ldots + \beta_m x_{mi} + log(\tau) \tag{6.1}$$

where log(t) is the natural logarithm of the time to 'failure' (PSM to conception interval within cow-lactation), α is an intercept term, $(\beta_1 x_{1i} + \ldots + \beta_m x_{mi})$ is a linear combination of the m explanatory variables and their regression coefficients and log(τ) is an error term. Using this approach the accelerated failure time coefficients represent the expected change in log(t) for one unit change in the predictor.

Previous studies of days to conception in dairy cattle using parametric models have been based on either the Weibull distribution, which assumes fertility increases steadily throughout the lactation (Harman et al. 1996, Schnier et al. 2004) or the log-normal distribution which assumes that fertility increases steadily up to day 100 to 120 post calving after which time it decreases (Meadows et al. 2007). Meadows et al. (2007) evaluated the suitability of six distributions to describe days open in dairy cattle, concluding that the log-normal distribution provided the best fit to their data. A similar approach was taken in this study. Based on Figure 6.1, we evaluated the exponential, Weibull, log-normal, and log-logistic distributions that can be interpreted in the AFT metric. Hazard curves, showing the instantaneous probability of conception as a function of days since calving, were plotted for each distribution. The fit of each candidate distribution to the data was evaluated using a fixed effect model with null predictor using Akaike's Information Criterion (AIC). A smaller AIC statistic indicates a better fit (Kleinbaum & Klein 2005).

To select those explanatory variables that best explained PSM to conception interval a backward stepwise approach was used. The significance of each explanatory variable in the model was tested using the Wald test. Explanatory variables that were not statistically significant were removed from the model one at a time, beginning with the least significant, until the estimated regression coefficients for all retained variables were significant at an alpha level of <0.05. Relevant two-way interactions were assessed. To account for the influence of season on PSM to conception intervals (due to, for example, changes in farm management and climatic effects) production season was fitted as a two-level fixed effect. Finally, LW at calving, ΔLW_{long} and lameness were forced into the final model to account for their confounding effects (*a priori*) on PSM to conception intervals.

The final model is reported in terms of adjusted time ratios (TR) for each explanatory variable. An adjusted time ratio (and its 95% confidence interval) of greater than one indicates that, after adjusting for other variables in the model, exposure to the explanatory variable increased PSM to conception intervals. An adjusted time ratio (and its 95% confidence interval) of less than one indicates that exposure to the explanatory variable decreased PSM to conception intervals and a time ratio equal to one indicates that the predictor had no influence on PSM to conception intervals. Statistical analyses were performed using the survival package (Therneau & Lumley 2010) implemented within R (R Development Core Team 2010).

6.3 Results

Descriptive statistics for each of the explanatory variables and the outcome variable for this study are shown in Tables 6.1 and 6.2. Forty *percent* (374 of 930) of lactation records were censored. On the basis of the AIC for each of the three distributions applied to the AFT model and consideration of the biological features of conception patterns in dairy cattle (Meadows et al. 2007), it was concluded that the log-normal distribution provided the best fit to the data and was used in the analyses reported here (data not shown).

PSM to conception intervals were associated with parity, calving to PSM interval, ΔLW_{long}, ΔLW_{short}, milk protein percentage, breed, mastitis, the presence of a fertility treatment and mating season (Table 6.3). Holding all of the entered fixed effects in the model constant, a 1% positive change in ΔLW_{long} shortened PSM to conception intervals by 2% (time ratio [TR] 0.98, 95% CI 0.96 to 1.00; P = 0.08). PSM to conception intervals for cows with zero or positive LW change in ΔLW_{short} were 74% of those for cows with negative LW change in ΔLW_{short} (TR 0.74, 95% CI 0.48 to 1.00; P = 0.05). Figure 6.2 shows the instantaneous hazard of conception as a function of days from PSM, based on the log-normal model presented in Table 6.3.

Figure 6.3 shows the predicted effect of positive and negative LW in the ΔLW_{long} and ΔLW_{short} periods on time to conception after PSM as estimated from the final AFT model for a set of hypothetical scenarios. The following is an example on how these estimates were calculated based on the results shown in Table 6.3. For a first parity crossbred cow weighing 400 kg at calving that, with average milk production, calved 40 days from PSM, had not received a fertility, mastitis, or lameness treatment in the 2009 mating season, with negative (5% LW loss) ΔLW_{long} but positive ΔLW_{short} the expected PSM to conception interval was 46 days (95% CI 34 to 58). PSM to conception interval for the same cow with negative ΔLW_{short} was 66 days (95% CI 37 to 96). Figure 6.3 shows this graphically.

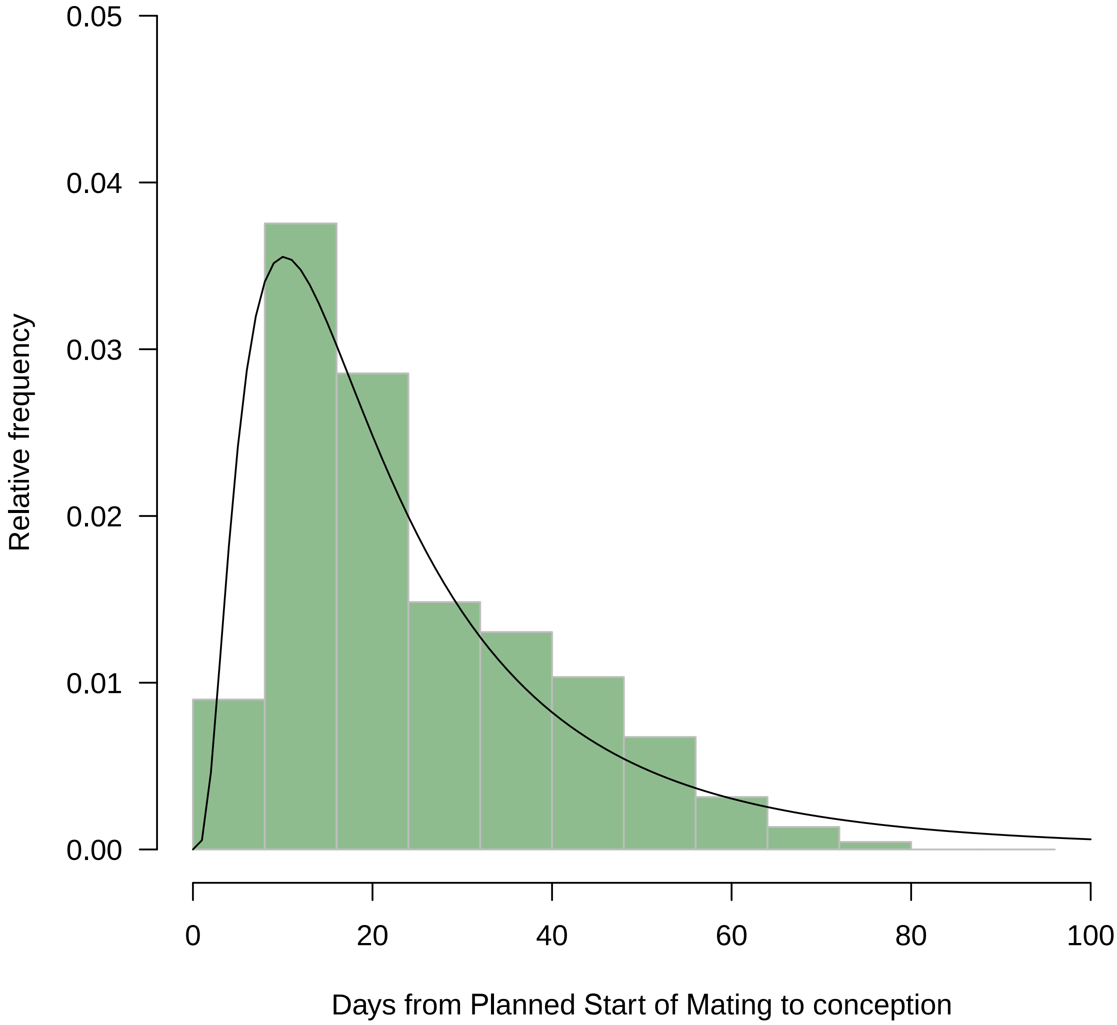

Figure 6.1: Frequency histogram showing the number of days from Planned Start of Mating to conception for 930 lactations from 595 cows in the 2008 and 2009 milking seasons. Superimposed is a lineplot of a log-normal distribution fitted to the data.

Table 6.1: Descriptive statistics of parity, liveweight at calving, relative liveweight change in the first 4 weeks of milk (ΔLW$_{long}$), relative liveweight change in the 21-day period before PSM (ΔLW$_{short}$), milk production, breed and disease records for the 2008 and 2009 milking seasons.

Variable	n	Mean (SD)	Median (Q1,Q3)	Min, Max
Parity	930	4 (2)	4 (3, 5)	1, 14
LW at calving (kg)	930	470 (65)	466 (415, 525)	304, 638
ΔLW$_{long}$ (%) [a]	930	-4 (5)	-4 (-6, -2)	-24, 20
ΔLW$_{short}$ (%) [b]	930	0.43 (0.94)	0.20 (0.0,0.8)	-3.0, 6.2
Calving to PSM interval (days)	930	61 (21)	66 (48, 77)	0, 114
PSM to conception interval (days)	930	25 (16)	23 (10, 37)	2, 73
Milk yield (L.cow^{-1}.day^{-1})	930	21 (6)	21 (17, 25)	3, 44
Protein (%)	930	3.4 (0.3)	3.4 (3.2, 3.7)	2.0, 4.6
Fat (%)	930	5.3 (1.1)	5.2 (4.6, 6.3)	1.7, 11.0
Fertility treatment:				
CIDR [c]	166			
Prostaglandin [d]	105			
Breed:				
Holstein-Friesian	367			
Crossbred	563			

Key: SD, standard deviation; Q1 25th percentile, Q3 75th percentile, PSM Planned Start of Mating.

[a] (LW at DIM$_{28}$ minus LW at calving) $\div$ LW at calving.

[b] (LW at PSM minus LW at PSM - 21 days) $\div$ LW at PSM - 21 days.

[c] Intravaginal controlled internal drug releasing insert (eight day CIDR programme; Pfizer Animal Health, Auckland, New Zealand).

[d] Prostaglandin F2α (Estroplan, Parnell, Auckland, New Zealand).

Table 6.2: Incidence risk of health disorders diagnosed from PSM to the end of mating for the 2008 and 2009 milking seasons.

Variable	Cases	Non-cases	IR (95% CI) [a]
Lameness	71	859	7.6 (6 to 10)
Mastitis	52	878	6 (4 to 7)
Metabolic or reproductive disorders [b]	25	905	3 (2 to 4)
Fertility treatment:	271	659	29 (26 to 32)
CIDR [c]	166	764	18 (15 to 21)
Prostaglandins [d]	105	828	11 (9 to 14)

[a] Incidence risk expressed as the number of cases per 100 cows. See Rothman 2002, pp. 130 – 143 for details on calculation of 95% CIs.
[b] Milk fever n = 20; assisted calving n = 5.
[c] Intravaginal controlled internal drug releasing insert (eight day CIDR programme; Pfizer Animal Health, Auckland, New Zealand).
[d] Prostaglandin F2α (Estroplan, Parnell, Auckland, New Zealand).

Table 6.3: Estimated regression coefficients and their standard errors from the final multivariable accelerated failure time model of risk factors on PSM to conception intervals in dairy cattle.

Variable	Cows (n)	Pregnant (n)	Coefficient (SE)	P	TR (95% CI)
Intercept			4.7377 (0.2650)	<0.01	
Parity:					
1 – 3	193	87	0.7553 (0.1416)	<0.01	2.13 (1.61 to 2.81)
> 3	737	469	Reference		1.00
LW at calving (kg):					
<470	247	159	Reference	-	1.00
≥470	683	397	0.1849 (0.1195)	0.12	1.20 (0.95 to 1.52)
Calving to PSM (days):					
<30	101	40	Reference	-	1.00
≥30	829	516	-0.6861 (0.1758)	<0.01	0.50 (0.35 to 0.71)
ΔLW$_{long}$ (%) [a]			-0.0195 (0.0111)	0.08	0.98 (0.96 to 1.00) [b]
ΔLW$_{short}$ (%): [c]					
<0	76	33	Reference	-	1.00
≥0	854	523	-0.3666 (0.1921)	0.05	0.74 (0.48 to 1.00)
Milk protein (%):					
<3.4	471	258	Reference	-	1.00
≥3.4	459	298	-0.2051 (0.1022)	0.05	0.81 (0.67 to 0.99)
Breed:					
Holstein-Friesian	367	199	Reference	-	1.00
Crossbred	563	357	-0.2105 (0.1071)	0.05	0.81 (0.66 to 1.00)
Mastitis:					
Absent	878	536	Reference	-	1.00
Present	52	20	0.6790 (0.2296)	<0.01	1.97 (1.25 to 3.10)
Lameness:					
Absent	859	516	Reference	-	1.00
Present	71	40	0.0761 (0.1795)	0.70	1.07 (0.75 to 1.53)
Fertility treatment:					
Absent	699	422	Reference	-	1.00
Present	231	134	0.2852 (0.0746)	<0.01	1.33 (1.14 to 1.54)
Season:					
2008	474	355	Reference	-	1.00
2009	456	325	-0.2898 (0.1057)	0.01	0.75 (0.61 to 0.92)

Key: SE standard error; TR time ratio; CI confidence interval; LW liveweight; PSM Planned Start of Mating.

Wald test P for all variables in the final model (χ^2 = 6162.5, df = 12) was < 0.01.

[a] (LW at DIM$_{28}$ minus LW at calving) $\div$ LW at calving.

[b] Interpretation: controlling for the effect of parity, LW at calving, ΔLW$_{short}$, milk protein, breed, season and the presence mastitis, lameness and fertility treatments, 1% increases in ΔLW$_{long}$ shortened PSM to conception intervals by 2% (TR 0.98; 95% confidence interval 0.96 to 1.00).

[c] (LW at PSM minus LW at PSM - 21 days) $\div$ LW at PSM - 21 days.

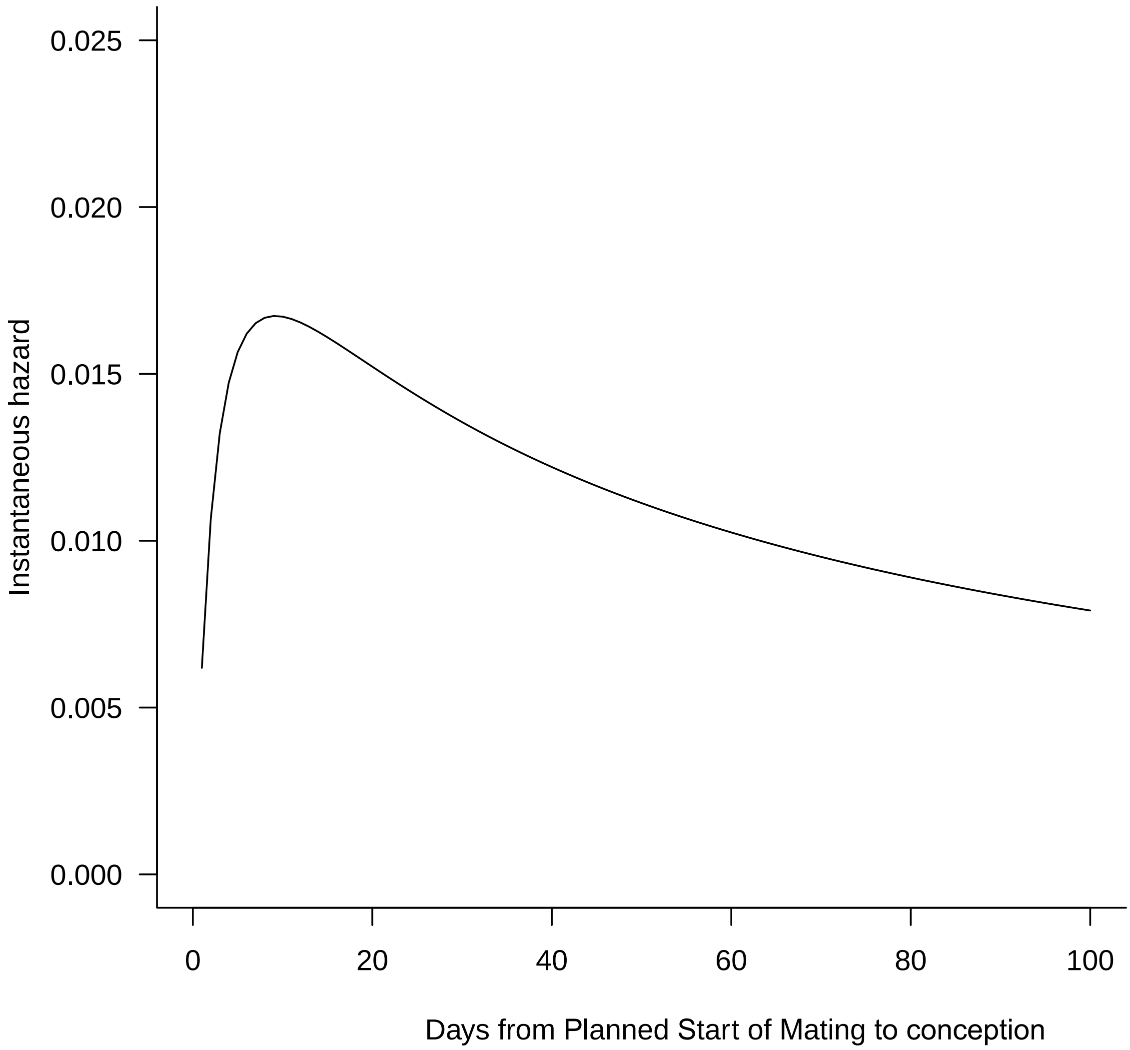

Figure 6.2: Line plot showing the instantaneous hazard of pregnancy as a function of the number of days from Planned Start of Mating to conception, based on the log-normal model shown in Table 6.3.

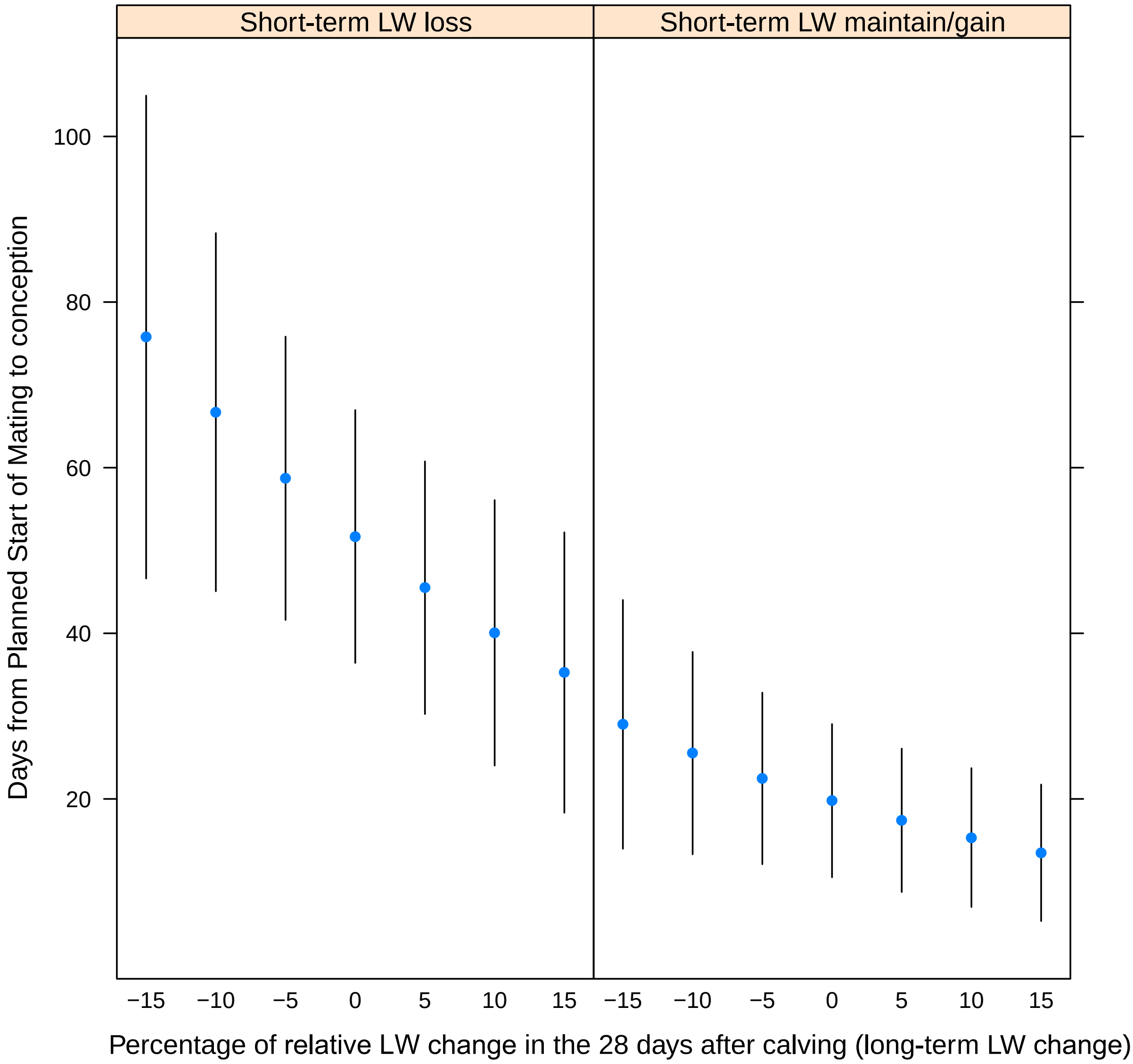

Figure 6.3: Error bar plot showing predicted PSM to conception intervals as a function of percentage liveweight loss in the 28 days after calving for a first parity, average producing cross-bred cow weighing 400 kg at calving that had calved 30 days at the time of PSM and had not received fertility, mastitis, or lameness treatments in the 2009 mating season, based on the accelerated failure time model presented in Table 6.3. The left hand panel shows predicted PSM to conception intervals (and their 95% confidence intervals) where $\Delta\mathrm{LW}_{short}$ was negative. The right hand panel shows predicted PSM to conception intervals (and their 95% confidence intervals) where $\Delta\mathrm{LW}_{short}$ was either zero or positive.

6.4 Discussion

Reproductive failure is the most frequent reason for the involuntary culling of cattle in New Zealand dairy herds (Harris 1989). Because of this, a range of strategies have been (and continue to be) developed to optimise herd-level reproductive performance (Macmillan & Asher 1990). The key breeding objectives in New Zealand dairy herds are to achieve the highest pregnancy rate in the shortest time after PSM and to minimise the effect of factors that negatively impact on pregnancy rate. This study demonstrates how analysis of individual cow LW change, as a proxy variable for energy status, can be used to further understand factors influencing reproductive performance in pasture fed dairy herds. Our most important finding was that, in this herd, ΔLW_{long} and ΔLW_{short} were associated with PSM to conception intervals with ΔLW_{short} having the more prominent effect. Based on the accelerated failure time model presented in Table 6.3, the predicted PSM to conception interval for a reference category cow ($>$3 parity, Friesian, with LW $<$470 kg, calved more than 30 days at PSM, producing $<$3.4% milk protein, with no record of a mastitis, lameness, or fertility treatment and no weight change during the first 4 weeks after calving and no weight change in the 3 weeks prior to PSM) was 57 days. For an identical animal where ΔLW_{short} was positive (i.e. an animal that gained weight in the 3 weeks prior to PSM) the predicted PSM to conception interval was 40 days. When ΔLW_{short} was negative ΔLW_{long} had to be +19% to produce a predicted PSM to conception interval of 40 days. That is, while both positive ΔLW_{long} and ΔLW_{short} were associated with reduced PSM to conception intervals, the amount of positive weight change required to produce a beneficial effect on PSM to conception intervals was substantially less when it occurred during the 3 weeks prior to PSM, compared with weight change during the first 4 weeks after calving.

Liveweight loss in the 4-week interval after calving (i.e. negative LW change in ΔLW_{long}) approached statistical significance (TR 0.98, 95% CI 0.96 to 1.00; P = 0.08) and was included in the final model. Our justification for this was firstly, there are good physiological grounds for ΔLW_{long} as a determinant of reproductive performance in dairy cattle (Britt 1992). Secondly, it is possible that if the number of subjects in our study was greater, resulting in more statistical power, then ΔLW_{long} may have indeed been statistically significant. Britt reasoned that NEB during early postpartum folliculogenesis impairs follicular development with a subsequent negative effect on fertility. Furthermore, the impact of LW loss in ΔLW_{long} on reproductive performance is a classical effect of nutrition levels on the growth rate and persistency of the dominant follicle. It has also been hypothesised that both long-term (Bishop et al. 1994) and short-term (Diskin et al. 2003) NEB negatively impacts on the levels of hormones and metabolites that help control reproductive events (Roche 2006) such as endocrine insulin-like growth factor-I (IGF-I; Roche 2006, Wathes et al. 2007). A reduction in IGF-I levels affects the quality of follicles, the fate of the dominate follicle, and survival of the early embryo (Robinson et al. 2000, Robinson 2005, Wathes et al. 2007). Nutritional stress clearly influence follicular function and reproductive outcomes. However, reproductive outcomes are also influenced by a number of other animal level factors such as genetic strain (Burke & Roche 2007) and health status (McDougall et al. 2007) as well as herd level factors such stocking density (Baudracco et al. 2010) that were not accounted for in this study. Although the evidence in the literature about how these factors impact on fertility is increasing, it remains a complex and debatable subject (Chagas et al. 2007) that requires further research.

Our findings are consistent with previous studies that have examined the relationship between LW and BCS in New Zealand, pasture fed dairy herds. Roche, Macdonald, Burke, Lee & Berry (2007) assessed LW, BCS and the reproductive performance of 2,635 lactation records from 897 spring-calving Holstein-Friesian dairy cows in New Zealand. In their study, an increased rate of LW loss after calving was associated with a reduced odds of pregnancy in the first 21 days after PSM (OR 0.87 95% CI 0.79 to 0.96; $P < 0.05$). Fulkerson et al. (2001) identified a positive relationship between LW gain 4 weeks before PSM and pregnancy rate in the first 24 days of the mating period. Cows that became pregnant gained 0.95 kg, while non pregnant cows gained 0.4 kg during the same time frame. Moller & Shannon (1972), in a cohort study of 3,659 spring calving New Zealand dairy cows, found that cows that lost 2% of their LW around PSM had lower reproductive performance compared with those that gained greater than 2%. Burke, Williams, Hofmann, Kay, Phyn & Meier (2010) in a study of 2,763 mixed age and breed dairy cows found that cows within herds that experienced acute feed restrictions (dry matter allowances of around 8.0 kg.day$^{-1}\pm$ 1.7 kg.day^{-1}) at the onset of PSM had reduced ($P < 0.05$) 21-day submission rates and reduced three- and six-week pregnancy rates (88%, 45%, and 71%, respectively). In a comparison group, where cows were on dry matter allowances of 14.3

kg.day^{-1} $\pm$ 2.3 kg.day^{-1} 21-day submission rates, three- and six-week pregnancy rates were 94%, 53% and 78%, respectively. Similar results have been reported by Youden & King (1977) and Heinonen et al. (1988).

In pasture fed dairy herds maintaining cows in a state of positive energy balance can be challenging (Roche, Lee, Macdonald & Berry 2007). Dairy cows tend to respond to improved feeding by increasing milk production rather than portioning energy to LW gain (Holmes et al. 2002, McDougall et al. 1995). Efforts to promote LW gain in pasture fed dairy herds has been shown to yield a smaller economic effect compared with strategies aimed at preventing excessive LW loss (Roche, Lee, Macdonald & Berry 2007). The findings of Roche, Lee, Macdonald & Berry (2007) are consistent with the effect of LW change in ΔLW$_{long}$ on reproductive performance identified in this study, but conflict with our findings relating the effect of LW change in ΔLW$_{short}$ on reproductive performance. In our study, the impact of short term LW change was greater than long term LW change. We found at least a 25% reduction in PSM to conception intervals for those cows that gained LW in ΔLW$_{short}$ compared with those that lost weight during the same period.

In this study, we identified a positive association between milk protein yield and reproductive performance (TR 0.81 95% CI 0.67 to 0.99). The percentage of protein in milk is influenced by dry matter intake (Buckley et al. 2003, Fulkerson et al. 2008) and the content of the ration offered (Beever et al. 2001, Morton 2004, Fulkerson et al. 2008). Rations comprised of high quality starches generally result in higher milk protein concentrations (Beever et al. 2001) while reduced starch intake lowers milk protein concentrations (Auldist et al. 2000). In times of NEB a shortage of blood glucose restricts the synthesis of milk protein in the udder. NEB also causes a reduction of IGF-I, LH and oestradiol, which consequently delays ovarian follicular development and reduces fertility (Bossis et al. 2000, Diskin et al. 2003, Richards et al. 1995). A number of recent studies have identified a positive association between milk protein yield and reproductive performance (Morton 2004, McDougall & Compton 2005, Fulkerson et al. 2008). This consistency supports a causal association between the two. Morton (2004) showed that milk protein content was positively associated with submission rate, pregnancy rate to first service, and pregnancy rate after 21 days of breeding in a large prospective cohort study of 168 herds conducted in Australia. McDougall & Compton (2005) showed that for cows with a milk protein percentage between 3.4% to 3.6% the risk of conception in the first 28 days from PSM was 41% greater (RR 1.41 95% CI 1.13 to 1.71; P <0.05) than those with milk protein percentages of 2.3% to 3.2%. Similar findings have been reported elsewhere (see, for example, Buckley et al. 2003 and Fulkerson et al. 2008). A small number of earlier studies (Carroll et al. 1994, Burke et al. 1997) demonstrated little or no association between milk protein yield and reproductive outcomes. In summary, research to date indicates that milk protein content determined at or before PSM has some potential as a means for identifying cows at risk of reproductive failure.

PSM to conception intervals were increased by a factor of 1.97 (95% CI 1.25 to 3.10) for cows that had a clinical mastitis event between calving and PSM, compared with those that had no clinical mastitis. These findings are in agreement with other studies that have used survival analysis to investigate the effect of udder health on reproductive performance in dairy cattle. Meadows et al. (2006) used survival analysis on data from 1,700 mixed age and mixed breed dairy cattle from Ohio, USA and reported a 11% (HR 0.89, 95% CI 0.85 to 0.95; P <0.01) reduction in the daily hazard of pregnancy when somatic cell scores (log scores) exceeded 4.5. Another study of 752 Jersey cows in Tennessee, USA reported that subclinical and clinical mastitis impaired reproductive performance (Schrick et al. 2001). The effect of mastitis is evident on PSM to conception intervals in this study, but the decision of managers to milk cows with mastitis once a day and run them as a separate group may have affected the efficiency of oestrus detection and thus influenced their probability of being submitted for insemination.

6.5 Conclusions

We conclude that LW change in the four weeks after calving and LW change before PSM are important indicators of cows at risk of poor reproductive performance in this seasonally calving, pasture fed dairy herd. Moderate LW loss in the four weeks after calving and short- term LW gain after PSM reduced PSM to conception intervals. The findings of this study are consistent with those that have been reported in the literature and better define the impact of long- and short-term liveweight change on reproductive performance, providing the opportunity to design feeding programmes in pasture fed dairy herds that have positive effects on fertility.

CHAPTER 7

The impact of clinical lameness on liveweight in a seasonally calving, pasture fed dairy herd

Abstract – This paper investigates the impact of lameness on liveweight in pasture fed dairy cattle. The data comprised 222,446 averaged daily liveweight measurements from 828 lactations of 542 mixed age cows in a seasonally calving, pasture fed New Zealand dairy herd. LW measurements for individual cows were aggregated into weekly averages and analyses conducted to evaluate the effect of a diagnosis of lameness on LW change after controlling for the effect of week in milk, parity, liveweight at calving, breed, calendar month, and season. In lame cows, liveweight decreased for up to three weeks before lameness was diagnosed and for up to four weeks after treatment. Total liveweight loss arising from a single lameness episode was, on average, 61 kg (95% CI 47 to 74 kg). The results from this study demonstrate how liveweight records for individual animals can be used to enhance a herd manager's ability to detect lame cows and present them for treatment. The methods presented in this paper provide a first attempt to show how daily LW monitoring might be used as a tool for early detection of lameness in dairy cattle.

7.1 Introduction

In dairy cattle dry matter intake is influenced by the ability of an animal to harvest and consume feed and by factors influencing the metabolism of nutrients that are consumed and absorbed (Bach et al. 2007, Holmes et al. 2002). When energy requirements are high and an animal's ability to harvest feeds is compromised body fat reserves are mobilised so that nutrients can be used for the maintenance of physiological homeostasis as well as the synthesis of milk (Bach et al. 2007, Roche, Friggens, Kay, Fisher, Stafford & Berry 2009). Lameness, the presence of painful lesions of the foot and leg that result in impaired mobility, compromises an animal's ability to harvest feed. This has important negative effects on production and involuntary culling rates (Green et al. 2002, Onyiro et al. 2008). Lameness can cause significant pain and suffering in affected animals (Whay 2002) which means that as well as having important economic consequences on herd profitability it also represents an important animal welfare issue. Impaired mobility that arises from lameness conditions of the foot and the response to successful treatment reflect the amount of pain and distress that lameness causes in affected animals (Laven & Holmes 2008).

Given the negative impact of lameness on herd profitability and animal welfare it is important that those involved in managing dairy cattle are able to identify affected animals as quickly as possible. Identification of affected animals sooner, rather than later, means that appropriate therapeutic interventions can be initiated early. This, in turn, reduces the likelihood that acute conditions of the foot progress to become chronic. A secondary benefit is that recovery times are likely to be shorter which means that animals are more quickly able to return to a productive state. Given the economic drivers of milk production in New Zealand have resulted in an increase in the national median herd size and a decrease in the number of labor units per cow (Anonymous 2010) it is likely that there has, and will continue to be, a decrease in the ability of individual herd managers to monitor stock intensively so as to detect lameness events early. Further, with increasing levels of automation on dairy farms the necessity for those working with dairy cattle to have high levels of animal husbandry skills is likely to decrease (Frost et al. 1997). un turn this is likely to have a negative impact on how quickly lame cows are detected and presented for treatment. Given these trends it is important that additional methods for identifying lame cows are investigated. Detection of decreases in daily milk yield presents one opportunity for early detection of lame cows (Green et al. 2002). An alternative is detection of liveweight (LW) change using walkover scales positioned at either the entry or exit to a milking parlor. Walkover scales allow the LW of individual animals to be recorded at least twice daily. Ongoing, real time analysis of LW records should allow animals with acute and severe decreases in LW to be identified, signally to a herd manager that these animals should be presented for examination.

Gröhn et al. (1999) used a repeated measures generalized linear mixed model to determine the effect of ketosis on milk production in 2,604 Holstein-Friesian dairy cows in 8 herds in New York, USA. This approach allowed short term average weight change before and after the date of diagnosis to be quantified. The objectives of this study was to use an approach similar to that of Gröhn et al. (1999) to determine the effect of observed lameness events on LW change (ΔLW) and to estimate the total LW loss associated with these events. By doing so we hope to provide a more quantitative estimate of lameness on animal welfare, and to provide a first attempt at how daily LW monitoring might be used as a tool for early detection of lameness.

7.2 Materials and methods

Study animals

This was an observational study of 828 lactations in 542 mixed aged and breed (Holstein-Friesian, Jersey, and Holstein-Friesian $\times$ Jersey) dairy cows that calved during the 2008 and 2009 seasons in a university owned, seasonally calving, pasture fed dairy herd in Palmerston North in the lower North Island of New Zealand (longitude 175°, latitude -40°). Cows grazed as a single group at pasture and had free access to water. The herd was managed so that the pasture allowance (14 – 16 kg DM.cow^{-1}.day^{-1}) and access to supplementation after the morning milking (palm kernel meal to a maximum of 2 kg DM.cow^{-1}.day^{-1} and maize silage to a maximum of 2 kg DM.cow^{-1}.day^{-1}) was sufficient for maintenance and production requirements of a 400 kg cow producing 2.0 kg milksolids.day^{-1}. The pasture was dominated by ryegrass (*Lolium perene*) throughout the year. White clover (*Trifolium repens*) contributed up to 20% of pasture dry matter. Cows were milked twice daily, starting at 0530 and 1500 hrs through a 50 bale rotary-platform milking parlour (DeLaval^{TM} Parallel Rotary, DeLaval International, Sweden).

Cows were identified using a radio frequency electronic identification system. This comprised low frequency (134.2 kHz), high performance, non-reusable half duplex ear tags (transponders complied with ISO 11784 and ISO 11785 standards) fitted to each cow and an antenna (Allflex^{TM} New Zealand Limited, Palmerston North, New Zealand). Walkover LWs were recorded for each cow from the time it joined the milking herd after calving. LWs for each cow were measured using an automatic walkover weighing system comprised of the electronic identification system and a calibrated electronic walkover scale system (WoW! XR-3000®, Tru-Test, Auckland, New Zealand).

Clinical lameness cases were identified and managed according to normal farm practice.

At the start of the study the farm manager received detailed instructions from the herd veterinarian to clarify issues around detection of lameness and preliminary treatment of identified cases. The farm manager then trained all staff members to ensure consistent identification and management of lame cows. The following protocol was applied: any cow which was observed by the farm staff as having a persistent gait abnormality was drafted for further investigation. If the diagnosis was footrot cows identified as lame on examination were then treated by farm staff, otherwise they were held for veterinary examination. All diagnoses other than footrot were made by the herd veterinarian. After treatment, which was antibiotics for cows with footrot, and trimming for cows with claw horn lesions (with analgesics or antibiotic treatment, if necessary), lame cows were placed on a once-daily milking regime and kept separate from the main herd in paddocks near to the milking parlor, until the farm staff considered that they had recovered when they were returned to the main milking herd.

Data management

Throughout the 2008 and 2009 milking seasons LW data were downloaded from the scale indicator to a portable personal computer twice weekly. Downloaded data included each cow's electronic identifier, the date and time of each weigh event, and the LW record (kg) as estimated by the scales. Data were transferred to a dairy herd management software package (DairyWIN v99.91.148; Massey University, Palmerston North, New Zealand) allowing LW data to be matched with each cow's biographical and lactation event details (e.g. calving date, insemination date(s), herd test details and treatment dates and details).

A series of data cleaning procedures were carried out before analysis. A lameness event identified within 14 days of a prior lameness diagnosis was considered to be the same event unless it occurred in another foot. The two LW records for each cow for each day were averaged to provide a single daily measurement. If one record was missing the remaining record was used as the LW for that day (see Chapter 3 for further details). In the remainder of this paper we use the term 'daily LW measurement' to refer to the averaged daily LW records. The daily LW measurements were then averaged to produce a single weekly LW measurement for each week in milk for each cow. The main reason for doing this was to minimise any possible variation in LW measurement that could arise from differences in gut fill, herd management and milk volume.

Statistical analyses

The dataset was comprised of 31,778 weekly LW records (occurring in 222,446 days in milk) and was arranged so that each weekly LW record was regarded as a single observation. Each observation comprised details of the cow's identity and the following: (1) weekly LW measurement; (2) parity; (3) breed; (4) LW at calving; (5) weekly LW relative to LW at calving (weekly LW minus LW at calving); (6) the presence or absence of a lameness event (occurring at least once in any day in the relevant week); (7) production season as a categorical variable with two levels (2008 and 2009); (8) calendar time as a categorical variable with three levels (June to September, October to December, and January to May).

The incidence risk of lameness was defined as the total number of cows experiencing at least one lameness event from 50 days after calving to the end of lactation, divided by the average number of cows (Dohoo et al. 2009, pp. 77 – 80) present in the herd throughout the same period. The incidence rate of lameness was defined as the total number of lameness diagnoses made from 50 days post calving to the end of lactation divided by the total number of cow-days at risk. Cow-days at risk for each member of the herd comprised the number of days from day 50 in milk to the date of dry off. For cows that died or were culled days at risk was the number of days from day 50 in milk (because there was interest in assessing LW change up to eight weeks before diagnosis, see later) to the date of culling or death. Cows that were identified as lame stopped contributing days at risk from the date the lameness event was diagnosed until 14 days after the last recorded treatment date. After that time they became re-eligible to contribute time at risk, as described above.

A mixed linear model that included a random intercept and slope term for each cow was used to estimate LW on any given week relative to the week of lameness taking into account the confounding effect of parity, breed, LW at calving, season and calendar time. Our interest was to estimate ΔLW for the weeks before and after an identified lameness event. The time frame of interest was the eight week period before and after an identified lameness event. We developed a derived variable of 18 levels termed LAMIDX: 8 levels for the 8 weeks prior to the week in which lamenes was diagnosed, 1 level for the week in which lameness was diagnosed, 8 levels for the 8 weeks after lameness was diagnosed and 1 level for all other weeks. This allowed us to estimate the difference in LW at a given LAMIDX level compared with a specified reference level after adjusting for parity, breed, LW at calving, season, calendar month and individual cow-level effects.

First, second and third order polynomials of weekly LW were used to represent the shape of the LW curve (Dohoo et al. 2009). Breed, parity, LW at calving, season and calendar time were entered into the model *a priori* as fixed effects. LAMIDX was then entered and a Wald test performed to determine the significance of the regression coefficients for each level of LAMIDX. The levels of LAMIDX were then revised to include only those levels that were significant at the alpha level of 0.05 as shown in Table 7.2. The structure of the model was as follows:

$$\begin{aligned} Y_{ijklmnop} &= \beta_0 + \beta_1 t_i + \beta_2 t_i^2 + \beta_3 t_i^3 + \text{parity}_j + \text{breed}_k + \text{LWcalv}_l \\ &+ \text{season}_m + \text{period}_n + \text{LAMIDX}_o + \alpha_{0p} + \alpha_{1p} t_i + \alpha_{2p} t_i^2 + \epsilon_{ijklmnop} \end{aligned} \tag{7.1}$$

In Equation 7.1 $Y_{ijklmnop}$ is the i^{th} relative weekly (t) LW measured on cow p, β_0 a regression coefficient for the intercept and β_1, β_2 and β_3 are regression coefficients for the third order polynomial terms to estimate weekly relative LW as a function of week in milk across all cows in the herd and LW at calving. The terms parity_j, breed_k, LWcalv_l, season_m, period_n and LAMIDX_o represent the fixed effects of parity, breed, LW at calving, season and LAMIDX on $Y_{ijklmnop}$, respectively. The terms α_{0p}, α_{1p} and α_{2p} are random intercept and slope terms (respectively) describing the deviation of cow p's relative weekly LW from that of the rest of the herd. $\epsilon_{ijklmnop}$ represents the random residual error. Residuals errors were assumed to follow a first-order autoregressive correlation pattern for relative weekly LW measurements within each cow (Diggle 2002). The order of the polynomial terms was based on models Akaike's Information Criterion (AIC). Raw and normalised residuals were evaluated graphically against predicted values to test the assumption of homogeneity of variance of the error terms. The mixed model was fitted using the restricted maximum likelihood (REML) procedure within the nlme package (Pinheiro et al. 2011) in R (R Development Core Team 2010).

7.3 Results

Data from 828 lactations from 542 cows were used in these analyses. Twenty-two cows were excluded due to incomplete production records (n = 8 were culled and n = 6 died within the first 50 days postpartum) or because they were observed lame in the first 50 days in milk (n = 8). Table 7.1 shows the total number of lameness cases detected and the total number of lameness lesions diagnosed in this herd over the two seasons. A total of 59 and 46 cases of lameness were detected in the 2008 and 2009 seasons, respectively. Over the two seasons the lactational incidence risk of lameness was 13 cases per 100 cows (105 of 828, 95% CI 10% to 15%).

The effect of lameness on LW is shown in Table 7.2. Negative values indicate weekly LW loss and positive values indicate weekly LW gain. Compared with the weeks where lameness was not observed, lame cows experienced LW loss up to three weeks before a diagnosis of lameness was made. Lame cows lost the most LW in the week when lameness was detected (12 kg, 95% CI 10 to 14; P $<$0.01) and for two weeks after (11 kg, 95% CI 9 to 13 kg; 10 kg, 95% CI 9 to 12 kg, respectively). The total amount of LW loss arising from a lameness event was estimated to be in the order of 61 kg (95% CI 47 to 74 kg).

Table 7.1: Incidence risk and incidence rate of lameness for the 2008 and 2009 milking seasons, stratified by lameness diagnosis.

Lameness diagnosis	Lame n	Cows at risk n	Cow-days at risk n	Incidence risk [a]	Incidence rate [b]
Footrot	33	828	199,346	3.9 (2.8 to 5.6)	0.02 (0.01 to 0.02)
White line disease	54	828	184,646	6.5 (4.9 to 8.4)	0.03 (0.02 to 0.04)
Bruising and other causes	18	828	209,846	2.2 (1.3 to 3.4)	0.01 (0.00 to 0.02)
Total	105	828	222,446	13.0 (11.0 to 15.0)	0.05 (0.04 to 0.06)

[a] Cases per 100 cows at risk.

[b] Cases per 100 cow-days at risk.

See Rothman 2002, pp. 130 – 143, for details on calculation of 95% CIs.

Table 7.2: Estimated regression coefficients and their standard errors from a mixed-effects linear regression model of factors influencing liveweight in dairy cattle.

Variable	Weeks n	Lame n	Coefficient (SE)	95% CI	P
Intercept			-21.23 (1.92)	-25.00 to -17.46	<0.01
Week in milk	31,778	105	-3.43 (0.12)	-3.67 to -3.20	<0.01
Week in milk^2			0.18 (0.01)	0.17 to 0.20	<0.01
Week in milk^3			-0.21 (0.01)	-0.23 to -0.19	<0.01
Parity:					
1	6,476	25	Reference	-	-
3 – 4	12,818	44	11.13 (1.66)	7.86 to 14.40	<0.01
5+	12,484	36	21.74 (2.04)	17.74 to 25.74	<0.01
Breed:					
Holstein-Friesian	19,331	65	Reference	-	-
Crossbred	12,447	40	-6.16 (1.35)	-8.82 to -3.51	<0.01
LW at calving	31,778	105	-0.13 (0.01)	-0.16 to -0.11	<0.01
Production season:					
2008	16,604	63	Reference	-	-
2009	15,174	42	9.83 (1.21)	7.46 to 12.21	<0.01
Calendar time:					
June - September	5,547	8	Reference	-	-
October – December	15,688	60	4.78 (0.42)	3.96 to 5.59	<0.01
January – May	10,543	37	0.60 (0.55)	-0.47 to 1.68	0.27
LAMIDX:					
-4 weeks	31,778	104	Reference	-	-
-3 weeks	31,778	103	-2.07 (0.96)	-3.42 to -0.72	0.04
-2 weeks	31,778	98	-6.06 (1.19)	-7.73 to -4.39	<0.01
-1 week	31,778	100	-9.78 (1.29)	-11.59 to -7.99	<0.01
Week of detection	31,778	88	-11.87 (1.31)	-13.71 to -10.03	<0.01
+1 week	31,778	99	-10.99 (1.33)	-12.85 to -9.13	<0.01
+2 weeks	31,778	89	-10.49 (1.32)	-12.35 to -8.65	<0.01
+3 weeks	31,778	100	-6.42 (1.22)	-8.13 to -4.71	<0.01
+4 weeks	31,778	104	-3.19 (1.04)	-4.64 to -1.74	0.02
Random effects:					
Intercept (SD)			16.74	15.85 to 17.68	
Week in milk (SD)			2.18	2.07 to 2.31	
Week in milk^2 (SD)			5.68	5.36 to 6.02	

Key: SE standard error; CI confidence interval; SD standard deviation.

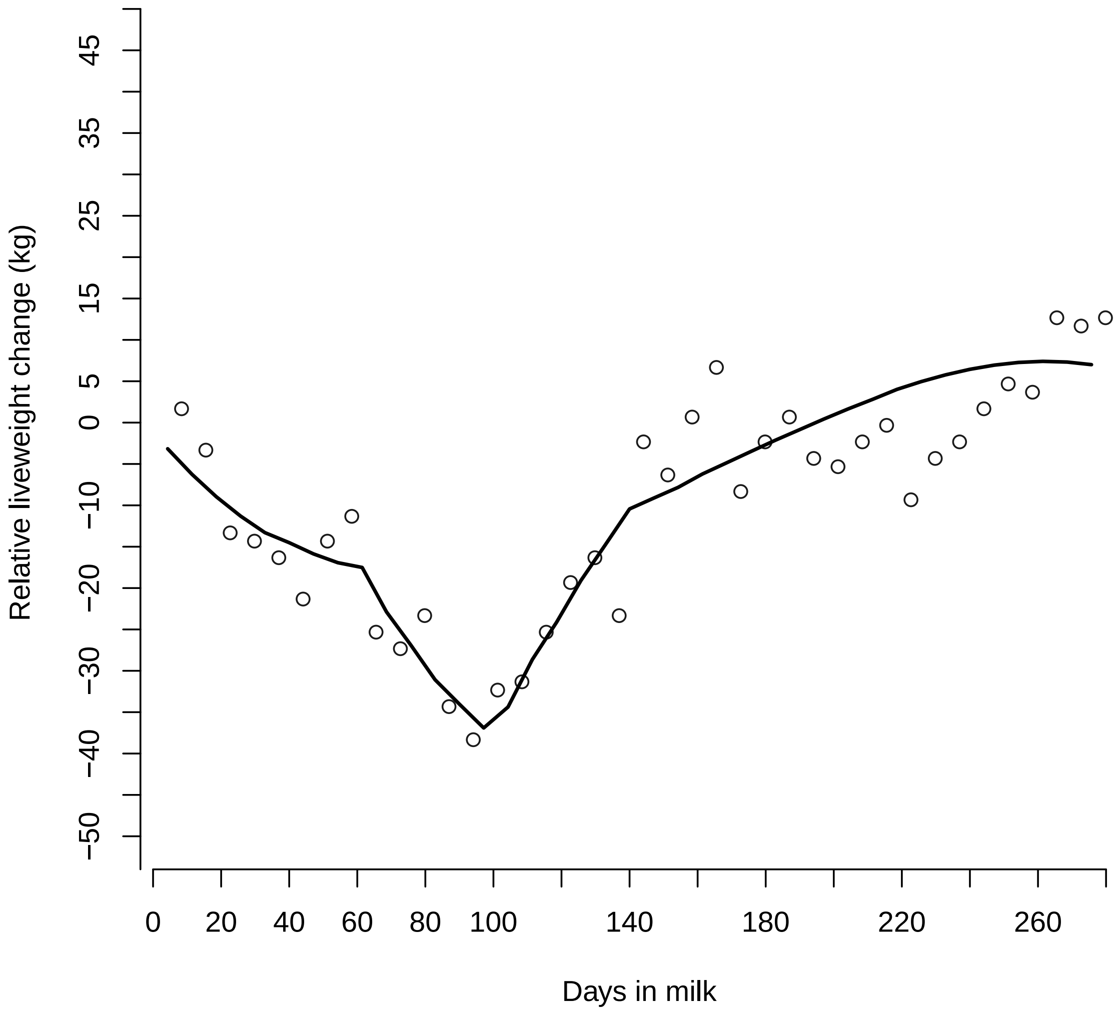

Figure 7.1: Scatter plot showing relative daily liveweights change recorded for a cow diagnosed with lameness at 100 days in milk (○). Superimposed is a line plot showing the estimated relative daily liveweight change from the random slopes and random intercepts model shown in Table 7.2.

7.4 Discussion

Lameness is an important economic and animal welfare problem in pasture fed dairy herds. Although some studies have investigated and quantified the impact of lameness on production loss, the impact on animal welfare is difficult to quantify. In this study, we investigated the effect of an observed lameness event using automatically recorded daily LW data collected in the 2008 – 2009 milking seasons. Our objective was to estimate the effect of observed lameness events on weekly LW change and to estimate the total amount of LW loss associated with these events. Our motivation for this was to provide a more quantitative estimate of lameness on productivity and animal wellbeing.

We identified LW loss up to three weeks before a cow was detected as clinically lame by farm staff and presented for treatment (Table 7.2, Figure 7.1). The total amount of LW loss arising from a single lameness event after adjusting for the confounding effects of weeks in milk, parity, breed, LW at calving, calendar time, and season was estimated to be 61 kg (95% CI 47 to 74 kg). It is logical to assume that discomfort in a cow's leg or foot (depending on the severity of the causative lesion) will alter a cow's mobility, negatively impacting on the ability to harvest forage (Bach et al. 2007, Maltz et al. 1997). Detecting lame cows is a challenging task for those managing dairy herds primarily due to a cow's natural instinct to mask any signs of pain or discomfort (O'Callaghan et al. 2003). In some cases lame cows continue to produce milk and breed, even in the absence of therapy (O'Callaghan et al. 2003). Better strategies need to be applied to detect lame cows early so that effective treatment can be initiated. Early diagnosis and appropriate treatment improves animal welfare, shortens recovery times, and reduces economic loss.

The increased LW loss before a diagnosis of lameness could have been confounded by health events that occurred earlier in the lactation. For example, cows could have suffered an episode of a metabolic disorder such as ketosis or milk fever and LW loss is a common sequelae to metabolic disorders (Green et al. 2002). In this case, LW loss before a lameness event was diagnosed was caused by a separate insult, not by the later occurring lameness event. An alternative explanation is that cows were subclinically lame or simply left undiagnosed (Whay 2002) until their lesion become obvious to farm staff later in lactation (Collick et al. 1989, Green et al. 2002, Leach et al. 1997).

The overall incidence risk of lameness for the two seasons over which this study was carried out was 13 (95% CI 11 to 15) cases per 100 cows at risk (Table 7.1). In a study carried out in the same area Laven et al. (2008) evaluated lameness data from 2,800 dairy cows from 9 herds in the 2007 – 2008 milking seasons. In that study the incidence risk was 17 (95% CI 13 to 19) cases per 100 cows at risk. Tranter & Morris (1991) monitored 831 cows from 3 herds in the same region between August 1989 and July 1990. In their study, the incidence risk of lameness was 16 (95% CI 14 to 18) cases per 100 cows at risk. The results of our study and the studies of Laven et al. (2008) and Tranter & Morris (1991) indicate that the incidence of lameness in this area of New Zealand has changed little over the past 18 years. This can be attributed to consistent farming practice and a reasonably consistent level of surveillance to detect lameness cases by herd managers that participated in each of the three studies.

The most common cause of lameness in this study was white line disease (52% of all lame cows, 54 of 105), followed by footrot (31%, 33 of 105) and bruising (17%, 18 of 105). Chesterton et al. (2008) evaluated lameness lesions from 4,488 dairy cows presented for veterinary examination in the Taranaki region from 1995 to 2007. In that period white line disease was the most frequently reported lesion (42%) followed by sole injury and bruising (29%). Tranter & Morris (1991) reported similar findings. Although there is agreement in the reported incidence of lameness and partial disagreement in the lameness lesions reported between our study and the cited literature, these findings should be interpreted carefully because of an inherent level of misclassification bias that occurs because the design of our study relied on a herd manager's ability to assign a diagnosis to each identified lame cow.

In our study selection bias may also have occurred due to differences in the diagnostic capability of individual farm staff. In the studies of Tranter & Morris (1991), Laven et al. (2008) and Chesterton et al. (2008) herd managers readily agreeing to take part in the respective studies may have been a form of selection bias. Tranter & Morris (1991), Laven et al. (2008) and Chesterton et al. (2008) may have also introduced surveillance bias. The herds used in these studies were those under the authors' veterinary care and all cows observed lame (or suspected lame) were subject to veterinary examination for assessment and lesion diagnosis. Bias may have been introduced due to the higher than average veterinary encounters in the participating herds resulting in improved disease surveillance. However, Laven et al. (2008) and Tranter & Morris (1991) studies were descriptive and the authors didn't directly examine the association between exposure variables and lameness. Nevertheless, if a measure of association was reported in those studies it would have been biased away from the null therefore strengthening the association between the exposure variable and lameness. Lack of denominator data in Chesterton et al. (2008) makes it difficult compare the overall incidence of lameness with other studies.

One of the limitations of this study was that we did not distinguish between the type of foot lesion causing each lameness event. This was because the relatively small number of cases made it difficult to conduct a valid subgroups comparison. Also, lameness detection was carried out by a number of farm staff over the course of the study. Variation in the diagnostic capability of different farm staff represented a form of misclassification bias, presumed to be non-differential. Overcoming this problem in future studies would be difficult. One approach might be to have farm staff take a digital photograph of each foot they examine (using, for example, a mobile phone) and then to have these photographs reviewed by an experienced veterinarian. Furthermore, the results presented here are only applicable to the study herd and are not likely to be generalisable to all herds. It is expected that different management practices and farm geographical location and topography would influence the incidence and quantity of LW loss. However, the general principle, that lame cows do lose a significant amount of LW and do so before and after they are diagnosed as lame is likely to be true in all pasture fed dairy herds.

Difficulty in detecting lameness in individual animals in large herds (Chapinal et al. 2010) has led to increasing interest in alternative detection methods. Some of these focus on monitoring gait (Flower & Weary 2006, Flower et al. 2006) or movement (Pastell et al. 2009) using image analysis techniques and accelerometers, respectively. Other studies focus on monitoring behaviour such as the frequency and duration of resting (Ito et al. 2010) or feeding (Gonzalez et al. 2008). A profitable area of future research might be to evaluate the sensitivity and specificity lameness detection using the one or more of these tools in combination with LW analyses similar to those described in this paper.

7.5 Conclusions

Observed lameness events were associated with a sharp decline in LW originating three weeks before the week of lameness detection and the total amount of LW loss arising from a single lameness event was estimated to be 61 kg (95% CI 47 to 74 kg). We propose that ongoing monitoring of LW in dairy herds could be a useful tool to assist herd managers to detect lame cows. Real time analysis of LW records should allow animals with acute and severe decreases in LW to be identified, signaling to a herd manager that these animals should be presented for examination. Identification of lame cows sooner, rather than later, means that appropriate therapy can be initiated more rapidly. Shorter recovery times will have positive effects in terms of animal welfare.

CHAPTER 8

General discussion

8.1 Overview

Advances in dairy systems technology now make routine LW recording of dairy cows an animal- and operator-friendly management task. As the size of dairy herds increase, the ability to study irregularities in LW change and its impact on herd- and individual cow-level performance provides a useful addition to the list of management tools available to the herd manager. The research component of this thesis comprised collection and analysis of LW records from a standalone WoW system in a seasonally calving, pasture fed dairy herd. This provided the opportunity to address several issues that could potentially represent an obstacle to more widespread uptake of WoW technology. These issues fall into two major categories. The first relates to issues around data quality, that is, how confident the herd manager can be in the LW data captured by WoW systems. The second relates to identifying ways LW data can be used to improve herd management.

The first category of issues was addressed in Chapter 3. In Chapter 3 we developed a methodology for dealing with 'unusual' LW records and quantified the agreement between cow LWs measured using the walkover system and those measured statically. The second category of issues was addressed in Chapters 4, 5, 6 and 7. The underlying goal of these chapters was to demonstrate how LW measurements can be used to assist herd management. For example, the continuous monitoring of LW allowed us to quantify the association between LW change and reproductive performance (Chapter 6), the onset of oestrus (Chapter 5), and lameness (Chapters 4 and 7).

In the planning stage of this project it was intended for the WoW system to be fully integrated with the herd's milking parlour (DeLaval Parallel Rotary PR3100HD, DeLaval International, Sweden) and existing electronic identity system (EID). A trial was conducted over several days at the start of the study to measure performance of the DeLaval EID system (see Appendix A for details). Results from this trial identified an unacceptable EID read and misallocation error. These findings redirected the course of the research. After several attempts to rectify the problem with the DeLaval reader the system was eventually abandoned and the Allflex EID system used to associate cow identifiers with LW measurements for the duration of the project. While this meant that we had confidence relating LW measurements to heat, service and health events recorded throughout the lactation we were unable to make associations between daily milk yield data (recorded by the DeLaval system) and daily LWs. Those conducting this type of research in future would be advised to assess the read and misallocation error in existing EID systems before starting observational or intervention studies of the type presented in this thesis.

A novel feature of the work presented in Chapter 3 was that we classified unusual LW records into one of two types: those that were biologically implausible and those that were potentially erroneous. Also in Chapter 3 we demonstrated a high level of agreement between WoW and those LWs measured statically using the same set of scales and clarified the use of daily versus weekly LW measurements. Under controlled conditions, WoWs showed a near perfect association with LWs that were measured statically (Figure 3.3; r^2 = 0.99). The 95% limits of agreement show that LWs measured using WoW may be 4.2 kg above or 8.8 kg below those recorded statically. Under routine operating conditions, approximately 10% of WoW records were detected as outliers (i.e. biologically implausible or potentially erroneous). LWs measured using the WoW system on a given day were independent (unlikely to be correlated) with LW measurements taken seven or more days apart. Although there is little published literature addressing these issues, this information should be of great practical use, providing system users with guidelines around how frequently individual weigh events should occur.

In Chapter 3 uneven cow flow over the weigh platform was cited as a likely reason for the detected outliers. Slow cow flow led to congestion in the exit race of the milking parlour and an increased likelihood of more than one cow being on the scale platform at a time, resulting in overestimation of LW for the leading cow. Variation in individual daily LWs could be a consequence of a range of factors including individual animal eating behaviour, the quantity and quality of available forages, water availability and the distance cows have to travel to and from paddocks for grazing (Gonzalez et al. 2008, Maltz et al. 1997). This variation not only influences the relatedness of successive LW measurements using the WoW system, but also influences WoW potential application at both the herd and individual animal level (Chapter 3).

The effect of excessive LW loss and milk yield in the immediate postpartum period on the risk of lameness was investigated in Chapter 4. The effect of LW loss and milk yield in the immediate postpartum period on subsequent lameness risk was relatively small. We estimated a reduction in the lactation (>50 DIM) incidence risk of lameness in the order of 4 (95% CI 2% to 10%) cases per 100 cows if LW loss in the immediate postpartum period was prevented.

A common objective in many epidemiological studies is to determine whether an exposure, or risk factor, is causally related to the development or progression of a given disease (Dohoo et al. 2009). It was of interest to investigate if there was an association between LW loss in the first 50 days in milk (termed the early postpartum period), milk yield and the risk of lameness after 50 days in milk. To address this question, the presence of interaction between the two exposure variables was considered. Interaction occurs when two exposure variables act together in a way that deviates from additivity (Rothman & Greenland 1998). Our analyses showed that the risk of lameness was greatest for high producing cows that lost excessive LW in the early postpartum period (RR 4.4, 95% CI 4.2 to 8.2, $P < 0.01$) and that the combined effect of milk yield and LW change was beyond that expected if the two effects were additive. More research is required to first define and then evaluate the implication of 'excessive' LW loss and milk yield on an animal's risk of lameness.

Reproductive performance of dairy cattle worldwide is declining (Gouttenoire et al. 2010). Factors such as increased milk production (Ingvartsen et al. 2003), herd size and inadequate oestrus detection are often cited as causal factors (McDougall 2006). Most dairy herd managers have adopted technologies such as artificial insemination to achieve genetic gains in production efficiency in order to maintain a competitive agricultural business. As a result, detection of oestrus has become an important task on modern dairy farms, as erroneous inseminations reduce profit due to insemination costs, extended calving intervals, milk loss and increased veterinary costs (de Vries & Conlin 2003, McDougall 2006). In Chapter 5 we showed that, in cows that conceived, negative daily LW change began one day before the observed onset of oestrus, reaching the lowest level on the day of oestrus (-9.6 kg, 95% CI -11.3 to -7.8 kg; $P < 0.01$). In non-conceiving cows the negative daily LW change peaked on the day before oestrus detection (-4.3 kg, 95% CI -7.7 to -0.85 kg; $P = 0.02$) (Chapter 5). While the results from this study are applicable to this herd only, our findings raise an interesting issue around the relative importance of inappropriate timing of insemination as a cause of insemination failure (Dransfield et al. 1998, Saacke et al. 2000). This study also showed that the combined use of daily LW change with commercially available oestrus detection tools could improve oestrus detection sensitivity. The predicted sensitivity and specificity of combined use of LW change and visual observation of tail paint as a heat detection method was 0.86 and 0.94, respectively. This means that in a herd of 400 cows over a mating period of 42 days, an additional 67 cows in oestrus (17% of the herd) will successfully be identified and submitted to AI.

In Chapter 6 it was concluded that LW change in the first four weeks postpartum and LW change around the time of the Planned Start of Mating are associated with reproductive failure in this seasonally calving, pasture fed dairy herd. The effect of 1% LW gain in the four weeks after calving (termed long-term LW change) was estimated to shorten PSM to conception intervals by 2% (time ratio [TR] 0.98, 95% CI 0.96 to 1.00; $P = 0.08$). PSM to conception interval for cows that either maintained or gained LW relative to LW at PSM (termed short-term LW change) was estimated to be 74% of that of cows that lost LW in the same period (TR 0.74, 95% CI 0.48 to 1.00; $P = 0.05$). The findings of this study are consistent with those that have been reported in the literature and better define the impact of long- and short-term liveweight change on reproductive performance, providing the opportunity to design feeding programmes in pasture fed dairy herds that have positive effects on fertility.

Lameness in dairy cows is a painful condition (Laven et al. 2008) that decreases productivity and is a major welfare problem of dairy cows (Fraser et al. 1997). In Chapter 7 we found that after controlling for the effect of weeks in milk, parity, breed, calendar month and season, the LW of clinically lame cows was reduced up to three weeks before the date of diagnosis and treatment and continued for up to four weeks after the date of first treatment. The total LW loss arising from a single lameness event was estimated to be in the order of 61 kg (95% CI 47 to 74 kg). This reflects the degree of discomfort negatively impacting on a cow's mobility and its ability to harvest food.

One of the limitations of this study was that we did not distinguish between the type of foot lesion causing each lameness event. This was because the relatively small number of cases made it difficult to conduct a valid subgroups comparison. Also, lameness detection was carried out by a number of farm staff over the course of the study. Variation in the diagnostic capability of different farm staff represented a form of misclassification bias, presumed to be non-differential. Overcoming this problem in future studies would be difficult. One approach might be to have farm staff take a digital photograph of each foot they examine (using, for example, a mobile phone) and then to have these photographs reviewed by an experienced veterinarian.

Difficulty in detecting lameness in individual animals in large herds (Chapinal et al. 2010) has led to increasing interest in alternative methods. Some of these focus on monitoring a cow's gait (Flower & Weary 2006) or movement (Pastell et al. 2009) using image analysis techniques and accelerometers, respectively. Other studies focus on monitoring behaviour such as the frequency and duration of resting (Ito et al. 2010) or feeding (Gonzalez et al. 2008). A profitable area of future research might be to evaluate the sensitivity and specificity lameness detection using the one or more of these tools in combination with LW analyses similar to those described in this chapter.

Measurement of ΔLW is an objective approach that lends itself well to assessment of the economic impact of changes to a herd's feeding programme, health, reproductive performance on profitability. For example, basic partial budget model calculations could be used to estimate the net cost and benefits of preventing, reducing or monitoring LW loss throughout a lactation. The main input variables for a partical budget model could be firstly, those related to feed supplementation for the proportion of cows in the herd experiencing excessive LW loss or feed supplementation required to maintain LW. Secondly, those variables related to marginal response in milk yield elicited by feed supplementation offered (see Holmes et al. 2002, page 305 for more details). Thirdly, those related to the impact of earlier conception resulting from improved calving performance on DIM in the subsequent lactations (McDougall 2006). Furthermore, improved reproductive performance in seasonally calving herds would also influence the distribution of calvings for the next lactation and would have a carryover effect in subsequent milking seasons (Morton 2004). In a partial budgeting model, economic effects are calculated as total revenues weighed against total costs. For example, monitoring LW change to optimise animal health and productivity (as compared with a ‘do nothing’ approach) is profitable when the total revenues of monitoring LW change are greater than the total costs. Total revenues are calculated as extra revenue plus reduced costs. It is envisaged that monitoring LW change would result in a net positive economic effect per cow over a lactation. Further research is required to demonstrate the potential benefits of monitoring ΔLW on herd profitability.

8.2 Implication of thesis findings and future work

Over the last 30 years computer technologies have led to substantial improvements in the quantity and quality of information recorded on individual dairy farms. To date these developments have not yet delivered comprehensive systems that will allow the whole herd system to be monitored and managed. The research described in this thesis represents a contribution to this overall objective. An attractive feature of the WoW system deployed in this series of studies was that it was completely integrated into daily farming routine. The novelty of this work is that we demonstrate how data can be turned into knowledge, further improving the objectivity of herd decision making.

Furthermore, it is possible for analytical methodologies described in this thesis to be extended to other areas of the dairy farming operation where information is captured on a daily or short-term basis. In seasonally calving herds both LW and milk production show a characteristic temporal pattern, so too do bulk milk somatic cell counts (Radostits 2001). It is proposed that the methods applied in this thesis could be adapted to detect deviations in milk yield in response to disease events (in the same way that we quantified the effect of lameness on LW in Chapter 7). This would allow one to quantify the direct losses from lameness (arising from lost milk production), providing a more objective basis for decision making concerning the amount of money to spend on lameness prevention strategies.

A further application might be the implementation of a syndromic surveillance-type system that interrogates on-farm veterinary product usage. The required data for such a system resides in the accounting software used in veterinary practices. The use of these accounting software could be maximised by extracting relevant information (transaction date, product sold and quantities) and subjecting them to time series analyses similar to those described in this thesis. For example, estimating the number of mastitis cases for a given herd in a given period of time from the product sold to that herd manager can be achieved by tracking the sales of intramammary tubes or other antibiotics used specifically on mastitic cows. Once an 'unusual' trend in mastitis treatments was observed, it might prompt veterinary investigation (or follow-up) to prevent or at least contain a mastitis problem.

The method presented for outlier detection in Chapter 3 requires further development. In practice this method should be able to be used in real time, that is the process should use LW records accumulated for a given cow up to a given day in milk. The current outlier detection approach runs retrospectively, that is, LW records before and after a given day in milk are used to identify biologically implausible and potentially erroneous values. Modification of the algorithm to handle the detection of outliers in real time would be useful. In this way outliers could be detected and removed as soon as they were recorded on the scale indicator.

The approach used to identify outlier LW records was distance based and relied on estimation of the standard deviation of each cow's LW records for the interval DIM_1 to DIM_{100}. The challenge here is to reliably estimate the standard deviation of LWs recorded during the early lactation, say the first two weeks postpartum (see Chapter 3). One option would be to use records from the previous lactation for individual multiparous cows. For primipara an age-specific SD could be used. Another option would be to use age-specific means and SDs for the entire herd if historic LW data were unavailable. Once the SD for each cow was defined, screening LW records for outliers could then be conducted using the method described in Chapter 3.

The influence of exercise (specifically, the distance walked each day) on gut fill and its contribution to the variation in daily LW estimates requires clarification. Gut fill can be estimated by measuring the circumference of a cow's abdomen and comparing it with daily LW measurements. The working hypothesis would be that increases in daily walking distance decreases gut fill resulting in LW estimates being a closer approximation of bodyweight. The implications of such a study would be that it would allow LW estimates to be adjusted to account for the effect of walking distance. This is an important factor to consider if LW is to be used as a tool for oestrus detection. Also, further work is required to investigate the role of cow strain on daily LW and daily liveweight change.

In large dairy herds the identification of lame cows can be a challenging task but the advantage of using repeated measurements is that algorithms can be developed to scan to an individual cow's LW data to detect deviations from what is 'normal' for that individual. This should allow physiological disorders (including lameness) to be more promptly detected. In the case of lameness, earlier detection means that treatment can be instituted quicker, increasing the likelihood of therapeutic success. Statistical process control charts are commonly used to detect significant or systematic variation in a given process around its mean (in this example a cow's LW) and differentiate that change from normal random variations around the process mean (de Vries & Reneau 2010). The sensitivity of statistical process control charts can be adjusted to detect subtle short-term changes or long-term changes in process trends. A profitable area of future research would be to quantify LW change arising from specific lameness lesions, for example sole ulcer (Amory et al. 2008, Green et al. 2002), white line disease (Bicalho et al. 2007, Green et al. 2002) and solar bruising. We speculate that this information is useful in terms of providing herd managers and their veterinarians with an indication of how aggressively specific lesions should be treated once they have been first diagnosed. In addition, greater clarity around the economic effect of lameness on herd profitability would provide a more objective basis to justify additional labour inputs to support surveillance and early detection of problem cows.

This thesis has identified periods throughout the lactation where LW and LW change influences health and reproductive performance. While 'traditional' usage of walkover scales on dairy farms has involved the recording of LW and LW change as a means for monitoring and adapting changes to the herd feeding program, the studies presented here have shown how LW records have the potential to provide information that can be used to better manage a range of herd level activities, particularly those related to reproductive management and health.

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APPENDIX **A**

Assessment of the DeLaval electronic identification system at Massey University Dairy 4 Unit

Abstract – Electronic animal identification (EID) is an important component of intensive livestock management systems. Massey University Dairy 4 unit (MUD4) has a DeLaval rotary milking parlour, with an integrated EID system. The objective of this study was to assess the accuracy of the DeLaval EID system performance in use at MUD4. The study population comprised those animals in milk on the day of the evaluation (n = 348). Data were collected during the morning and afternoon milking sessions. The identity of each cow was determined by reading each cow's ear tag as she entered the milking parlour. The sequence of manually-read cow identifiers was then compared with the recorded milking event history generated by the DeLaval system. A total 1641 observations were recorded and used in the analysis; 109 observations were omitted from cows on once a day milking and cows without EID collars.

Cows were successfully identified by the DeLaval EID system as cows walked through the entrance readers. As cows positioned themselves in the stalls 464 of 1177 read events (28%) were incorrect. There were 130 events in total (28%) where manually recorded error data and DeLaval's error self recognition data agreed, compared with 334 events (72%) where there was disagreement.

We conclude that there is an unacceptable level of error in the DeLaval EID system in its current configuration at MUD4, rendering it unsuitable as a means for identifying animals in our proposed program of research.

A.1 Introduction

Electronic animal identification (EID) is an important component of intensive livestock management systems. The objectives of an EID system can be shortlisted into three main categories comprising animal health and disease management, reproductive management, and genetic improvement. New Zealand dairy producers have access to a variety of EID systems adopting different technologies. DeLaval is one of the leading global agricultural companies that provide integrated EID solutions for dairy farmers. Massey University Dairy 4 unit has a DeLaval rotary milking parlour, with an integrated EID system. The objective of this study was to assess the accuracy of the DeLaval EID system performance currently in use at MUD4.

A.2 Materials and methods

This project was performed at MUD4 from Friday 7^{th} March to Sunday 9^{th} March 2008. The study population comprised those animals in milk on the day of the evaluation (n = 348). Data were collected during the afternoon (14:25 to 16:00, n = 3), and morning (06:00 to 08:00; n = 2) milking sessions.

The identity of each cow was determined by reading each cow's ear tag as she entered the milking parlour. The observer was positioned approximately 8 stalls from the entrance stall to avoid interruption of cow flow onto the milking platform. Data recorded for each animal included cow (ear) tag number, cow EID as displayed by DeLaval system, and matching stall EID and cow ID. The sequence of manually-read cow identifiers was then compared with the recorded milking event history generated by the DeLaval system.

Two tables were generated. Table A.1 shows the numbers of cows correctly and incorrectly identified at each milking session. A correct stall reading event occurred when the cow ear tag number matched the displayed cow EID. An incorrect stall reading event occurred when the observed cow ear tag number did not match the displayed EID. The DeLaval milking log files were compared with the manually collected data (Table A.2). The DeLaval system detects incorrect cow EID to stall placement errors, and deletes the milking event details (milk yield, stall position, milking time, etc) for that animal. This process is referred to as error self recognition.

In Table A.2 two terms are used:

1. Cow to stall placement error agreement: when manually collected data observed an error in cow (X) displayed EID and stall (YX) placement, and that coincided with error self recognition by DeLaval's milking log file, and

Table A.1: Numbers and proportions of cows correctly and incorrectly identified in their stalls by the DeLaval electronic identification system in use at Massey University Dairy 4 unit.

Date and time	Stall placement after electronic identification		Total (%)
	Correct stall (%)	Incorrect stall (%)	
7 March 2008 pm	220 (70%)	96 (30%)	316 (100%)
8 March 2008 am	257 (74%)	92 (26%)	349 (100%)
8 March 2008 pm	228 (73%)	86 (27%)	314 (100%)
9 March 2008 am	251 (72%)	98 (28%)	349 (100%)
9 March 2008 pm	221 (71%)	92 (29%)	313 (100%)
Total	1,177 (72%)	464 (28%)	1,641 (100%)

2. Cow to stall placement error disagreed: when manually collected data observed an error in cow (X) displayed EID and stall (YX) placement, and no error self recognition by DeLaval's milking log file occurred.

A.3 Results and discussion

All cows were successfully identified by the DeLaval EID system as cows walked through the entrance readers, but discrepancies were found between the stall displayed EID number, and the actual cow identity number for that stall. Tables A.1 and A.2 refer to cow stall placement relevant to correct or incorrect EID number displayed on the stall unit and not initial EID as cows walk into the milking shed.

Throughout the study a total 1641 observations were recorded and used in the analysis. One hundred and nine entries were omitted from the analysis, 99 entry from cows on once a day milking management, and 10 entries from cows without EID collars.

Table A.1 shows that over the five milking sessions a total of 1177 of 1641 (72%) cows were correctly identified in their stalls. Table A.2 shows that there were 130 events (28%) where manually recorded error data and DeLaval's error self recognition data agreed, compared with 334 events (72%) where there was disagreement.

We conclude that there is an unacceptable level of error in the DeLaval EID system in its current configuration at MUD4, rendering it unsuitable as a means for identifying animals in our proposed program of research.

Table A.2: Numbers and proportions of cows where there was agreement and disagreement in cow stall placement after error self recognition by the DeLaval electronic identification system in use at Massey University Dairy 4 unit.

Date and time	Cow to stall placement error agreement		Total (%)
	Agreement (%)	Disagreement (%)	
7 March 2008 pm	25 (26%)	71 (74%)	96 (100%)
8 March 2008 am	36 (39%)	56 (61%)	92 (100%)
8 March 2008 pm	31 (36%)	55 (64%)	86 (100%)
9 March 2008 am	26 (27%)	72 (73%)	98 (100%)
9 March 2008 pm	12 (13%)	80 (87%)	92 (100%)
Total	130 (28%)	334 (72%)	464 (100%)