# Milk Production and Survival of Spring-calving Carryover Cows in New Zealand Dairy Herds

A thesis presented in partial fulfilment of the

requirements for the degree of

**Master of Science**

**in**

**Animal Science**

**at Massey University, Manawatu, New Zealand**

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**2017**

# Abstract

Non-pregnant cows are generally culled from dairy herds and replaced with two-year-old heifers. Alternatively, non-pregnant cows can be dried-off at the end of lactation, retained for one year (carried over), before being mated and returned to a milking herd in the following year. In this study, calving interval was used as a tool to identify and define the carryover cow population in spring-calving dairy herds. Linear modelling methods were used to compare carryover cow milk production with that of heifers, lactation-matched and age-matched non-carryover cows. Lastly, the survival for second-lactation carryover cows was compared with that of two-year-old heifers and lactation-matched non-carryover cows. Results showed that annually, 2.5% of spring-calving cows had returned to a milking herd after a carryover period in the previous year. Of those carryover cows, 43% returned to a milking herd at four years old, after failing to conceive in their first lactation. Most (69%) dairy herds contained less than 5% carryover cows and 17% of dairy herds comprised of zero carryover cows. The difference between the proportion of Holstein-Friesian in the carryover cow and non-carryover cow group was minimal (2%) but statistically greater ($P<0.01$) for the carryover cow group. Estimated breeding values (EBVs) for milk traits (milk yield, fat yield, protein yield and somatic cell count) were greater ($P<0.01$), but fertility EBVs were lower ($P<0.01$) for the carryover cow group in the year when they failed to conceive, compared to those for the non-carryover cow group. These were reflected in greater ($P<0.01$) selection indices (Breeding Worth and Production Worth) for carryover cows. After the carryover period, EBVs for milk traits and fertility decreased, and Breeding Worth was lower ($P<0.01$) for the carryover cow group, compared to the non-carryover cow group. Carryover cow milk yield, fat yield, protein yield and somatic cell score was greater ($P<0.01$) than those for heifers, lactation-matched and age-matched non-carryover cows in their first carryover year. This milk production advantage was maintained for up to three carryover years, if the carryover cow maintained an annual calving pattern, but at a decreasing rate. The probability of survival (days) was lower ($P<0.01$) for second-lactation carryover cows when compared to heifers and lactation-matched non-carryover cows. These findings are important for

the New Zealand dairy industry as they can aid on-farm culling (removal from the herd) decisions.

## Acknowledgements

I would firstly like to thank Lorna McNaughton for developing the original carryover cow topic idea. The three months spent working on this topic as a summer internship student at Livestock Improvement Corporation (LIC) gave me a head start on my Masters. Over that summer period you warmly welcomed me as a part of the research and development group at LIC. The connections and friendships made during this time are invaluable. Your continued support, topic development ideas and feedback throughout my Master's degree is greatly appreciated.

To my Massey supervisors, Penny Back and Nicolas Lopez-Villalobos, I am very thankful for the time you have spent supporting me and refining my project. Penny, you always provided an interesting off-topic story, followed by some superb suggestions in red pen to improve my thesis. Nicolas, I appreciate the time you spent teaching me how to use SAS, how to manage large datasets, and that linear modelling is not as scary as it looks. I am sure that the data analysis and writing skills you have both taught me will be beneficial for my future career.

Katie Eketone, I am grateful for your patience during the numerous hours spent communicating between Lorna and myself, and for completing the data extraction process. The project would have not been possible without your help.

Financial assistance from LIC's Patrick Shannon scholarship, Massey University, Helen E Akers Postgraduate scholarship and C Alma Baker Trust is greatly appreciated. The study would not have been possible without this financial support.

To my friends and flatmates, thank you for always making time to support me, while having a blast throughout our time in Palmy. To my gypsy parents, you provided great holiday locations on the yacht and always reassured me that I can reach my goals I have set. And lastly, Hamish, thank you for providing continual support, for being a great weekend adventure buddy and for your acceptance of my strict 8am start time (it's just about to get a whole lot earlier!). I look forward to the new adventures and challenges upon us.

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# List of Abbreviations

BCS = Body condition score

BW = Breeding Worth

CIDR = Controlled internal drug release

CO = Carryover

EBV = Estimated Breeding Value

FY = Fat yield

LIC = Livestock Improvement Corporation

LW = Lactation Worth

MY = Milk yield

NCO = Non-carryover

NZAEL = New Zealand Animal Evaluation Limited

PW = Production Worth

PY = Protein yield

SAS = Statistical Analysis System

SCC = Somatic cell count

SCS = Somatic cell score

# Chapter 1 General Introduction

## 1.1 Introduction

The majority (95%) of New Zealand milk is produced from spring-calving, pasture-based dairy systems (Blackwell *et al.*, 2010). To maximise pasture utilisation and minimise the requirement for imported feed sources, calving interval, which is the number of days between consecutive parturition dates, should remain close to 365 days (Macmillan and Moller, 1977). Maintaining annual, spring parturition dates ensures that the increased pasture growth rates during the spring, are matched to the increased animal energy requirements during early lactation (Blackwell *et al.*, 2010; Holmes *et al.*, 2002).

The gestation length of a cow is approximately 282 days, which leaves a maximum of 83 days for the cow to resume ovarian cycling, be mated and conceive (Blackwell *et al.*, 2010). During this 83 days, a cow experiences a period of anoestrus (absence of ovarian cycling), which can be up to 50 days, depending on factors such as cow breed, age and nutritional status (McDougall, 1994). Genetic selection for milk traits, which have been shown to have a negative genetic correlation with fertility traits (Grosshans *et al.*, 1997), and selection for Northern Hemisphere Holstein-Friesian genetics that are unsuited for New Zealand pasture-based systems, have contributed to extending this post-partum period (Harris and Kolver, 2001). A cow that calves late in the calving period has less time to resume ovarian cycling than a cow that calves early and consequently, may fail to be submitted and/or conceive during the herd's mating period.

Each year, approximately 10% of dairy cows fail to conceive (Xu and Burton, 2003). Non-pregnant cows are generally culled (removed) from the herd, and replaced with two-year-old heifers (Holmes *et al.*, 2002). However, this practice comes with considerable capital loss, especially if the cow is relatively young and yet to reach their peak milk productivity, as well as, herd wastage (Pangborn and Woodford, 2010) and, animal welfare concerns (Compton *et al.*, 2017). Consumer demand for sustainable food products that are sourced from industries with satisfactory animal welfare may escalate the need to decrease dairy cow wastage. An alternative to culling non-pregnant cows is to dry them off (lactating to non-lactating) at the end of lactation, retain them for one non-lactating year, and return them to a milking herd in the following year after mating (Pangborn and Woodford, 2010). In the New Zealand dairy industry, these cows are referred to as carryover cows.

Despite the well-known existence of carryover cows in the New Zealand dairy industry, and the potential impact that carrying over non-pregnant cows may have on dairy farm productivity and profitability, minimal studies have investigated the topic. Previous New Zealand work has shown that carryover cows had a milk production advantage (kilogram milksolids (kg MS)) in their first year once they had returned to a milking herd, and this was maintained for up to three subsequent years, when compared to mixed-age (greater than three years old) non-carryover cow groups and heifers (Pangborn and Woodford, 2010; Pangborn and Woodford, 2013). The former study (Pangborn and Woodford, 2010) found that carryover cow reproductive performance was inferior to non-carryover groups. However, in the more recent study (Pangborn and Woodford, 2013), aggregated survival percentages for carryover cows from first to second, second to third, and third to fourth carryover year were shown to be similar to the survival percentages for non-carryover cows that were presented in the New Zealand dairy statistic at the time. Furthermore, a small economic analysis conducted by Pangborn and Woodford (2010) suggested that carryover cows, produced more profit ($228) in the first carryover year than a two-year-old heifer in the 2008 year.

Two major limitations that were recognised in the earlier study (Pangborn and Woodford, 2010) was the lack of replication for other carryover cow groups and a limited amount of data to analyse subsequent lactation and reproductive performance for carryover cows. These limitations were minimised in the later study (Pangborn and Woodford, 2013), where an additional two carryover cohorts were included. However, data shortage continued to be a limiting factor and meant no within-herd survival comparisons could be made (Pangborn and Woodford, 2013). Furthermore, the trials were only conducted in one region of New Zealand (Canterbury), and the herds under investigation comprised a large proportion of Holstein-Friesian genetics (55-76%). Consequently, the results were not representative for the wider New Zealand dairy industry and provided no description of the carryover cow population.

For these reasons, the primary aims of this thesis were to firstly, define the spring-calving carryover cow population, in terms of their frequency, breed and genetic merit (Chapter 3); secondly, determine the milk production of carryover cows and compare this to heifers, lactation-matched and age-matched non-carryover cows for up to three years (Chapter 4); and lastly, compare the probability of survival over time (days) for carryover cows with that of two-year-old heifers and lactation-matched non-carryover cows (Chapter 5). A better understanding of the potential productivity of carryover cows and the feasibility of this practice will aid on-farm culling decisions.

The thesis begins with a literature review (Chapter 2), which includes an overview of the New Zealand dairy industry, describes the main milk production and reproductive measures for dairy cows, then discusses previous carryover cow research and factors that affect dairy cow productivity. At the completion of the literature review, three specific aims are defined, which are addressed in the three research chapters (Chapter 3, 4 and 5). Chapter 6 includes a general discussion of the main findings, study limitations, implications, further study opportunities and key conclusion.

# Chapter 2 Literature Review

## 2.1 Introduction

In New Zealand, dairy cow mating is followed by pregnancy diagnosis to confirm whether a cow is pregnant or non-pregnant. Non-pregnant cows are generally culled from herds, which includes either slaughter or sale to another herd, and are replaced with two-year-old heifers (Holmes *et al.*, 2002). Alternatively, non-pregnant cows can be dried off at the end of lactation, retained for one non-lactating year, before being mated and returned to a milking herd in the following year. In the New Zealand dairy industry, these cows are often referred to as carryover cows. The average non-pregnant rate for New Zealand dairy cows has been shown to be 10% but for the top quarter of dairy herds, non-pregnant rate is less than 5% (Xu and Burton, 2003). However, even at a 5% non-pregnant rate, a farmer that owns a 500 cow herd is required to make the annual decision of whether to retain (carryover) or cull 25 non-pregnant cows. This review investigates the options for non-pregnant cows, with emphasis on carryover cows and their potential performance, as well as factors that affect dairy cow productivity. It begins with an overview of the New Zealand dairy industry, a description of spring-calving dairy systems, and an outline of the common fates for non-pregnant cows. Following this, reproduction and milk production performance measures for dairy cows are defined. Lastly, factors that affect dairy cow performance are reviewed, including body condition score (BCS), breed, genetics, lactation number, age, animal health and farm management practices. The review focuses on spring-calving, pasture-based dairy systems.

## 2.2 The New Zealand dairy industry

The bovine dairy industry is the largest primary sector in New Zealand and world exporter of dairy commodities (Fonterra, 2014). More than 90% of the milk products produced in New Zealand are exported overseas, which has a significant contribution to the national economy (Blackwell *et al.*, 2010). In the 2015/16 season, 21 billion litres of milk was produced, but this equated to a mere 3% of the total milk produced worldwide (LIC and DairyNZ, 2016).

Approximately 11,900 herds are distributed across the country on 1.8 million hectares (LIC and DairyNZ, 2016). The majority (73%) of these herds are found in the North

Island and the remaining 26% are found in the South Island (LIC and DairyNZ, 2016). Between the year 2005 and 2015, the number of dairy cows increased by 31% to a population size of 5 million cows (LIC and DairyNZ, 2016). This was accompanied with a 33% herd size increase to an average of 419 cows per herd (LIC and DairyNZ, 2016).

Until the late 1960s, Jersey was the predominant dairy breed (Harris and Kolver, 2001). After this time, New Zealand Jersey cows were crossed with New Zealand Holstein-Friesian cows, as well as with North American Holstein-Friesian cows (Harris and Kolver, 2001). In 1955 Jersey cows made up 75% of the New Zealand dairy herd (Harris and Kolver, 2001), but this percentage has decreased to 10.1% in 2016 Figure 2.1 (LIC and DairyNZ, 2016). Today, the majority (47.2%) of the New Zealand dairy herd is made up of Holstein-Friesian x Jersey crossbreed cows and Holstein-Friesian (33.5%) cows Figure 2.1 (LIC and DairyNZ, 2016). The remaining 9.3% of the New Zealand dairy herd is comprised of Ayrshires, Brown Swiss, Milking Shorthorn, Guernsey and their crosses (LIC and DairyNZ, 2016).

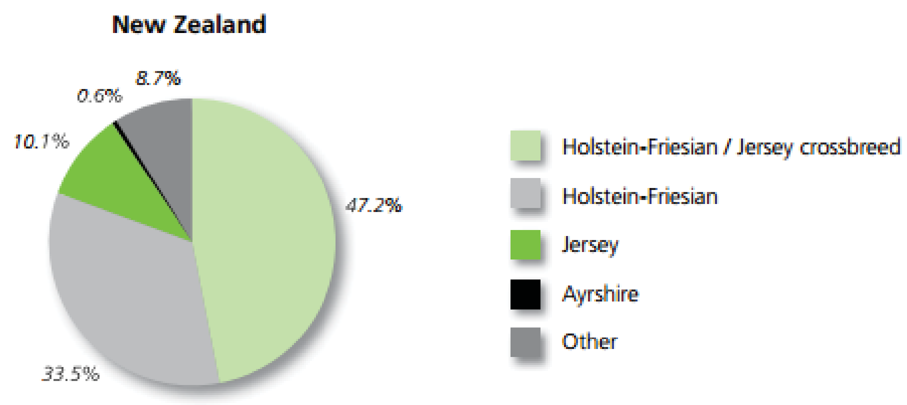


**Figure 2.1** The percentage of Holstein-Friesian x Jersey, Holstein-Friesian, Jersey, Ayrshire, and other cows in the New Zealand dairy industry (LIC and DairyNZ, 2016).

New Zealand dairy production systems are unique to those found in other parts of the world as the majority of feed is sourced from pasture that is harvested by the cows (Holmes and Roche, 2007). The New Zealand dairy levy organisation (DairyNZ) has defined production systems on a one to five scale, depending on the proportion of feed imported on-farm; production system one dairy farms import no supplements; whereas, production system five dairy farms import between 25% and 45% supplements (DairyNZ, 2017a). Favourable climatic conditions for pasture growth, high importation costs for concentrate feeds, and comparatively low prices received for milk in New Zealand, compared to other parts of the world, drives the requirement for low-input, pasture-based systems (Harris and Kolver, 2001).

Over the past decade dairy cow milk production has increased. On average, a dairy cow produced 372 kg MS in the 2015/16 season (LIC and DairyNZ, 2016). This was 31% greater than a dairy cow in the 1995/96 season that produced 283 kg MS (Figure 2.2) (LIC and DairyNZ, 2016). The milk payment system is based on the amount of milksolids present in the milk, which is the sum of total fat (kg) and protein (kg) content, minus total milk volume (L). The value ($) paid for milk is volatile and in the past 20 years the 2014/15 season had the lowest inflation-adjusted milk price at $4.30, compared to $8.68 and $8.51 in the 2007/08 and 2013/14 seasons, respectively (LIC and DairyNZ, 2016).

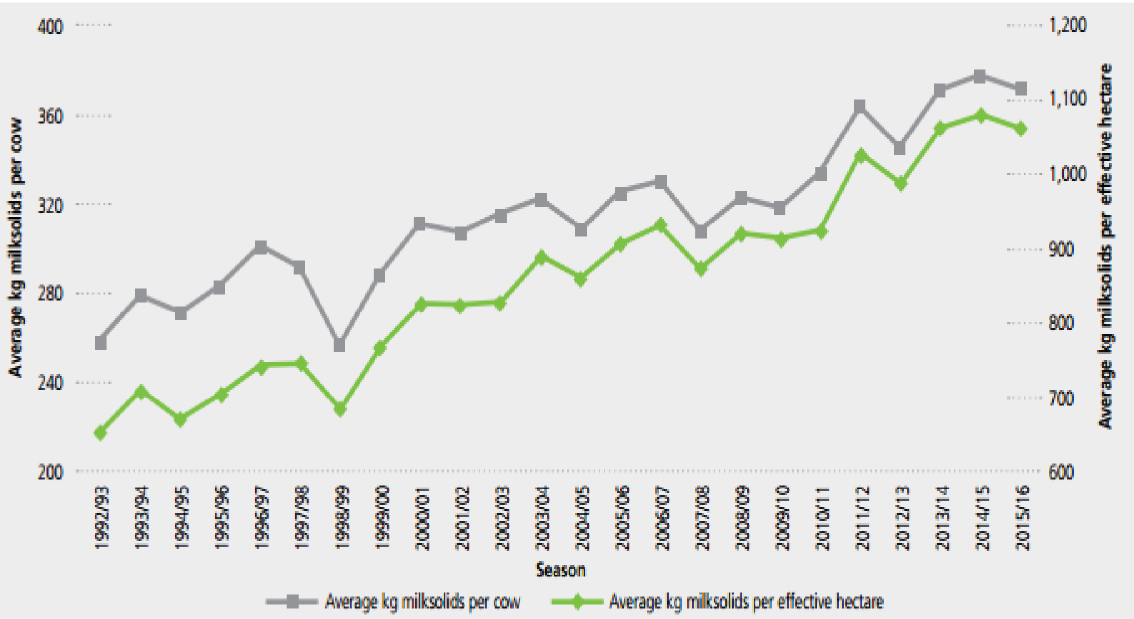


**Figure 2.2** The average kilograms of milksolids produced per cow and per effective hectare between the 1992 and 2015 season (LIC and DairyNZ, 2016).

## 2.3 Seasonal calving pattern

As established in Chapter 1, the majority (95%) of New Zealand milk is produced from spring-calving, pasture-based dairy systems (Blackwell *et al.*, 2010). Concentrated, spring-calving patterns are a feature of New Zealand seasonal dairy systems (Macmillan and Moller, 1977). Having a compact calving period, during the spring period, ensures that cow lactation length is maximised (Macmillan *et al.*, 1984) and that the increased energy requirements for the cow after parturition are matched to the increased pasture growth rate during the spring period (Blackwell *et al.*, 2010; Holmes *et al.*, 2002). Dairy cows are dried-off (lactating to non-lactating), during late autumn when pasture growth rates begin to decline, allowing pasture cover (kilograms dry matter) to accumulate prior the next calving period (Blackwell *et al.*, 2010; Holmes *et al.*, 2002).

In order to maintain an annual calving period, a herd's average calving interval, which is the number of days between consecutive parturition dates, should remain close to 365 days (Buckley *et al.*, 2003; Macmillan and Moller, 1977). In theory, cows will have a 305 days' lactation period, followed by a 60-day non-lactation period, prior to parturition (Capuco *et al.*, 1997). In New Zealand, the current average lactation period for dairy cows is closer to the 276 days (LIC and DairyNZ, 2016). As described above, it is important to maintain an appropriate calving interval to minimise the impact of feed deficits by matching animal energy requirements with pasture growth patterns (Blackwell *et al.*, 2010; Holmes *et al.*, 2002). Furthermore, generally all cows in a herd are dried-off at the same time of the year (late autumn) and therefore, cows with long calving intervals will have a shorter lactation length for that lactation (Blackwell *et al.*, 2010; Holmes *et al.*, 2002).

Although the 365-day calving interval minimises feed deficits, the time restriction can have an impact on the reproductive performance of a dairy cow. The seasonal time constraint requires that cows resume ovarian cycling, display oestrus, are mated and conceive within 83 days after the farm's planned start calving date (Blackwell *et al.*, 2010). The success of maintaining an annual calving period is driven by the previous year's mating management. Generally, artificial insemination takes place for the first four to six weeks of the mating period to generate replacement stock, and is followed by natural mating for seven to twelve weeks for dairy cows that did not conceive to artificial insemination (Blackwell *et al.*, 2010; Macmillan and Moller, 1977). Cows that fail to conceive during the herds mating period are confirmed non-pregnant at pregnancy diagnosis.

## 2.4 Non-pregnant cow fates

As described earlier, the average non-pregnant rate for New Zealand dairy herd is 10% per year (Xu and Burton, 2003). Non-pregnant cows are generally removed from dairy herds and replaced by two-year-old heifers (Holmes *et al.*, 2002). As an alternative to being culled and replaced by a two-year-old heifer, non-pregnant cows can be dried off at the end of lactation, carried over for one year as a non-lactating cow, and returned to a milking herd in the following year after mating (Pangborn and Woodford, 2010). Figure 2.3 illustrates the mating, pregnancy diagnosis, and lactation start and end points for spring-calving carryover cows versus non-carryover cows.

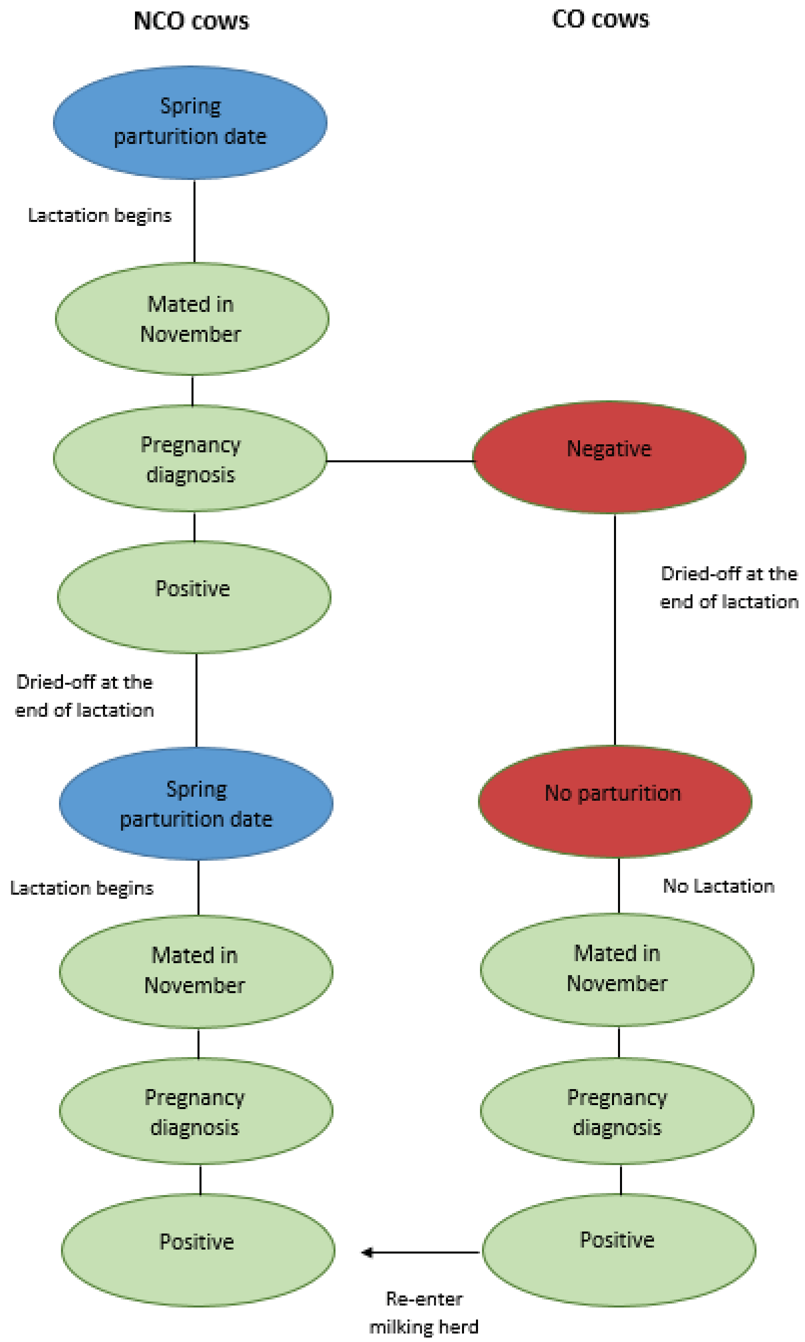


**Figure 2.3** The parturition, lactation, mating and pregnancy diagnosis events for carryover (CO) cows and non-carryover (NCO) cows.

Non-pregnant cows in split-calving (autumn and spring-calving) herds, can also be carried over. Split-calving herds have two calving periods, and generally the herd is split into two herds, where the cows in one herd calve during the autumn period and the cows in the second herd calve during the spring period (Taylor, 1996). Dairy herds with split-calving patterns supply milk to processing companies throughout the year (Garcia and Holmes, 1999) and are suited to areas of New Zealand that are summer drought prone, and have daily winter pasture growth rates between 15 and 20 kg dry-matter per hectare (Fulkerson and Dickens, 1985). Non-pregnant cows from autumn-calving herds can have an extended lactation period, and then be mated with the spring-calving herd, or vice versa, for a non-pregnant cow from the spring-calving herd (Auldist *et al.*, 2007; Holmes *et al.*, 2002; Kolver *et al.*, 2007; Pryce *et al.*, 2004). In split-calving herds it is more desirable to extend the lactation of non-pregnant cows than to dry them off as the cow will continue to contribute to farm profits (Patton, 2012). However, split-calving herds represent the minority (less than 5%) of dairy herds in New Zealand (Blackwell *et al.*, 2010) and therefore, they are considered no further in this review.

## 2.5 Carryover cow impact

There are several reasons a farmer may consider carrying over a non-pregnant cow, as an alternative to culling her (removal from the herd) and introducing a two-year-old heifer. Culling decisions have a significant impact on farm profits and are influenced by market prices (Lehenbauer and Oltjen, 1998). The cull value of a non-pregnant cow can be 25% less than the market value of an equivalent pregnant cow and therefore, culling them can result in considerable capital loss, especially if the cow is still young (Pangborn and Woodford, 2013).

Furthermore, it has been suggested that retaining non-pregnant cows could reduce the amount of herd wastage (Pangborn and Woodford, 2013). An historical study stated that New Zealand had an average herd wastage of 19%, which was less than the wastage percentage reported in American and British reports (Macmillan and Murray, 1975) but more than the 12% reported in an Irish study (Cunningham *et al.*, 1976). A later New Zealand study showed that herd wastage is around 22.6% in New Zealand (Anderson, 1985). Reducing herd wastage is likely to become increasingly important as consumers seek food products that are sourced from sustainable production systems.

Utilising carryover cows will reduce the requirement for herd replacements, which has a positive impact on farm profitability (Tozer and Heinrichs, 2001). Raising herd replacements represents a considerable cost to farm systems (Gartner and Herbert, 1979). Studies have shown that reducing replacement rates not only reduces farm costs but it also maximises the average per cow milk production, as the herd is comprised of less, low producing two-year-old heifers (Gartner and Herbert, 1979; Lopez-Villalobos and Holmes, 2010; Vollebregt and Vollebregt, 1998). The average replacement rate for New Zealand dairy herds is between 20% and 23% per year, where replacement rate represents the proportion of herd that is replaced by two-year-old heifers (Anderson, 1985; Jackson, 1983). However, a United States study showed that reducing the culling rate and therefore, the amount of animals reared by 3%, reduced the farms overall net costs by up to 25% (Tozer and Heinrichs, 2001). In support of this, Lopez-Villalobos and Holmes (2010) (New Zealand) showed that herd reducing replacement rate to 15%, increased farm profits and resulted in genetic gain as measured by Breeding Worth.

From an economic point of view, it may be assumed that utilising carryover cows will improve farm profits. However, it cannot be concluded whether the reduction in costs that are associated with reduced replacement rate, would out-weigh the costs of carrying over a non-lactating cow for one year. Pangborn and Woodford (2010) calculated the cost of a carryover cow at calving to be $1409, which was greater than a two-year-old heifer that cost $1184 at first parturition. Once the production advantage (128 kg MS) for the carryover cow was accounted for, the net return was $228 in favour of the carryover cow (Pangborn and Woodford, 2010). These costs included the initial value of the animal, rearing costs (heifer), grazing costs, breeding costs, animal health and cost of death or failure to conceive (Pangborn and Woodford, 2010). However, it must be noted that these costs fluctuate from year to year, and the study only considered the income generated by the cows in first lactation. Furthermore, NZAEL (2013) has estimated the cost of a replacement to be $1433, which is much higher than that specified by Pangborn and Woodford (2010). Thus, a comprehensive economic simulation study is required before it can be confirmed whether it is feasible to carryover a non-pregnant cow.

Lastly, carryover cows may have an impact on non-economic factors. For example, the management of an additional stock class (carryover cows) that require different feed allocations and breeding management, compared to the young stock and the milking herd, will have an impact on farm management complexity (Pangborn and Woodford, 2010; Patton, 2012). However, carryover cows may be useful on mixed contour farmland, where they can graze poorer country relative to a heifer that is required to be growing. Accordingly, the decision to carryover a cow will impact several aspects of a farm system.

## 2.6 Dairy cow performance

The main measures of dairy cow performance are based on milk production and reproduction (Blackwell *et al.*, 2010). Dairy cows can be selected for these traits, or culled, based on their selection indices (Montgomerie, 2002).

### 2.6.1 Breeding values and selection indices

The New Zealand Animal Evaluation Limited (NZAEL) is a wholly owned subsidiary of DairyNZ that manages the National Breeding Objective and aims to identify animals whose progeny will be the most efficient converters of feed into farm profit (NZAEL, 2015). More specifically, selection indices have been developed to determine which animals (cows and bulls) are the most efficient at converting five tonnes of dry-matter into farm profit (NZAEL, 2015). Currently, there are three main selection indices; the meaning, use and traits included into each of the selection indices are summarised in Table 2.1. Breeding Worth (BW) ranks both male and female cattle for their genetic ability to produce valuable replacements; Production Worth (PW) ranks female cattle on their lifetime milk productivity; and lastly, Lactation Worth (LW) ranks female cattle on their current milk productivity performance for that year (NZAEL, 2015). Breeding Worth and PW are used regularly as tools to identify cows that should be culled or selected as replacements (Montgomerie, 2002).

**Table 2.1** The meaning, use and cow traits that contribute to Breeding Worth (BW), Production Worth (PW) and Lactation Worth (LW) (NZAEL, 2015).

| | Selection index | | |
|---|---|---|---|
| | BW | PW | LW |
| Meaning | Genetic ability for breeding replacements | Lifetime milk production performance | Current milk production performance |
| Use | Selecting bulls and replacements | Culling and purchasing cows | Culling |
| Traits | Milk yield, fat yield, protein yield, live-weight, fertility, somatic cell count, body condition score and residual survival | Milk yield, fat yield, protein yield and live weight (includes heterosis) | Milk yield, fat yield, protein yield and live weight |

Breeding Worth is calculated by summing the breeding values for each of the traits shown in Table 2.1, multiplied by their current economic value (estimated breeding values (EBV)) (Montgomerie, 2002). Breeding values are the genetic value of an individual cow trait compared to the genetic Base Cow (NZAEL, 2015). The genetic Base Cow is a reference group of cows, where the genetic value for production traits are set to zero for these cows (NZAEL, 2015). Information from herd tests ((milk yield (MY), fat yield (FY), protein yield (PY) and somatic cell count (SCC)), as well as live weight recordings, and mating records are compared to the Base Cow values for each of the respective traits (NZAEL, 2015). The difference between the cow values and the Base Cow values form the breeding values for each milk trait (MY, FY, PY), live weight, fertility, longevity and recently (February, 2016), BCS (NZAEL, 2015). In June 2016, the Base Cow reference point was increased to 2005 born cows, as part of a five yearly update (NZAEL, 2015). Breeding Worth indicates how much extra profit an animal is expected to generate, compared to the Base Cow. For example, a cow with a BW of

$100 would generate an additional $100 profit per five tonnes of dry matter, compared to the Base Cow.

The information incorporated into each cow's BW value is sourced from information on current animal records and relatives (e.g. parents and progeny). A reliability value indicates the amount of information that contributed to the cow BW value (Harris and Johnson, 1998). Reliability values indicate how accurate the selection indices estimate the true genetic merit of the animal (Harris and Johnson, 1998). Figure 2.4 shows that heifers have the lowest (38%) reliability values, as all the information that contributes their BW is sourced from ancestry records. As individual records and progeny records are incorporated into the BW value, the reliability for a cow can increase up to 61% when five individual and three progeny records contribute to the BW value (Figure 2.4) (DairyNZ, 2017b).

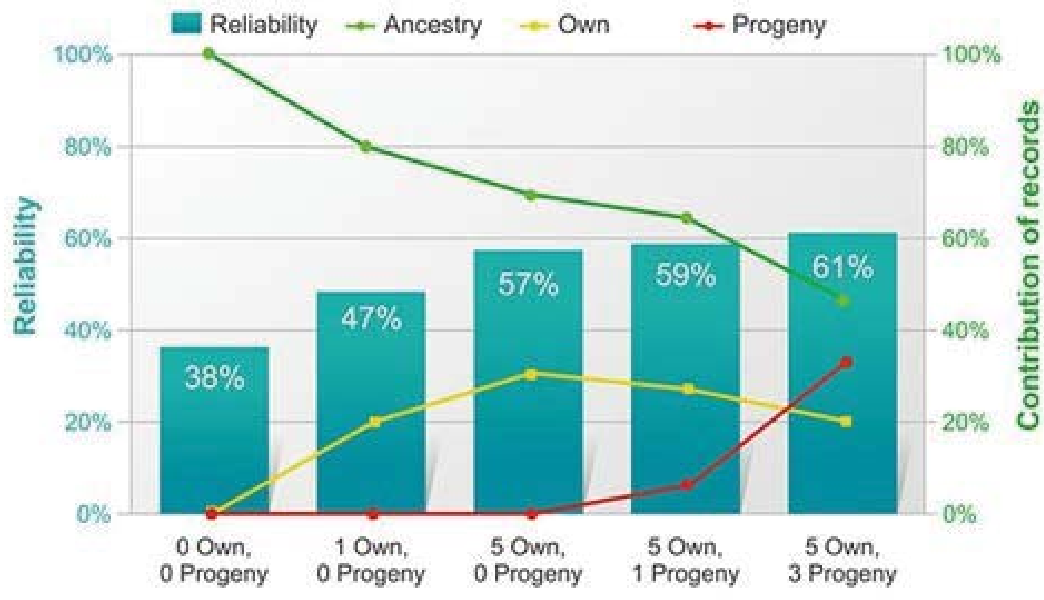


**Figure 2.4** The average reliability percentage and contribution of individual, ancestry, and progeny records to the Breeding Worth of heifers and cows up to their fifth lactation (DairyNZ, 2017b).

A similar calculation process is used to produce PW and LW values for each cow. Production Worth is based on ancestry, individual and progeny records for MY, FY, PY, live weight and an estimation of the contribution of heterosis, but the trait values are weighted more heavily towards individual records to ensure the cow's PW value has a high repeatability from one season to the next (LIC, 2009; NZAEL, 2015). Whereas, LW accounts for individual herd test records for MY, FY and PY and live weight for the current season, rather than for the cow's lifetime (LIC, 2009).

### 2.6.2 Milk production and milk quality

According to the New Zealand dairy statistics, an average New Zealand dairy cow produces 4311 L milk, 204 kg fat and 165 kg protein, and have an average SCC of 187,000 cells per millilitre of milk (LIC and DairyNZ, 2016). Herd test measurements provide information on the current MY, FY, PY and SCC for each cow at that milking.

Somatic cell count is a measure of the number of somatic cells per millilitre (cells/mL) of milk, and is made up of mainly white blood cells and epithelial cells (Blowey and Edmondson, 2010; Eberhart *et al.*, 1979). Somatic cell count naturally varies with lactation, cow age and time since parturition (Blowey and Edmondson, 2010; Duirs and Macmillan, 1979; Miller *et al.*, 1993). However, during infection, the number of white blood cells increases significantly (Blowey and Edmondson, 2010). Eberhart *et al.* (1979) showed that the SCC of milk samples taken from mammary glands that have had no previous history of infection ranged between 113 000 and 251 000 cells/mL milk, depending on cow age (Eberhart *et al.*, 1979). In contrary, SCC taken from cows that had a previous history of infection were up to 600 000 cells/mL milk (Ward and Schultz, 1972). The milk production loss, for fourth-lactation cows, when SCC doubles during infection, has been estimated to be up to 99.0 L milk, 3.6 kg fat and 2.7 kg protein (Winkelman, 2007). The bulk SCC (whole herd average) is required to be below 400,000 cells/ml at each tanker pickup or financial penalties can be incurred (Schukken *et al.*, 2003).

#### *2.6.2.1 Carryover cow milk production*

Prior to considering carrying over a non-pregnant cow, the future productivity of the cow should be considered, as this will influence the cow's contribution to farm profit. Two previous studies, conducted in the Canterbury region (New Zealand) have shown that carryover cows have greater milksolid production (kg MS) in their first year after a carryover period (carryover year one), compared to mixed-age (greater than three years old) non-carryover herd-mates and heifers (Pangborn and Woodford, 2010; Pangborn and Woodford, 2013)

Pangborn and Woodford (2010) study consisted of two carryover cow groups, where the first group (carryover cow Group 1) was of higher BW but lower body condition, compared to the second group (carryover cow Group 2). During early lactation, carryover cows produced 15% and 28% more milksolids than mixed-age non-carryover cows and heifers, respectively (Pangborn and Woodford, 2010). Table 2.2 shows that the production advantage (average daily kg MS production) of carryover cows in early lactation continued into mid- and late-lactation (Pangborn and Woodford, 2010). Once milksolid production was averaged across the whole year, carryover cows produced an additional 40 kg MS and 128 kg MS compared to mixed-age non-carryover cows and heifers, respectively (Pangborn and Woodford, 2010). The production advantage for carryover cows in year one was confirmed when a later study showed that three cohorts of carryover cows (returned to a milking herd in the 2007/08, 2008/09 and 2009/10 year, respectively) produced an average of 81 kg MS more than non-carryover cow groups (Pangborn and Woodford, 2013).

The milk production advantage for carryover cows continued for up to four carryover years, but at a decreasing rate (Pangborn and Woodford, 2013). On average, carryover cows produced an additional 38 kg MS, 45 kg MS and 10 kg MS in their second, third and fourth carryover years, respectively (Pangborn and Woodford, 2013). However, as shown in Table 2.3, in some cases, the production advantage was statistically insignificant.

**Table 2.2** The average daily milksolids (ADMS), expressed as kilograms of milksolids (kg MS), produced by carryover cows (CO) and mixed age (greater than three years old), three-year-old and two-year-old non-carryover (NCO) cows in early-, mid- and late-lactation (Pangborn and Woodford, 2010).

| | Early lactation | | Mid lactation | | Late lactation | |
|---|---|---|---|---|---|---|
| Group | No. cows | ADMS | No. cows | ADMS | No. cows | ADMS |
| CO Group 1* | 98 | 2.10 | 98 | 1.73 | 79 | 1.49 |
| CO Group 2* | 162 | 2.21 | 162 | 1.61 | 116 | 1.40 |
| Mixed-age NCO | 149 | 2.03 | 148 | 1.54 | 135 | 1.32 |
| Three-year-old NCO | 86 | 1.97 | 86 | 1.49 | 85 | 1.35 |
| Two-year-old NCO | 170 | 1.46 | 171 | 1.19 | 163 | 1.11 |

*Carryover over cow Group 1 was of higher Breeding Worth but lower body condition compared to carryover cow Group 2.

**Table 2.3** The annual milksolid (kg MS) production advantage for carryover cow groups versus non-carryover cow groups in first, second, third and fourth carryover year (Pangborn and Woodford, 2013).

| | Carryover year | | | |
|---|---|---|---|---|
| Carryover group | First | Second | Third | Fourth |
| 2007/08 | - | 36* | 48* | 10 |
| 2008/09 | 57* | 48* | 41* | - |
| 2009/10 | 106* | 31 | - | - |

*Statistically significant values ($P<0.05$).

There was no evidence to suggest that the SCC of carryover and non-carryover cows was different (Pangborn and Woodford, 2010). However, both mixed-age cows (carryover and non-carryover) had higher ($P<0.05$) SCC than heifers (Pangborn and Woodford, 2010). This is expected as SCC naturally increases with age and lactation number (Blowey and Edmondson, 2010; Duirs and Macmillan, 1979).

The two studies (Pangborn and Woodford, 2010; Pangborn and Woodford, 2013) illustrated that carryover cows have a milk production advantage over non-carryover cows. However, it must be acknowledged that the number of carryover cows involved in these studies were relatively small (20-162 cows), and based on a single Canterbury herd that comprised of a high proportion of Holstein-Friesian (55-76%) genetics.

### 2.6.3 Reproduction and survival

#### *2.6.3.1 Reproductive performance measures*

Dairy cow reproductive performance, in spring-calving herds, is one of the most important determinants of farm production efficiency and profitability (Grosshans *et al.*, 1997; Xu and Burton, 1996). The success of a concentrated calving pattern is driven by the mating management during late spring in the previous year (Macmillan and Moller, 1977). However, cows are required to initiate ovarian cycling, prior to the herd's planned start of mating for pregnancy to occur (Xu and Burton, 1996). After parturition, ovulation and oestrus are absent for up to 50 days (McDougall, 1994). This time period is commonly referred to as the postpartum anoestrus interval (Lamming *et al.*, 1980; McDougall, 1994). The postpartum anoestrus interval is affected by the cow's nutritional status, breed, age, milk yield, health, reproductive disorders and milking/suckling frequency (Lamming *et al.*, 1980; McDougall, 1994). When the cow has initiated ovarian cycling, farm managers/workers are required to accurately detect expression of oestrus, so that the cow is submitted for artificial insemination at the correct time (Xu and Burton, 1996). Reproductive performance measures allow farm managers to monitor both individual cow and whole herd fertility.

The majority of fertility measures focus on oestrus detection (McDougall *et al.*, 2014), and maximising the number of pregnant cows (Xu and Burton, 1996). Figure 2.5 summarises the common reproductive measurements used in New Zealand dairy systems. Submission rate is the percentage of cows which are submitted for mating during a specified time (Brownlie, 2012; Morton, 2010). This is usually expressed as the percentage of cows that are submitted in the first three weeks (21 days) of mating, which is the number of days for one cow oestrous cycle (Schams *et al.*, 1977; Walters *et al.*, 1984). Conception rate is the percentage of all inseminated cows that are confirmed as pregnant (Macmillan and Watson, 1973) and is generally based on the number of cows that conceive to first insemination (first service conception rate) (Brownlie, 2012; Grosshans *et al.*, 1997).

The six-week in-calf rate is the percentage of cows which conceive within 42 days of the herds planned start of mating and is directly influenced by three-week submission rate and first-service conception rate (Brownlie, 2012; Grosshans *et al.*, 1997; McDougall *et al.*, 2014). An Ireland report estimated that a 1% change in six-week in-calf rate had a €9.26/cow per annum impact (Shalloo *et al*, 2014), which was equivalent to $14.90/cow per annum (2014 exchange rate). This highlights the impact of dairy cow reproductive performance on farm profits.

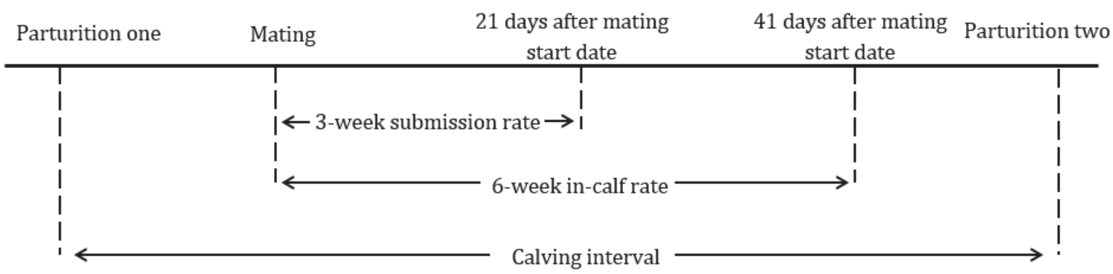


**Figure 2.5** The common reproductive measurements used on New Zealand dairy farms (adapted from (Grosshans *et al.*, 1997)).

The industry targets suggest that herds should aim for a 78% six-week in-calf rate, 90% three-week submission rate, 60% conception rate and 6% final non-pregnant rate (for a twelve week mating period) and have been based on the results of a study by Xu and Burton (2003). The targets were established from the average reproductive performance for the top quartile of 123 New Zealand dairy herds between 1998 and 2000 (Xu and Burton, 2003) and therefore, a large percentage of herds have lower reproductive performance than the industry targets. The six-week in-calf rate for New Zealand dairy herds ranged between 57% and 78% for herds in the bottom and top quartile for reproductive performance, respectively (Xu and Burton, 2003). Non-pregnant rate ranged between 5% and 17% for herds in the bottom quartile (desired) and top quartile, respectively (Xu and Burton, 2003). Current dairy cow records for the 2015/16 season show that New Zealand dairy herds have an average six week in-calf rate of 67%, which is driven by an 80% three-week submission rate and 52% first-service conception rate (LIC and DairyNZ, 2016).

Calving interval, which is a measure of the number of days between a cows consecutive parturition dates, is another important reproductive measure (Figure 2.5) (Macmillan and Moller, 1977; Pryce *et al.*, 2000). As discussed in section 2.3, farm managers aim to keep their average calving interval close to 365 days (Blackwell *et al.*, 2010; Holmes *et al.*, 2002). Currently, the average calving interval for New Zealand dairy herd is 368 days (LIC and DairyNZ, 2016). It has been shown that calving interval is up to nine days longer for heifers than mature-aged herd-mates (Grosshans *et al.*, 1997; Macmillan and Moller, 1977). However, this may be influenced by the common practice of calving two-year-old heifers one to two weeks earlier than the rest of the herd (Grosshans *et al.*, 1997; Macmillan and Moller, 1977).

#### *2.6.3.2 Survival*

Reproductive performance has a major influence on dairy cow survival. Poor reproductive performance has been shown to be the cause of 43% of culled cows in New Zealand (Verkerk *et al.*, 2000). It is also the primary reason for culling in the United States (Bascom and Young, 1998), and the United Kingdom (Esslemont and Kossaibati, 1997). Animal breeders often conduct survival analysis studies to estimate genetic parameters for survival in dairy herds (Ducrocq, 1994; Ducrocq *et al.*, 1988; Smith and Quaas, 1984). Survival can be defined as the number of days from a cows first parturition date and final date of culling (Ducrocq *et al.*, 1988), or as a percentage that survived from one lactation to the next (LIC and DairyNZ, 2016). Harris (1989) showed that the average lifetime for dairy cows in a herd decreased from 5.2 lactations (1898 days) in the 1955 season to 4.8 lactations (1752 days) in the 1985 season.

In general, herds with high survival rates have greater milk yields as there is a larger number of high producing, mature cows and the costs of rearing replacements is less than a herd with low cow survival rates (Patton, 2012; Pritchard *et al.*, 2013; Vukasinovic *et al.*, 2001). Furthermore, if a herd has low survival rates there is a loss in genetic gain for milk production, as cows are culled for low reproductive performance rather than milk production (Verkerk *et al.*, 2000; Xu and Burton, 1996). Lastly, the genetic selection intensity is reduced for herds with low survival rates as more animals are required to be replaced, and therefore the selection response will be lower (Vukasinovic *et al.*, 2001).

**Table 2.4** The average annual survival percentage of cows that are between two and nine years old for the past ten years (LIC and DairyNZ, 2016).

| Age (years) | 2-3 | 3-4 | 4-5 | 5-6 | 6-7 | 7-8 | 8-9 |
|---|---|---|---|---|---|---|---|
| Survival (%) | 86.5% | 87.0% | 87.1% | 83.1% | 77.6% | 72.1% | 67.1% |

Reproductive management, genetic selection and cow health influence the ability of a cow to survive from one lactation to the next (Beaudeau *et al.*, 1995; Dillon *et al.*, 2003; Harris, 1989; Pritchard *et al.*, 2013). There are two main types of culling; voluntary culling, when a farmer chooses to remove a healthy, fertile cow due to low milk production; and involuntary culling, when a productive dairy cow is removed from a herd due to ill health, infertility or death (Weigel *et al.*, 2003). Studies have shown that survival is reduced or the probability of culling is increased as proportion Holstein-Friesian and cow age is increased; for cows with teat abnormalities; for cows in early and late lactation; or for cows that are low producers or have poor reproduction (Beaudeau *et al.*, 1995; Dillon *et al.*, 2003; Harris, 1989; Vukasinovic *et al.*, 2001). Harris (1989) showed that the rate of survival decreased from 87% for two-year-old cows to 58% for ten-year-old cows. This was driven by an increased rate of both involuntary and voluntary culling as cow age increased (Harris, 1989). Current statistics show that the percentage of dairy cows surviving from two to three years old is 86.5% and this is decreased to 67.1% for cows surviving from seven to eight years old (Table 2.4) (LIC and DairyNZ, 2016).

### *2.6.3.3 Reproductive performance and survival of carryover cows*

The reproductive performance of carryover cows has been described as 'poor' when compared heifers and mature-aged non-carryover herd-mates (Pangborn and Woodford, 2010). The non-pregnant rate was 20% and 25% for cows with high BW (Group 1) and low BW (Group 2), which was greater (P<0.05) than that for mixed-age non-carryover cows (5%), three-year-old cows (1%) and two-year-old cows (7%) (Table 2.5) (Pangborn and Woodford, 2010). However, when the non-pregnant carryover cows were culled and the remaining carryover cows were retained, the non-pregnant rates of the carryover cows in second carryover year were similar to the non-pregnant rates of non-carryover herd-mates (9-10%) (Pangborn and Woodford, 2010). The survival of carryover cows was 83%, 82% and 71% from first to second, second to third and third to fourth carryover years (Pangborn and Woodford, 2013). However, no comparison was made with the survival of non-carryover herd-mates.

**Table 2.5** The non-pregnant rate for carryover (CO) cow Group 1, CO Group 2, mixed-age non-carryover (NCO) cows, three-year-old NCO cows and two-year-old NCO cows (Pangborn and Woodford, 2010).

| Cow category | Non-pregnant rate |
|---|---|
| CO Group 1 | 20% |
| CO Group 2 | 25% |
| Mixed-age NCO | 5% |
| Three-year-old NCO | 1% |
| Two-year-old NCO | 4% |

*Carryover over cow Group 1 was of higher Breeding Worth but lower body condition compared to carryover cow Group 2.

## 2.7 Factors affecting dairy cow performance

### 2.7.1 Body condition score and energy balance

During early lactation, dairy cows experience a period negative energy balance, where animal feed requirements exceed their energy intake (Bauman and Currie, 1980). To counteract this effect, changes to the expression of key metabolic hormones result in an increased rate of lipolysis (fat breakdown), and in turn, non-esterified fatty acids are released into the animal's bloodstream (Bauman, 2000; Bauman and Currie, 1980). This equilibrium process is called homeostasis, which is a process that takes place in many body tissues of mammals (Bauman, 2000; Bauman and Currie, 1980). Cows that have been genetically selected for high milk yield have greater ability to mobilise body tissue as an energy source in early lactation, potentially due to lower concentration of insulin and greater insulin resistance in tissues, compared to cows of lower genetic merit (Chagas *et al.*, 2009).

Body condition score is an estimate of adipose tissue reserves and the nutritional status of a cow (Roche *et al.*, 2004; Roche *et al.*, 2009). Cows are scaled on a numerical system, which varies across the world, where a five-point scale is used in Ireland, an eight-point scale is used in Australia and a ten-point scale is used in New Zealand (Roche *et al.*, 2004; Roche *et al.*, 2009). From extensive research findings, a pre-calving BCS of 5.0 and 5.5 is recommended for mature dairy cows and heifers in New Zealand, respectively (Roche *et al.*, 2004). Over conditioned cows, and under conditioned cows experience a period of severe negative energy balance that can have a negative impact dairy cow performance (Garnsworthy and Topps, 1982; Roche *et al.*, 2004; Rukkwamsuk *et al.*, 1999). It has been shown that diet has no effect on the rate of BCS loss in early lactation, and therefore, appropriate management of cow BCS prior to parturition is mandatory (Roche *et al.*, 2006; Roche *et al.*, 2007a; Ruegg and Milton, 1995).

#### *2.7.1.1 Milk production*

The increased rate of lipolysis after parturition, not only provides long chain fatty acids for milk production, but also an energy substrate for non-mammary tissues, sparing glucose for lactose synthesis (Bauman and Currie, 1980; Garnsworthy and Topps, 1982). Domecq *et al.* (1997) showed that a one point (five-point scale) increase in BCS during the dry period, resulted in 545.5 L more milk produced per cow in the first 120 days of lactation. However, cows of higher BCS at parturition had greater rate of body condition score loss during those first 120 days of lactation (Domecq *et al.*, 1997), which may contribute to lower reproductive performance for that lactation. In contrary, earlier studies showed that cows with higher BCS had lower milk yield, possibly due to lower feed intakes than cows of lower BCS (Garnsworthy and Topps, 1982; Treacher *et al.*, 1986).

More recent studies have suggested that the positive effect of BCS on milk production is non-liner. It has been shown that milk yield increased by 628 L per cow when BCS increased from 2.0 to 3.0 (5-point scale), but above this BCS, the positive effect of BCS on milk production diminished (Roche *et al.*, 2007a). Further increases in BCS at parturition had a negative effect, and although the reasons for this negative correlation are unknown, it is suspected that leptin, a hormone that is positively correlated with body fat mass, may negatively impact the cows feed intake (Roche *et al.*, 2009).

#### *2.7.1.2 Reproduction and fertility*

Body condition score at calving, as well as the rate of BCS loss after parturition, have an impact on the reproductive performance of a cow for that lactation. A one-unit decrease in BCS after parturition has been shown to have detrimental effects on dairy cow reproductive performance, where first service conception rate is much lower (17%) compared to cows that lost less than 0.5 of a BCS unit (Butler and Smith, 1989) and cows are 1.17 times less likely to conceive than cows that lost no BCS (Roche *et al*., 2007b). Furthermore, for each 0.5 BCS unit increase the probability of pregnancy at six-weeks has been shown to increase by 1.28 (Buckley *et al.*, 2003) and 1.62 (Roche *et al*., 2007b).

As discussed in section 2.6.3.1, a dairy cow experiences a period of anoestrous directly after parturition. A dairy cows BCS and energy balance influence the length of this period (McDougall, 1993). Roche *et al.* (2007b) reported that a greater pre-calving BCS and less BCS loss after parturition, resulted in shorter post-partum anoestrous intervals. During post-partum anoestrous, uterine involution (size reduction) occurs and elevated progesterone and oestrogen, as well as low gonadotrophin (follicle growth stimulating) hormones return to normal concentrations (Lamming *et al.*, 1980). Cows that are anoestrous for greater than 45 days have been shown to have significantly lower BCS than cows that have resumed ovarian cycling (McDougall, 1993).

Ovarian cycling resumes when a luteinising hormone surge is induced, which causes ovulation (Butler and Smith, 1989; Moenter *et al.*, 1990). For an increased pulse release of luteinising hormone to occur, an increased oestrogen concentration is required to act on the hypothalamus to release gonadotrophin releasing hormone, and in turn luteinising hormone from the anterior pituitary (Kesner *et al.*, 1982; Moenter *et al.*, 1990). Oestrogen is released from the granulosa and theca cells (Leung and Armstrong, 1980). The amount of oestrogen secretion, and the number of luteinising hormone receptors increases as follicles grow (Crowe and Mullen, 2013). Over time, oestrogen concentrations reach the threshold level required to induce a surge of luteinising hormone, and consequently, ovulation, as well as behavioural oestrus occur (Crowe and Mullen, 2013).

The process of lipolysis (fat breakdown) results in changes to blood metabolites and metabolic hormones that can negatively impact the time before a cow resumes ovarian cycling. During lipolysis non-esterified fatty acids are released and any excess fatty acids are converted to ketones, commonly beta-hydroxybutyrate (Reist *et al.*, 2000). It has been shown that for every one micro mole increase in the concentration of non-esterified fatty acid, the risk of delayed ovarian cycling is increased by 0.5% (Giuliodori *et al.*, 2011). Similarly, it has been shown that cows that resume ovarian cycling early in the lactation, have lower beta-hydroxybutyrate concentrations than cows that resumed ovarian cycling later (Reist *et al.*, 2000). It has been suggested that increased concentrations of blood metabolites during negative energy balance results in a decreased pulse release of gonadotrophin releasing hormone, as well as reducing the sensitivity of the ovary to luteinising hormone (Jeong *et al.*, 2015). Furthermore, changes to metabolic hormone concentrations, such as, lower insulin-like-growth-factor-1, insulin and higher growth hormone concentrations have been shown to reduce the pulsatile release of luteinising hormone (Butler *et al.*, 2003; Lucy, 2011). These changes have a negative effect on the induction of an oestrogen surge, and in turn a luteinising hormone surge, delaying the resumption of ovarian cycling.

Despite these metabolic changes and the effects on ovulation, cows have been shown to establish follicular waves and dominant follicles during the early post-partum period (Beam and Butler, 1997; Diskin *et al.*, 2003; McDougall and Macmillan, 1993). This indicates that metabolic conditions that occur during negative energy balance do not limit the formation of follicular wave or dominant follicles but may affect the ovulatory ability of the dominant follicle. However, even if a cow does resume ovarian cycling, the oocyte quality can be diminished when a cow experienced a period of severe negative energy balance (Van Hoeck *et al.*, 2014). Consequently, it is essential that dairy cows have an appropriate pre-calving BCS to minimise these effects and optimise their milk production and survival.

### 2.7.2 Breed and genetics

The breed and genetic makeup of a dairy cow has an influence on milk production, reproductive performance and therefore, survival (LIC and DairyNZ, 2016; Pryce *et al.*, 1997). As discussed in section 2.2, 47%, 34% and 10% of the New Zealand dairy herd is made up of Holstein-Friesian x Jersey cows, Holstein-Friesian, and Jersey cows, respectively (LIC and DairyNZ, 2016). Table 2.6 shows that Holstein-Friesian dairy cows produce the highest milk yield, whereas, Jersey cows have the highest fat yield (LIC and DairyNZ, 2016) (Table 2.6).

**Table 2.6** The annual milk yield (MY), fat yield (FY), and protein yield (PY) produced by Holstein-Friesian, Jersey and Holstein-Friesian x Jersey dairy cows in New Zealand (LIC and DairyNZ, 2016).

| | Milk trait | | |
|---|---|---|---|
| Breed | MY (L) | FY (kg) | PY (kg) |
| Holstein Friesian | 4448 | 195 | 165 |
| Jersey | 3181 | 179 | 133 |
| Holstein-Friesian x Jersey | 3988 | 195 | 157 |

Holstein-Friesian cows have been shown to have lower survival than other breed types, including Holstein-Friesian x Jersey and Jersey cows (Brownlie and McDougall, 2014; Dillon *et al.*, 2003). Furthermore, the strain of Holstein-Friesian influences survival, where 33% of New Zealand Friesian cows that contained a high proportion of overseas genetics (e.g. North American) survived to lactation five. In contrast, 60% of New Zealand Holstein-Friesians that had a low proportion of overseas genetics survived to lactation five (Harris and Winkelman, 2000).

In the past, breeding objectives have focused on selecting for favourable milk production traits (Pryce and Veerkamp, 2001). Between the 1960s and 1980s, genetic selection was based solely on milk traits, but more recently the emphasis switched to other economically important traits, such as, fertility and health traits (Harris, 1998). In 2003, 66% of New Zealand's genetic selection was weighted towards selecting milk production traits, 24% towards health traits and 10% towards fertility traits (Miglior *et al.*, 2005). Currently, 49% of the emphasis in BW is on milk traits (NZAEL, 2015).

Some of this change for selection programmes occurred due to milk production traits having an unfavourable genetic correlation with fertility traits (Leroy *et al.*, 2008; Pryce *et al.*, 2004). The genetic correlation between milk yield and 21-day pregnancy rate has been estimated as -0.23 and -0.29 for first and second lactation cows, respectively (Grosshans *et al.*, 1997). These negative genetic correlations may have influenced the increased calving intervals, days to first oestrus and decreased conception rates for cows with high milk yields (Pryce and Veerkamp, 2001). Pryce *et al.* (1998) estimated that selection for a 100 L milk yield increase, per year, would be correlated to an annual 5 to 10-day increase to calving interval. Part of this increase to calving interval may be influenced by the higher incidence (19%) of extended anoestrous periods for Friesian cows, compared to Jersey (13%) and Holstein-Friesian x Jersey (14%) cows (Xu and Burton, 2003).

The submission rate of Holstein-Friesian cows has been shown to be lower (83%) than for Jersey (87%) and Holstein-Friesian x Jersey (87%) cows (Xu and Burton, 2003). The conception rate of Holstein-Friesian and Holstein-Friesian x Jersey cows was shown to be higher (56%) than Jersey cows (53%) (Xu and Burton, 2003). However, Holstein-

Friesian x Jersey cows had higher (72%) six-week in-calf rate when compared to that of Friesian (70%) and Jersey (70%) cows (Xu and Burton, 2003). Under New Zealand farming conditions, the fertility of North American Holstein-Friesian cows has been shown to be lower than New Zealand Holstein Friesians (McNaughton, 2003). Although, it appears that failure to conceive is the issue, rather than failure to resume ovarian cycling within the herds specified mating period (McNaughton, 2003).

The number of crossbred cows has increased in New Zealand, especially Holstein-Friesian x Jersey crossbreed cows, in an effort to capture positive heterosis effects for milk production and reproductive traits (Lopez-Villalobos and Garrick, 2006). Milk, fat and protein yield for crossbreds has been shown to exceed the average of both purebreed parents (Ahlborn-Breier and Hohenboken, 1991; Touchberry, 1992) The survival of crossbred cows has been shown to be 15.6% higher than for straightbred cows (Touchberry, 1992). Studies have shown that the proportion of cows pregnant to first service, cows in-calf during the first six-weeks and conception rate were higher ($P<0.05$), as well days to first oestrus were lower for Holstein-Friesian x Jersey cows compared to Holstein-Friesian and Jersey cows (Prendiville *et al.*, 2011; Vance *et al.*, 2013).

### 2.7.3 Lactation number and age

Provided a cow’s energy requirements are met and it remains healthy, milk production increases in each subsequent lactation, until lactation four or five or between the age six and seven years old (Holmes *et al.*, 2002; LIC and DairyNZ, 2016; Ray *et al.*, 1992). According to the New Zealand dairy statistics, the milk yield for a two-year-old Holstein-Friesian x Jersey cow is approximately 3256 L (LIC and DairyNZ, 2016). Milk yield increases to 4426 L at six years of age and declines from thereafter to 3843 L at ten years of age and greater (LIC and DairyNZ, 2016). Similar age trends occur for fat and protein yields (LIC and DairyNZ, 2016).

Age of the cow has been shown to have an impact on dairy cow reproductive performance (McDougall, 1994). It has been shown that two-year-old cows take an additional 13 days from parturition to first ovulation when compared to cows that are greater than three years-old (McDougall, 1994). Calving intervals for seasonal dairy systems were optimal between second and third parturition date (Evans *et al.*, 2006). Furthermore, as established in section 2.6.3.2, dairy cow survival to next lactation decreases as lactation number and cow age increases. This is likely to be influenced by New Zealand dairy cows reaching a maximum conception rate (59%) and six-week in-calf rate (75%) at four years old, and from thereafter, reproductive performance declined (Xu and Burton, 2003).

As cow age increases SCC has also been shown to increase (Carlén *et al.*, 2004; Hansen *et al.*, 2002; Syrstad *et al.*, 1979). This trend has been shown to occur up to nine to ten years of age, at which it is around five times greater than for two-year-old heifers (Syrstad *et al.*, 1979). The higher rate of infection in older cows, as well as increased milk production may contribute to this age trend for SCC (Carlén *et al.*, 2004; Emanuelson *et al.*, 1988; Syrstad *et al.*, 1979). However, it has been suggested that the age and lactation effects on SCC are minor if the gland remains unaffected throughout the cow's lifetime (Harmon, 1994).

### 2.7.4 Animal health

#### *2.7.4.1 Mastitis*

Mastitis is one the most prevalent diseases in dairy herds, and has a significant economic impact on farm profits (Blosser, 1979; Gill *et al.*, 1990; Seegers *et al.*, 1998). In New Zealand, the loss of annual profit, due to milk loss and additional health costs for infected cows, has been estimated to be $86 per cow (Holdway, 1992). At least 137 species of organisms have been identified as potential causes for bovine mastitis, but in New Zealand *Staphylococcus aureus* and *Streptococcus uberis* are two of the most common causes (Watts, 1988). Mastitis has short-term depressive effects on milk yield (Beck *et al.*, 1992; Houben *et al.*, 1993) but can also have long-term effects on milk yield (Fetrow *et al.*, 1991; Smith *et al.*, 1968). The annual negative effect of mastitis on the milk production has been estimated to be 527 L milk, 23 kg fat, and 14 kg protein for a second lactation cow (Houben *et al.*, 1993).

In addition to reducing milk yield, mastitis accounts for a significant proportion of cows culled (Esslemont and Kossaibati, 1997; Harris, 1989; Seegers *et al.*, 1998). In two

European studies, between 8% and 10% of culling cases were for mastitis (Esslemont and Kossaibati, 1997; Seegers *et al.*, 1998). In New Zealand, mastitis is the reason for culling in around 4% of cases (Xu and Burton, 2003), but the prevalence of culling due to mastitis has been shown to increase as cow age increased (Harris, 1989). Furthermore, cows with clinical mastitis have shown been shown to require a greater number of services per conception than cows that are unaffected by mastitis (2.1 versus 1.6) and longer number of days empty (140 versus 80 days) (Ahmadzadeh *et al.*, 2009).

### *2.7.4.2 Lameness*

Dairy cow lameness accounts for 20% of significant health issues in New Zealand dairy herds (Xu and Burton, 2003). A case study conducted in New Zealand on cows from three herds, showed that the incidence of lameness was between 2% and 38% (Tranter and Morris, 1991), and the risk of lameness was greater when farm tracks were not well maintained (Chesterton *et al.*, 1989). The majority of lameness cases were caused from sole bruising (42%) and white line separation (39%) (Tranter and Morris, 1991).

An American study showed that the milk production of lame cows can be up to 1.5 L per day lower, compared to herd-mates that have no history of lameness for that year (Warnick *et al.*, 2001). This trend is consistent with a New Zealand study that showed milk yield, fat yield and protein yield of lame cows was lower ($P<0.05$) than sound herd-mates (Tranter and Morris, 1991). Furthermore, lameness has been associated with an increased number of services per conception and decreased conception rates to first to service (Hernandez *et al.*, 2001; Melendez *et al.*, 2003). Cows that are lame within 30 days after parturiton were 2.3 times more likely to develop ovarian cysts prior to mating, which reduced their chance of conceiving by half (Melendez *et al.*, 2003). It has been proposed that some of these effects of lameness may be caused by increased concentrations of stress hormones, which reduces the secretion of lutenising hormone secretion from the anterior pituitary, and in turn delays the resumption of ovarian cycling (Melendez *et al.*, 2003; Walker *et al.*, 2008).

#### *2.7.4.3 Uterine and follicular health*

The inflammation and immune response that occurs with uterine infections is an important factor influencing dairy cow fertility (Sheldon and Dobson, 2004). It is common (greater than 80% of cows) for dairy cows to contain bacteria in the uterine lumen in the first two weeks postpartum (Sheldon *et al.*, 2006). Prior to fertilisation, a cow's uterus is required to undergo a period of uterine involution, which involves a reduction in uterine size and the restoration of endometrium (Sheldon *et al.*, 2006). Normal involution process begins immediately after parturition and has been shown to last for around 40 days (McDougall, 2001; Moller and MacDiarmid, 1981; Scully *et al.*, 2013). However, uterine involution is inhibited by bacterial contamination (Lewis and Gregory, 1997). Uterine health is an important factor influencing the reproductive performance by not only directly harming uterine tissue and endometrium, but also indirectly by altering the function of the hypothalamus and pituitary gland and therefore, delaying the resumption of ovarian cycling (Sheldon and Dobson, 2004).

Delayed uterine involution can be caused by abnormal parturition (Kiracofe, 1980), primarily due to increased risk of uterine infections that delay the involution process (Lewis and Gregory, 1997). Furthermore, the drugs (exogenous corticosteroids) used to induce calving (now prohibited in New Zealand) have been associated with increased retained foetal membranes (Villarroel and Lane, 2010). Retained foetal membranes are foetal membranes that have failed to be expelled from the animal within 24 hours (Ametaj *et al.*, 2010; Sheldon *et al.*, 2008). Retained placentas are commonly caused by dystocia and induced calving and hence, contribute to delayed uterine involution and therefore, reduced fertility (Sheldon *et al.*, 2008). The incidence of retained placenta has been shown to be higher for Holstein-Friesian cows (1.8%), compared to Jersey (1.3%) and Holstein-Friesian x Jersey cows (1.5%) (Xu and Burton, 2003).

### 2.7.5 Farm management practices

Farm management practices can have a significant impact on dairy cow productive and reproductive performance, and therefore survival. Some important farm management practices that impact dairy cow performance is discussed in this section. This includes mating management, planned start calving and dry-off dates and lastly, stocking rates and feed supply.

### *2.7.5.1 Mating management*

Due to the requirement for compact mating periods in New Zealand dairy systems, it is mandatory that accurate oestrous detection methods are imposed on-farm, to identify oestrus cows that are ready to be artificially inseminated (Macmillan and Watson, 1973). During the oestrus period the cow stands to be mounted, mounts other cows, has increased sniffing behaviours and vaginal discharge (Roelofs *et al.*, 2010; Roelofs *et al.*, 2005). The main method for detecting oestrus cows in New Zealand is the use of tail paint, where a visual disruption or disappearance of the paint provides evidence of an oestrus cow (Macmillan and Curnow, 1977; Macmillan *et al.*, 1988). Other methods include pedometers/accelerometers, chin-ball markers, mounting detectors (e.g. Kamar), and temperature or biochemical impedance measuring devices (for vaginal/milk temperature and vaginal mucus tests, respectively) (Kiddy, 1977; Lehrer *et al.*, 1992; Senger, 1994). Visual assessment with the aid of tail paint has been shown to detect at least 95% of cows in oestrus (Macmillan and Curnow, 1977; Xu *et al.*, 1998). However, the actual success of this management practice heavily relies on staff participation (Macmillan and Curnow, 1977). Poor oestrus detection can reduce the reproductive performance of the herd, even if the cows are cycling.

Anoestrous cows should be identified and managed accordingly at the start of mating (Xu and Burton, 1996). Progesterone can be used as a hormonal intervention treatment for anoestrous cows, as well as for synchronising herd oestrus (Lucy *et al.*, 2004). Progesterone synchronises cow oestrus with other cows by suppressing the luteinising hormone surge and oestrus behaviour (Lucy *et al.*, 2004). Generally, hormonal treatment programmes are 10 days, where on day 1 the cow is injected with gonadotrophin releasing hormone and a controlled internal drug release device (CIDR) inserted into the cow’s vagina, seven days later the CIDR is removed and the cow is injected with prostaglandin-2α (McDougall, 2010). Forty-eight hours later gonadotrophin releasing hormone is injected and 24 hours later the cow will be bred to artificial insemination (McDougall, 2010). This type of progesterone hormonal intervention can also be an effective treatment for anoestrous cows by promoting the resumption of ovarian cycling (Lucy *et al.*, 2004; McDougall, 2003; McDougall, 2010).

#### *2.7.5.2 Planned start calving and dry-off dates*

Planned start of calving and dry-off date have a significant impact on feed supply (Garcia and Holmes, 1999), and therefore, cow productivity. Matching calving date with the increase in pasture growth rate during the spring period, and the dry-off date with the decrease in pasture growth in late autumn, is important to ensure feed supply meets animal energy requirements at that time (Holmes *et al.*, 2002). A cow that calves on the planned start of calving date has 83 days to resume ovarian cycling before the next mating period, whilst a cow that calves a month later has only 53 days (Blackwell *et al.*, 2010). It has been shown that cows that had earlier parturition dates had less anoestrous problems (delayed resumption of ovarian cycling) (Xu and Burton, 2003) and cow survival is greater (Evans *et al.*, 2006) than for cows that had later parturition dates. Hence, reproductive performance and survival in the next lactation is negatively impacted by later parturition dates.

## 2.8 Conclusion

Maintaining an annual parturition is a key driver for the success of New Zealand's pastoral-based dairy systems. However, due to the calving interval time constraint, as well as management factors, a proportion of cows fail to conceive. No previous literature has estimated the frequency at which non-pregnant cows are carried over and returned to a milking herd, despite the potential impact of carryover cows on farm productivity. Two previous reports have indicated that carryover cows have a milk production advantage when compared to non-carryover groups and this can be maintained for up to three subsequent years. The reproductive performance of carryover cows has been shown to be lower than non-carryover cows. However, the number of dairy cows in these studies were relatively small (20-162), based in one region of New Zealand (Canterbury) and the herds consisted of a high proportion of Holstein-Friesian genetics (55-76%). A cow's pre-calving BCS, age, breed and genetics, animal health, as well as, farm management practices have been identified as factors that influence carryover and productivity once they returned to a milking herd.

### 2.8.1 Thesis objectives

After identifying the knowledge gaps in the literature and potential areas of research for carryover cows, the objectives of this study are to:

1. Identify and describe the spring-calving carryover cow population, in terms of their prevalence, breed and genetic merit and to compare this to the non-carryover cow population (Chapter 3).
2. Determine the milk production (MY, FY, PY and SCS) for carryover cows compared to heifers, lactation-matched and age-matched non-carryover cows for up to three years after they have returned to a milking herd (Chapter 4).
3. Determine and compare the survival of carryover cows once they return to a milking herd with that of heifers and lactation-matched non-carryover cows (Chapter5).

# Chapter 3 Carryover cow population

Paper: Gardner, R., Back, P.J., Lopez-Villalobos, N., and McNaughton, L.R. 2017. *The percentage of spring-calving carryover cows in New Zealand dairy herds and their milk production, compared to heifers, age-matched and lactation-matched non-carryover cows.* Proceedings of the New Zealand Society of Animal Production, 77:3-7.

Paper: '*The milk production and survival of spring-calving carryover cows in New Zealand'* submitted to Journal of Dairy Science

## 3.1 Introduction

The majority (95%) of New Zealand dairy cows calve during the spring period. In order to maintain a seasonal calving pattern, calving interval should remain close to 365 days (Holmes *et al.*, 2002). Each year, approximately 10% of dairy cows fail to maintain this seasonality and are confirmed as non-pregnant (Xu and Burton, 2003). Non-pregnant cows are generally culled (removed) from the herd and replaced by two-year-old heifers (Holmes *et al.*, 2002). Alternatively, non-pregnant cows can be dried off at the end of lactation, retained (carried over) for one non-lactating year, before being mated and returned to a milking herd in the following year (Pangborn and Woodford, 2010). Carryover cows may be returned to the same milking herd, or they could be sold to another herd. To the authors' knowledge, no studies have directly estimated the frequency of this management practice, despite its existence in the New Zealand dairy industry and its potential impact on farm productivity and profitability. Accordingly, the main objectives of this chapter were to determine the percentage of spring-calving carryover cows in the New Zealand dairy herd on a per year, cow age and per herd basis; and to determine if there is a difference between breed proportions, EBVs and selection indices for carryover and non-carryover cows in the New Zealand dairy industry.

## 3.2 Materials and Methods

### 3.2.1 Data extraction

A total of 20 million lactation records and animal information for dairy cows born between 2003 and 2013 were extracted from the Livestock Improvement Corporation (LIC) animal database. The lactation records were sourced from 5.6 million cows that were members of 15,692 herds that were herd tested at least three times per year. The data included information on lactation yields (MY, FY and PY), and herd test records for SCC corresponding to the lactation; as well as breed proportions, ancestry information, animal movement and parturition dates. All data manipulation steps (sections 3.2.2 and 3.2.3) were performed using SAS version 9.4 (SAS Institute Inc., Cary, NC, USA).

### 3.2.2 Carryover cow definition

Carryover cows fail to maintain a calving interval that is close to 365 days, whereas non-carryovers cow have a history of maintaining annual parturition dates. Accordingly, calving interval was used as a tool to identify cows that failed to maintain annual parturition dates. Calving interval was calculated as $PD_x - PD_{x-1}$, where $PD_x$ represented the successive parturition date (if it existed) and $PD_{x-1}$ represented the previous parturition date. The calculated calving interval was matched to the $PD_x$ lactation record. This procedure was repeated for every parturition date for the cow. Calving interval for lactation one was represented as a missing value.

Cows that had at least one calving interval that was between 547 days and 913 days were classified as carryover cows. The lower calving interval limit (547 days) accounted for cows that calved late in the previous year ($PD_{x-1}$ = 31$^{st}$ November), failed to conceive during the mating period, were carried over for one year, then calved early in the following year ($PD_x$ = 1$^{st}$ June). In contrast, the upper limit (913 days) accounted for cows that calved early in the previous year ($PD_{x-1}$ = 1$^{st}$ June), failed to conceive during the herd's mating period, were carried over for one year then calved late in the following year ($PD_x$ = 31$^{st}$ November).

Cows that had calving interval records that were consistently between 270 days and 546 days, throughout their lifetime, were defined as non-carryover cows. These limits provide a maximum and minimum calving interval value for a cow that maintained a seasonal calving interval on either side of it's carryover period. The lower limit (270 days) accounted for cows that calved prematurely (e.g. abortion) but had a lactation record for that year. The maximum number of days that a cow could maintain an annual parturition date was 548 days. A data check confirmed that zero lactation records in Dataset 1 fell between 547 days (the lower limit for a carryover cow lactation record) and 548 days. Thus, the upper limit for non-carryover cows was set to 546 days. All lactation records for cows that had at least one calving interval record that was less than, or greater than, the carryover and non-carryover calving interval limits (270 and 913 days) were discarded. Refer to Appendix A for the process of data exclusion for Dataset 1.

### 3.2.3 Data editing

*3.2.3.1 Breed*

Cow breed and ancestry breed (sire and dam) information was matched each cow's lactation record. Cows were considered as purebred Holstein-Friesian, or purebred Jersey, if their breed proportions (expressed as 16th) were at least $\frac{14}{16}$ (87.5%) for either respective breed. Crossbred cows were categorised into three groups: Holstein-Friesian x Jersey; Jersey x other; or, Holstein-Friesian x other, where other breeds included Ayrshire, Brown Swiss, Guernsey, Milking Shorthorn or any uncategorised breed. Cows were categorised as Holstein-Friesian x Jersey if their breed proportions were at least $\frac{3}{16}$ (18.75%) Holstein-Friesian and less than, or equal to $\frac{13}{16}$ (81.25%) Jersey, or vice versa. Similarly, cows were categorised as Jersey x other and Holstein-Friesian x other if breed proportions were at least $\frac{3}{16}$ (18.75%) Jersey or Holstein-Friesian, and less than, or equal to $\frac{13}{16}$ (81.25%) other breed proportions, and vice versa. Cows with at least $\frac{14}{16}$ (87.5%) other breed proportions were categorised as 'other'.

The coefficient of heterosis for each Holstein-Friesian x Jersey cow was calculated using the formula $h_{FJ} = \alpha_{sF}\alpha_{dJ} + \alpha_{sJ}\alpha_{dF}$, where $h_{FJ}$ was the coefficient of expected heterosis between fractions of Holstein-Friesian (F) and Jersey (J) in the cow and $\alpha_{dF}$, $\alpha_{dJ}$, $\alpha_{sF}$ and $\alpha_{sJ}$ were the proportion of F and J in the dam (d), and sire (s), respectively (Dickerson, 1973). If breed or ancestry information was unavailable, then breed category and/or heterosis was represented as a missing value.

*3.2.3.2 Spring-calving definition*

Cow records from herds that contained only spring-calving parturition dates (June to November) were retained for Dataset 1. Herds were defined as having a split-calving (spring and autumn) pattern if lactation records had parturition dates that were not consistently between June and November. It was assumed that cows that failed to meet the spring-calving limit were in a split-calving herd for their whole lifetime or transferred between split-calving herds and spring-calving herds.

### *3.2.3.3 Extended non-lactating period*

Cows that were identified as carryover cows according to the classification in section 3.2.2, but had greater than 305 days in milk for their previous lactation record were removed. It was assumed that these cows had an extended lactation period, rather than an extended non-lactating period. Thus, these cows were treated as a different group. Lactation records sourced from split-calving herds or from cows that had an extended lactation period were not considered any further in the analysis.

### *3.2.3.4 Age and lactation number*

Age limits were imposed as a data cleaning method to reduce the number of animals that had poorly recorded lactation information. Lactation records from cows that had their first parturition date before they were 1.7 years old or after they were 2.7 years of old were discarded. This age limit ensured autumn-born cows that maintained a spring parturition date throughout their lifetime were included in the dataset. Furthermore, cows were required to have a second, third, fourth and greater than fifth parturition date before they were 6.2, 8.7, 11.2 and 13.0 years old, respectively. These age limits accounted for an additional 913 days (~2.5 years) on the previous age limit to ensure that carryover cow lactation records were included in the dataset. For example, the age limit for parturition two (6.2) was calculated as 1.7 years (previous age limit) plus 2.5 years.  All lactation records for cows that did not meet all age limits were discarded.

Age at parturition was rounded down to a whole number (years) when it was between 0.1 and 0.7 of a whole number, whereas age at parturition was rounded up to a whole number when it was greater than 0.7 of a whole number. Age at parturition rounded (APR) was used to estimate lactation number (LN) using the formula LN = APR – 1 for non-carryover records, with no previous carryover records for that cow, and using the formula LN = APR – 2 for carryover records, or for any subsequent lactation records for carryover cows.

Table 3.1 compares the average raw age at parturition (prior to rounding) versus the average age after rounding had taken place for each lactation. It is evident that the rounding limits had no effect on the average age for each lactation.

**Table 3.1** The average age at parturition (AP) (years) and age at parturition rounded (APR) (years) for lactation 1 to 12.

| Lactation | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Raw AP (years) | 2.0 | 3.0 | 4.1 | 5.1 | 6.1 | 7.1 | 8.0 | 9.0 | 10.0 | 11.0 | 12.0 | 12.9 |
| APR (years) | 2.0 | 3.0 | 4.1 | 5.1 | 6.1 | 7.1 | 8.0 | 9.0 | 10.0 | 11.0 | 12.0 | 13.0 |

### 3.2.4 Statistical analysis

The Statistical Analysis System (SAS) software package version 9.4 (SAS Institute Inc., Cary, NC, USA) was used for the statistical analysis.

#### *3.2.4.1 The percentage of carryover cows by year, age and per herd*

The percentage of carryover cows in New Zealand dairy herds, on a per year, cow age and per herd basis was calculated from Dataset 1 after all data manipulations and exclusion took place (Appendix A). Table 3.2 summarises the number of carryover (CO) and non-carryover (NCO) cows, for each breed category in Dataset 1. In the study population of 4,879,361 cows, 8.7% of cows had carried over at one stage of their lifetime and of these carryover cows, 4% had carried over more than once.

The FREQUENCY procedure of SAS was used determine the number of carryover lactation records (cows) with parturition dates between the 2008 and 2015 years (14,928,832 lactation records). The number of carryover cows was expressed as a percentage of all productive cows (cows with a lactation record) in that year. The percentage of carryover cows for each year was averaged between 2008 and 2015. The FREQUENCY procedure of SAS was also used to determine the percentage of carryover cows that returned to a dairy herd at four, five, six and greater than seven years old.

**Table 3.2** The number of carryover (CO) cows and the number of non-carryover (NCO) cows for each breed category in Dataset 1.

| Breed | CO | NCO |
|---|---|---|
| Holstein-Friesian | 138,492 | 1,328,859 |
| Jersey | 49,030 | 520,933 |
| Other* | 10,133 | 112,042 |
| Holstein-Friesian x Jersey | 151,164 | 2,030,046 |
| Jersey x Other | 9,175 | 119,965 |
| Holstein-Friesian x Other | 31,418 | 374,684 |
| Unknown | 252 | 3,168 |
| Total | 389,664 | 4,489,697 |

*Other consists of Ayrshire, Brown Swiss, Guernsey, Milking Shorthorn or any uncategorised breed.

A total of 11,419 dairy herds were selected from 15,376 herds in Dataset 1 on the basis that they contained at least 70 cows per herd in each year. The FREQUENCY procedure of SAS was used to calculate the average percentage of carryover cows per herd in Dataset 1 between 2008 and 2015. The results were categorised into three groups: herds that comprised of zero carryover cows; less than 5% carryover cows; and, greater than 5% carryover cows. Further, of herds that contained carryover cows, the percentage of herds that contained greater, or less than 5% carryover cows were determined to identify herds that comprised of a small percentage (less than 5%) or a large percentage (greater than 5%) of carryover cows. Additionally, the percentage of carryover cows that were sold to another herd prior to returning to a milking herd, rather than returning to the same herd, was determined.

#### *3.2.4.2 The percentage of carryover cows in high and low performing herds*

Dataset 2 was formed from Dataset 1 (Appendix B) and was used to calculate the percentage of carryover cows in herds that were in the upper and lower quartiles (25%) for milk production. Dataset 2 was grouped by herd and year and the total number of cows, average Holstein-Friesian and Jersey breed proportions and MY, FY and PY was determined for each herd-year group. Breed proportions were averaged for each herd-year group were averaged according to the breed classification system established in section 3.2.3.1. Herds that met the breed classification limits for Holstein-Friesian, Jersey or Holstein-Friesian x Jersey were retained. Lactation records with suspected recording errors (<150 or <305 days in milk, <800 or >8000 L milk, <40 or >400 kg of protein, <30 or >300 kg of fat) were removed. Herd-year groups that contained less than 70 lactation records were discarded.

The MEANS procedure of SAS was used to determine the upper quartile and lower quartile for MY, FY and PY for each breed category (Holstein-Friesian, Jersey and Holstein-Friesian x Jersey) in Dataset 2. The upper quartile and lower quartile limits were recorded (Table 3.3) and used to categorise herds that were in the upper and lower quartile for milk production. The number of carryover cows per herd was calculated and expressed as a percentage of the total number of herds in each breed group. The T-TEST procedure of SAS was used to determine whether there was a significant (P<0.01) difference between the percentage of carryover cows in herds that were in the upper and lower quartile for milk production in each breed category.

**Table 3.3** The milk production limits (milk yield (MY), fat yield (FY) and protein yield (PY)) used to categorise the upper quartile (UQ) and lower quartile (LQ) herds for milk production.

| Breed | Limits for UQ herds | | | Limits for LQ herds | | |
|---|---|---|---|---|---|---|
| | MY (L) | FY (kg) | PY (kg) | MY(L) | FY (kg) | PY (kg) |
| Holstein-Friesian | 5169 | 223 | 187 | 3947 | 171 | 142 |
| Jersey | 3548 | 207 | 148 | 2800 | 160 | 116 |
| Holstein-Friesian x Jersey | 4509 | 220 | 174 | 3479 | 171 | 134 |

#### *3.2.4.3 Proportion Holstein-Friesian, Jersey and coefficient heterosis for carryover and non-carryover cow groups*

Dataset 1 was used to calculate the average proportion Holstein-Friesian, proportion Jersey and heterosis coefficient (Holstein-Friesian x Jersey) for carryover and non-carryover cow groups. Any cow records that had missing breed information were discarded. Table 3.4 displays the total number of carryover and non-carryover cow records that were included in the breed comparison. The MEANS procedure of SAS was used to determine the average proportion Holstein-Friesian and Jersey, as well as coefficient heterosis (Holstein-Friesian x Jersey) for the carryover and non-carryover cow groups. The T-TEST procedure of SAS was used to determine whether the difference for each group was significantly ($P<0.01$) different.

**Table 3.4** The total number of breed records for carryover (CO) cows and non-carryover (NCO) cows that were used to determine the average proportion of Holstein-Friesian, Jersey and coefficient of heterosis.

| Cow group | Number of records |
|---|---|
| CO | 389,664 |
| NCO | 4,489,697 |

### *3.2.4.4 Estimated breeding values and selection indices for carryover and non-carryover groups*

Carryover cows that returned to a milking herd in their second lactation and during the 2013 year were identified in Dataset 1 and combined with lactation records from non-carryover cows in the same lactation and year. The MEANS procedure of SAS was used to determine the average EBVs for milk traits (MY, FY, PY, SCS) and fertility, as well as BW and PW selection indices for each cow type (carryover and non-carryover). The difference ($P<0.01$) between the EBVs of each group was compared using the T-TEST procedure of SAS.

Lactation one records for the same carryover cows, prior to their carryover period in the 2011 year were identified and combined with lactation records for non-carryover cows that were in the same lactation and year. The same process, as specified in the previous paragraph, was used to determine the mean for each EBV and whether a significant ($P<0.01$) difference occurred between the carryover and non-carryover group.

This method was repeated for carryover cows that returned to a milking herd in lactation three and for the same cows in lactation two, prior to their carryover period. Table 3.5 summarises the number of lactation records for each group.

**Table 3.5** The number of lactation records for carryover cows (CO) that returned to a milking herd in lactation two and three (2013), and for their previous lactation (2011), as well as the number of non-carryover (NCO) comparisons.

| Lactation returned | Cow type | 2011 records | 2013 records |
|---|---|---|---|
| Two | CO | 22,202 | 22,202 |
| | NCO | 449,904 | 396,113 |
| Three | CO | 15,307 | 15,307 |
| | NCO | 372,232 | 345,653 |

## 3.3 Results

### 3.3.1 The percentage of carryover cows in spring-calving dairy herds

Figure 3.1 shows the distribution of calving interval for all lactation records in Dataset 1. Lactation records with calving intervals that were between 270 and 546 days represent non-carryover lactation records and lactation records with calving intervals that were between 547 days and 913 days represent carryover lactation records.

Annually, 2.5% of dairy cows in spring-calving herds had returned to a milking herd after a previous carryover year. The annual percentage of carryover cows in Dataset 1 ranged between 2.2% and 3.1% for the 2014 and 2009 years, respectively (Table 3.6). The majority of carryover cows (43%) returned to a milking herd at four years old, after failing to conceive during their first lactation. The percentage of carryover cows that returned to a milking herd at five, six, seven and greater than eight years old was 27%, 15%, 8% and 7%, respectively.

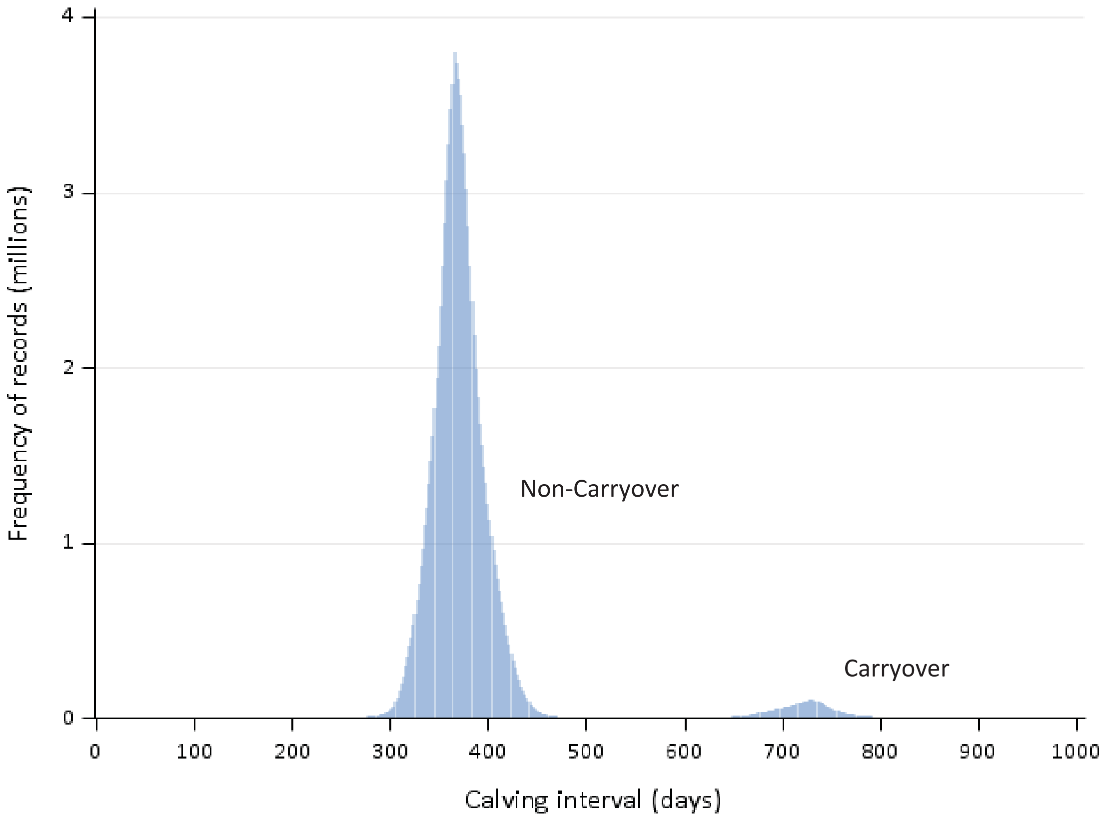


**Figure 3.1** The distribution of calving interval (days) records in Dataset 1. Non-carryover lactation records have calving intervals between 270 days and 546 days. Carryover lactation records have calving intervals between 548 days and 913 days.

**Table 3.6** The total number of non-carryover (NCO) cows and carryover (CO) cows and the percentage of spring-calving carryover cows in Dataset 1 between 2008 and 2015.

| Year | NCO | CO | Total | Percentage of CO cows |
|---|---|---|---|---|
| 2008 | 1,181,634 | 30,673 | 1,212,307 | 2.5% |
| 2009 | 1,358,028 | 43,692 | 1,401,720 | 3.1% |
| 2010 | 1,631,796 | 41,107 | 1,672,903 | 2.5% |
| 2011 | 1,848,437 | 44,716 | 1,893,153 | 2.4% |
| 2012 | 2,043,611 | 54,064 | 2,097,675 | 2.6% |
| 2013 | 2,247,948 | 60,189 | 2,308,137 | 2.6% |
| 2014 | 2,376,017 | 53,798 | 2,429,815 | 2.2% |
| 2015 | 2,241,361 | 58,361 | 2,299,722 | 2.5% |

The average percentage of dairy herds that contained zero, less than 5% and greater than 5% carryover cows between 2008 and 2015 was 17%, 69% and 14%, respectively. Of herds that contained carryover cows, the majority (82%) contained less than 5% carryover cows. Most (61%) carryover cows remained in the same milking herd, whereas, 39% of carryover cows returned to a different herd than the herd in which they were confirmed as non-pregnant (i.e. they were sold after being confirmed non-pregnant).

Holstein-Friesian dominant herds in the upper quartile for milk production, contained 3.4% carryover cows, which was less (P<0.01) than that for herds in the lower quartile for milk production (5.1% carryover cows) (Figure 3.2). The percentage of carryover cows in Holstein-Friesian x Jersey dominant herds in the upper quartile for milk production was 3.7%, which was less (P<0.01) than the percentage of carryover cows in Holstein-Friesian x Jersey herds in the lower quartile for milk production (4.3%) (

Figure 3.). In contrast, the percentage of carryover cows in Jersey dominant herds that were in the upper and lower quartile for milk production was not different (P=0.5). Jersey herds in the upper quartile for milk production comprised of 3.2% carryover cows, which was 0.2% more carryover cows than Jersey herds in the lower quartile for milk production (Figure 3.2).

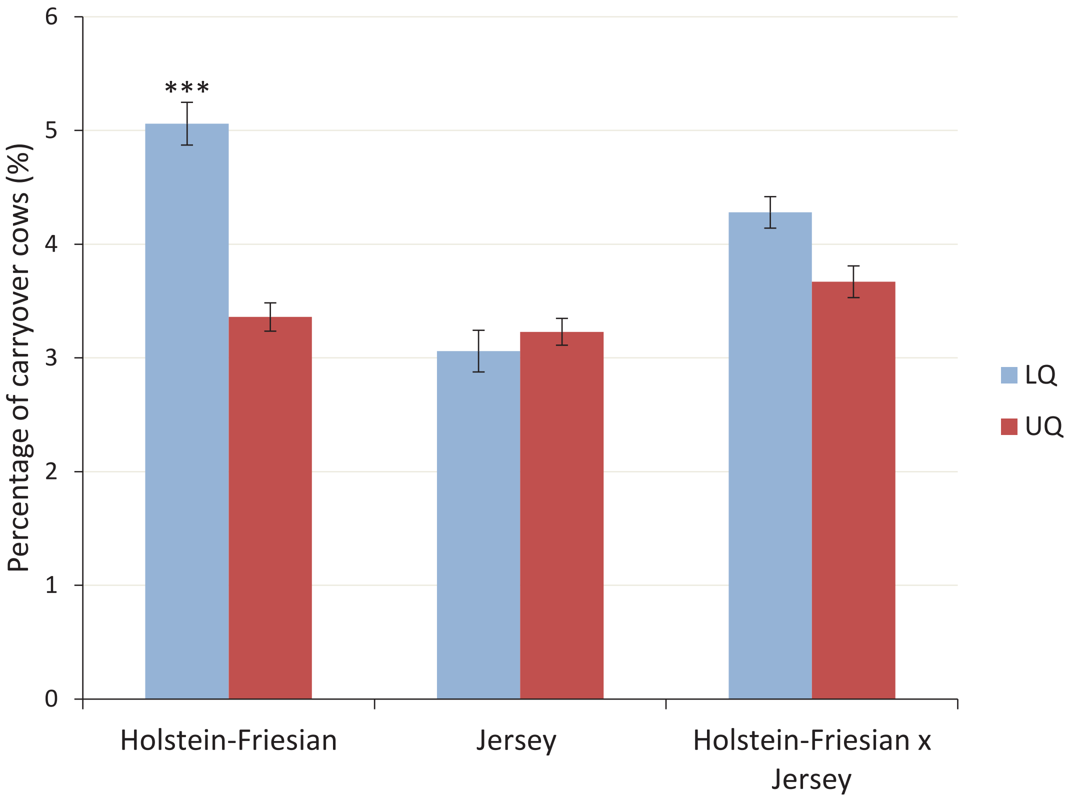


**Figure 3.2** The percentage of carryover cows in Holstein-Friesian, Jersey and Holstein-Friesian x Jersey herds that were in the upper quartile (UQ) and lower quartile (LQ) for milk production. ***Denotes a significant (P<0.01) difference between the UQ and LQ group.

### 3.3.2 Carryover over cow breed, estimated breeding values and selection indices

#### *3.3.2.1 Breed proportions*

The average proportion of Holstein-Friesian, Jersey and heterosis coefficient for Holstein-Friesian x Jersey carryover and non-carryover cows is presented in Table 3.7. The proportion Holstein-Friesian for the carryover group was 0.60, which was 0.022 greater (P<0.01) than the that for the non-carryover group. The proportion of Jersey for the non-carryover group was 0.018 greater (P<0.01) than the carryover group. The coefficient for heterosis for Holstein-Friesian x Jersey cows in the carryover group was 0.038 greater (P<0.01) than the non-carryover group.

**Table 3.7** The average proportion Holstein-Friesian, proportion Jersey and heterosis coefficient (Holstein-Friesian x Jersey) for carryover (CO) and non-carryover (NCO) groups.

| Average type | Cow group type | | P value |
|---|---|---|---|
| | CO | NCO | |
| Proportion Holstein-Friesian | 0.60 ± 0.0011 | 0.59 ± 0.0002 | <0.01 |
| Proportion Jersey | 0.32 ± 0.0013 | 0.34 ± 0.0002 | <0.01 |
| Heterosis coefficient | 0.27 ± 0.0012 | 0.31 ± 0.0002 | <0.01 |

*3.3.2.2 Breeding values and selection indices*

Figure 3.3 and Figure 3.4 show the EBVs (MY, FY, PY, SCC and fertility) and selection indices (PW and BW) for carryover cows that returned to a milking herd in a second and third lactation, respectively, compared to their non-carryover counterparts. Carryover cows that returned to a milking herd in their second and third lactation consistently had greater (P<0.01) EBVs for MY, FY, PY, and SCC in the lactation prior (2011) to their carryover period (Figure 3.3 and Figure 3.4). The difference between the EBVs for MY, FY and PY of carryover groups and non-carryover groups in 2011 decreased when the carryover cows returned to a milking herd (2013) (Figure 3.3 and Figure 3.4). However, the EBVs for carryover groups remained greater (P<0.01) than that for the non-carryover groups.

The SCC EBV for carryover cows that returned to a milking herd in second and third-lactation increased between their pre-carryover lactation to their post-carryover lactation and was consistently greater (P<0.01) than the SCC EBV for non-carryover groups.

Carryover cow fertility EBVs were lower (P<0.01) than those for lactation-matched non-carryover cows in 2011, prior to being carried over. After failing to conceive, being carried over and returning to a milking herd, the fertility EBVs of carryover cows were reduced further and were lower (P<0.01) than the fertility EBVs for non-carryover lactation-matched cows.

The PW of carryover cows that returned to a milking herd in second and third-lactation was greater (P<0.01) than non-carryover lactation-matched cows (Figure 3.3 and Figure 3.4). Production Worth decreased for carryover cows that returned to a milking herd in lactation two, and was not different (P=0.1) to the non-carryover group (Figure 3.3) Carryover cow PW also decreased when they returned to a herd in their third lactation, but was lower (P<0.01) than that of lactation-matched non-carryover cows (Figure 3.4). The BW for both carryover cow groups was greater (P<0.01) than that of non-carryover cows, in 2011, prior to being carried over. Breeding Worth decreased and was lower (P<0.01) than the BW for non-carryover groups when the carryover cows returned to a milking herd (Figure 3.3 and Figure 3.4).

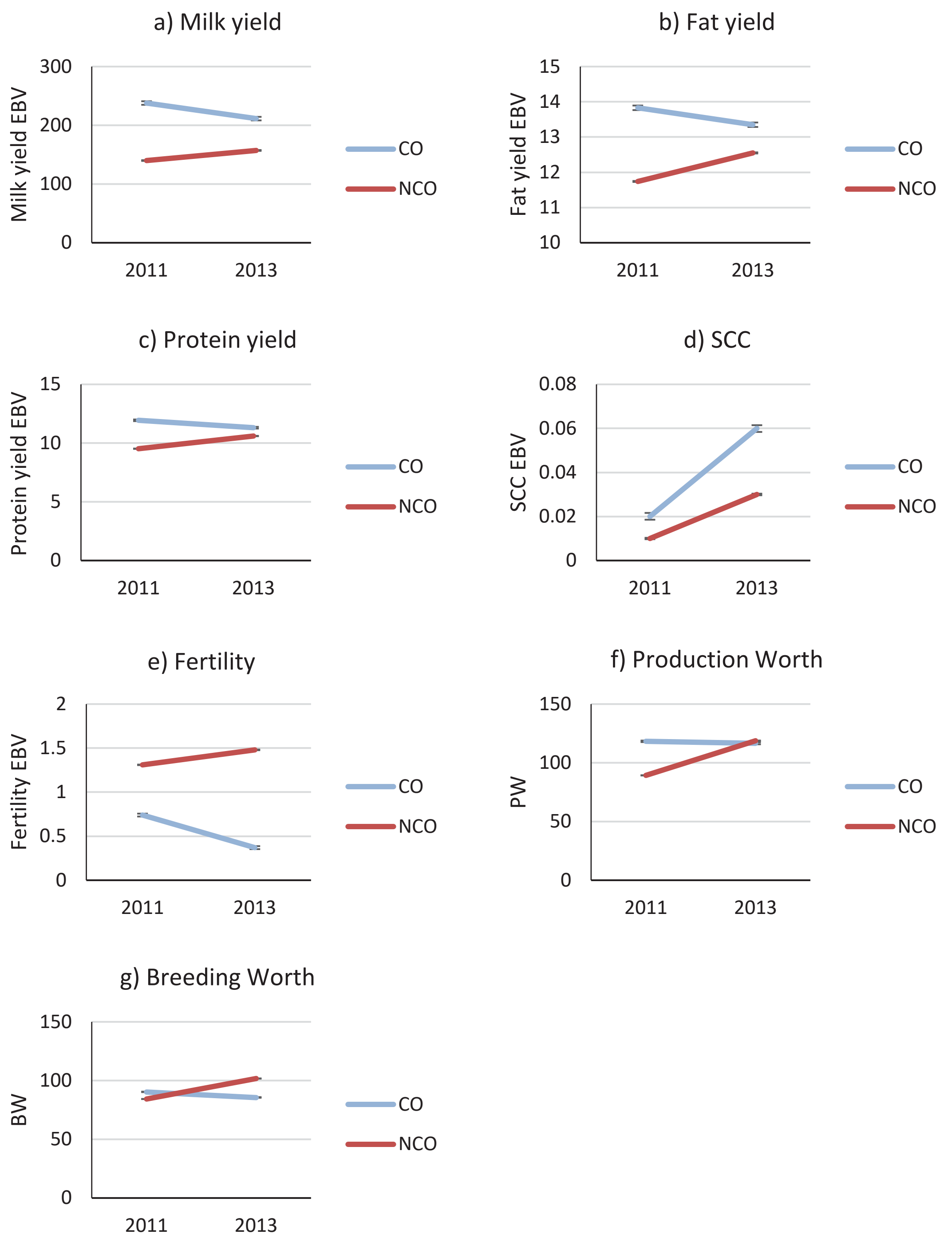


**Figure 3.3** The Estimated Breeding Values for (a) milk yield, (b) fat yield, (c) protein yield, (d) somatic cell count (SCC), (e) fertility, as well as, the (f) Production Worth and (g) Breeding Worth for carryover (CO) cows that returned to a milking herd in lactation two (2013) and for their previous lactation (2011) and for non-carryover (NCO) cows in the same lactation and year.

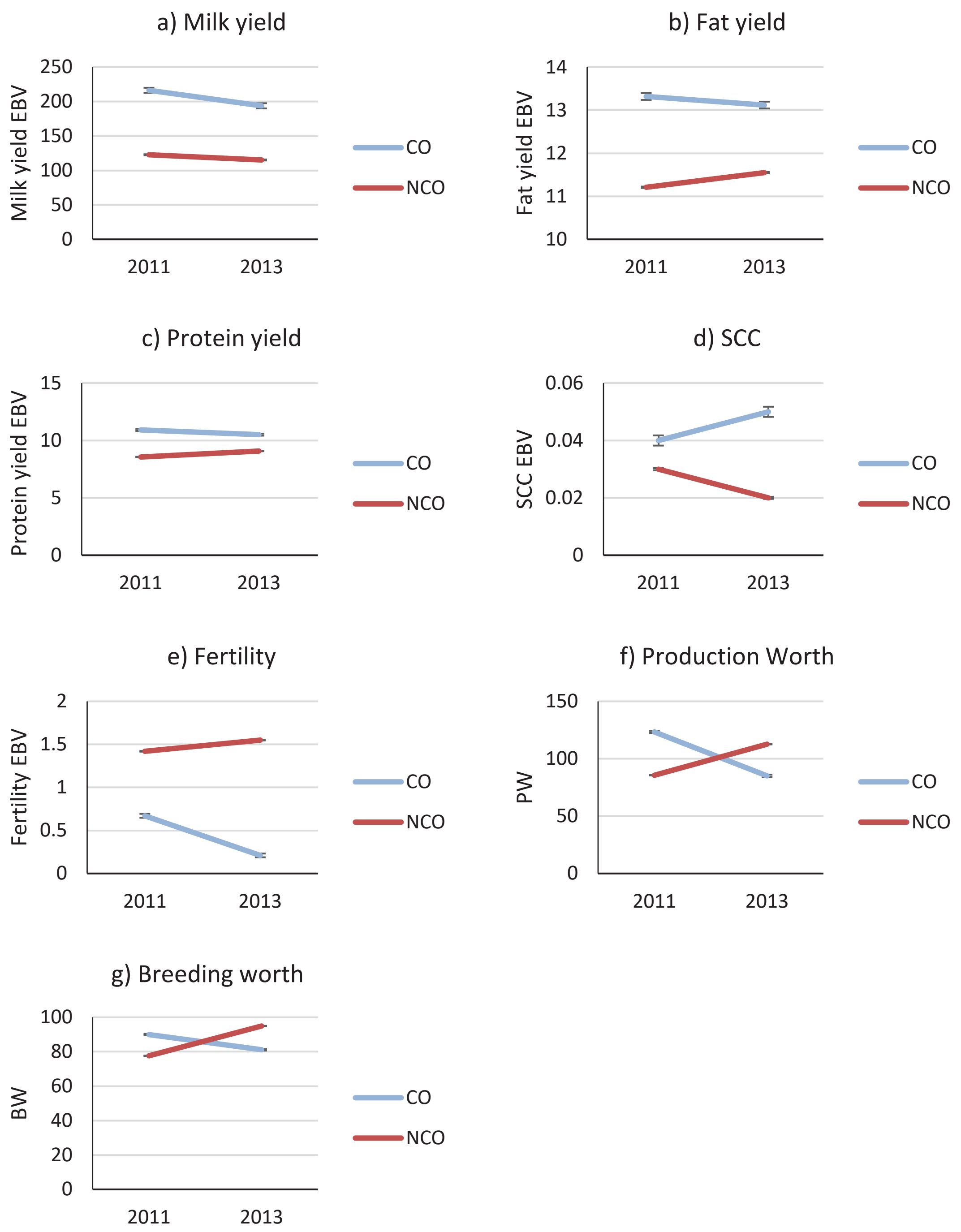


**Figure 3.4** The Estimated Breeding Values for (a) milk yield, (b) fat yield, (c) protein yield, (d) somatic cell count (SCC), (e) fertility, as well as, the (f) Production Worth and (g) Breeding Worth for carryover (CO) cows that returned to a milking herd in lactation three (2013) and for their previous lactation (2011) and for non-carryover (NCO) cows in the same lactation and year.

## 3.4 Discussion

The objective of this chapter was to determine the percentage of carryover cows in spring-calving dairy herds, on a yearly, cow age and per-herd basis; and to describe breed and genetic merit differences between carryover and non-carryover cow groups. To the author's knowledge, no previous literature has directly estimated these figures, despite the potential impact that carrying over non-pregnant cows could have on farm productivity and efficiency.

Figure 3.1 of section 3.3.1 showed that a proportion of New Zealand's spring-calving dairy cows have an extended calving interval. In the current study, calving interval appears to be normally distributed for each group, which is similar to the calving-interval distribution that was reported in Macmillan and Moller (1977). The results showed that 2.5% of spring-calving dairy cows in the New Zealand dairy herd had a carryover period in the previous year. This is similar to a figure that was estimated in Macmillan and Moller (1977), where there was a disparity of 2% between the percentage of production-tested cows culled for low fertility (3.6%) and the percentage of empty cows in their study (5.6%). It was suggested that this discrepancy may be accounted for by 2% of those empty cows being carried over (Macmillan and Moller, 1977). It must be noted that the use of calving interval in the current study does not capture cows that were carried over before their first parturition date (maiden heifers) and the proportion of cows that are carried over, but failed to conceive and subsequently, did not return to a milking herd.

Financial components, such as profit and cash flow have been identified as major factors that influence culling decisions (Lehenbauer and Oltjen, 1998). Therefore, annual fluctuations for milk price, cull cow prices or the cost to raise replacement heifers will contribute to the variability in the percentage of carryover cows that was shown in the results. The decision to carryover a non-pregnant cow takes place two years prior to when the carryover cow returns to a milking herd. Therefore, factors in two years prior to the present year impact on the current percentage of carryover cows in the national herd. The percentage of carryover cows was greatest (3.1%) in the 2009/10 year and two years prior to this (2007/08) the average milk price for Tatua, Fonterra and Westland was relatively high ($7.67 kg MS) (LIC and DairyNZ, 2016). When milk prices are relatively high, a farmer may be more inclined to carryover a young and/or high genetic merit non-pregnant cow as cash flow will be higher and may be used to support the extra grazing costs associated with the practice. However, often these management decisions are influenced by the farm manager as an individual (e.g. social factors) and their culling policies (Compton *et al.*, 2017; Lehenbauer and Oltjen, 1998). For example, Figure 3.2 showed that few farmers have high carryover cow rates, indicating that there is farm-to-farm variation. Further research is required to confirm the factors influencing the decision to carryover a non-pregnant cow.

If the forecasted milk price is relatively high, the expected returns from a carryover cow once they re-enter a milking herd will be greater than for a heifer, which on average, produces 28% less milk than mixed-age cows (greater than two years old) (LIC and DairyNZ, 2016). Previous studies have estimated the net profit of a carryover cow to be $228 greater than a heifer replacement when the milk price was $5.10 (Pangborn and Woodford, 2010). This evaluation incorporated the cost of breeding, grazing, animal health, failure to get pregnant and culling costs, all of which have annual price fluctuations. Therefore, it is difficult to comprehensively model the economics of retaining non-pregnant cows. An economics study of this type could determine what option (i.e. retain the non-pregnant cow or sell her to the abattoir or another farmer) is most viable to a farmer, depending on important considerations such as market prices, the age of the cow and the genetic merit of the cow

The majority (43%) of carryover cows returned to a milking herd at four years old, after failing to conceive during their first lactation. The percentage of carryover cows that returned to milking herds decreased as cow age increased. New Zealand dairy cows reach peak milk production between five and six years old (LIC and DairyNZ, 2016). Thus, non-pregnant cows that are carried over at greater than four years old will return to a milking herd beyond their peak milk production. This may negatively influence the farmers' decision to carryover older, non-pregnant cows, as an alternative to culling them and introducing a two-year heifer.

Management differences (e.g. culling policies, reproductive management) between herds that comprise of zero carryover cows and those that contain either less than, or greater than, 5% carryover cows. Furthermore, management differences between herds that were categorised as being in the upper and lower quartile for milk production, may contribute to the frequency with which non-pregnant cows were carried over. However, from the information provided in the dataset, it is difficult to determine the impact of these differences. It cannot be assumed that a herd in the lower quartile for milk production is poorly managed and therefore, the percentage of carryover cows for these herds is higher. It may be that some farms are low-input, or milk once-a-day all season, resulting in lower milk production and/or have a less strict culling policies when compared to a high-input farm that has relatively high milk production.

The EBVs reported in section 3.3.2.2 show that carryover cows had consistently (pre- and post-carryover) greater EBVs for MY, FY and PY, but lower fertility EBVs, when compared to non-carryover cow groups of the same lactation and year. Herd replacement and culling decisions are often based on cow BW and/or PW, and if culling decisions are made on the latter there is no consideration for cow fertility (LIC, 2009). It is likely that the high BW and PW of non-pregnant cows (pre-carryover period) positively influenced the decision to carryover the cow. The high EBVs for milk traits in carryover cows have a positive influence on BW, and masked the negative impact of low EBVs for fertility on BW.

The lower fertility EBV of carryover cows suggests that on average they are expected to have lower subsequent reproductive performance than non-carryover cows. One aspect that is incorporated into the calculation of fertility EBVs is whether the cow was submitted for mating in the first 21 days of lactation one, two and three (NZAEL, 2016a). Cows which fail to conceive have a lower likelihood of being submitted in the first 21 days which would be expected to result in a lower fertility EBV in a cow that was carried over, compared to a cow that conceived. In first lactation, milk volume is used in the calculation of fertility EBVs (NZAEL, 2016a). High milk volume in first lactation is negatively genetically correlated with fertility, and cows that were carried over had higher milk trait EBVs, which would have contributed to their lower fertility EBVs. The difference between carryover and non-carryover cow milk trait EBVs was less in the year when the carryover cows returned to a milking herd (2013), than for the 2011 year. Additionally, carryover cow EBVs for fertility were lower than those in their pre-carryover year. Such changes resulted in the BW of carryover cows being lower than non-carryover cows when they returned to a milking herd.

The milk trait and fertility EBVs of the non-carryover group tended to increase between the 2011 and 2013 year. However, to compare the genetic merit of carryover cows and lactation-matched non-carryover cows in the same year (2011 and 2013), the non-carryover cow group comparisons were required to be different cows. Consequently, it is difficult to compare the trend seen for the change in genetic merit of non-carryover cow and carryover cows.

The difference between the proportion of Holstein-Friesian in carryover and non-carryover groups was relatively small (2%) but significantly ($P<0.01$) greater for the carryover group. Holstein-Friesian cows have higher milk production, particularly milk yield, where their current breed average for milk yield EBV is 582 (NZAEL, 2016b). This is higher than for Jersey (-492) and Holstein-Friesian x Jersey (148) cows (NZAEL, 2016b). However Holstein-Friesian cows have lower fertility EBVs, where the current breed average is 0.7, 1.0 and 1.3 for Holstein-Friesian, Holstein-Friesian x Jersey and Jersey cows, respectively (NZAEL, 2016b). Xu and Burton (2003) showed that the submission rate of Holstein-Friesian (83%) was lower than for Jersey and Holstein-Friesian x Jersey (87%) cows. Also, the six-week in-calf rate of Holstein-Friesian x Jersey (72%) was higher than Holstein-Friesian and Jersey (70%) cows (Xu and Burton, 2003). These breed differences are likely to have an impact on the survival of carryover cows (Chapter 5).

Some of the breed differences for reproductive performance have been influenced by the introduction of overseas genetics into the New Zealand dairy cow population in the 1990s (Harris and Kolver, 2001). Overseas Holstein-Friesian cows that were bred for high milk production in year-round calving systems with high levels of concentrate feeding experience a severe period of negative energy balance when placed in pasture-based systems (Harris and Kolver, 2001). During this negative energy balance period, the hormonal changes and increased blood metabolites, that occur during lipolysis (fat breakdown) as an energy source, can inhibit the secretion of reproductive hormones that are required for the cow to resume ovarian cycling (Giuliodori *et al.*, 2011; Jeong *et al.*, 2015; Lucy, 2001; Reist *et al.*, 2000). This may contribute to the greater incidence of extended anoestrus periods for Holstein-Friesian (19%), compared to Jersey (13%) and Holstein-Friesian x Jersey (14%) cows (Xu and Burton, 2003). However, research presented in the same year showed that Holstein-Friesian cows with overseas genetics had lower fertility, and it appeared that the cows failed to conceive rather than failed to resume ovarian cycling within the required time period (McNaughton, 2003). Aside from this, the proportion of Holstein-Friesian was greater for the carryover group than the non-carryover group. This may be because Holstein-Friesian cows produce more milk but have lower fertility, compared to Jersey and Holstein-Friesian x Jersey cows, and thus, may be more likely be carried over.

The analysis has quantified the prevalence of non-pregnant cows that are carried over and then return to a milking herd in the following year. A large percentage of these cows were carried over after their first lactation and returned to a herd at four years old. The difference between the percentage of carryover cows in herds in the upper and lower quartile for milk production was different for Holstein-Friesian and Holstein-Friesian x Jersey herds. The proportion of Holstein-Friesian, proportion Jersey and heterosis coefficient was statistically different between carryover and non-carryover groups and proportion of Holstein-Friesian was greatest for the carryover group. The EBVs for carryover cows (pre-carryover period) were consistently and significantly greater for MY, FY, PY and SCC, when compared to non-carryover groups. However, the fertility EBVs for the carryover cow group was lower than those for the non-carryover group in the lactation prior to their carryover period, and were reduced further after the carryover period. Despite the lower fertility EBVs the carryover cows still had higher BWs and PWs than the non-carryover groups in the year prior to being carried over, which may have influenced the decision to carryover the non-pregnant cow. Subsequent chapters will determine the milk production performance and survivability of carryover cows, compared to that of non-carryover counterparts.

# Chapter 4 Carryover cow milk production

Paper: Gardner, R., Back, P.J., Lopez-Villalobos, N., and McNaughton, L.R. 2017. *The percentage of spring-calving carryover cows in New Zealand dairy herds and their milk production, compared to heifers, age-matched and lactation-matched non-carryover cows.* Proceedings of the New Zealand Society of Animal Production, 77:3-7.

Paper: '*The milk production and survival of spring-calving carryover cows in New Zealand*' submitted to Journal of Dairy Science

## 4.1 Introduction

It is demonstrated in Chapter 3 that a percentage of non-pregnant cows are carried over, rather than being culled. The average breed proportions for Holstein-Friesian were greater for the carryover cow group. Estimated breeding values for milk traits were greater for carryover cows prior to their carryover period when compared to non-carryover cows, which translated into, greater selection indices (BW and PW). Previous studies have shown that carryover cows had a milk production advantage (kg MS) over heifers and mature-aged (greater than four years old) non-carryover cows, and this persisted for up to three subsequent years after the carryover cow had returned to a milking herd (Pangborn and Woodford, 2010; Pangborn and Woodford, 2013). Due to the economic importance of milk production, it is essential to distinguish the potential milk production of carryover cows, before appropriate culling decisions can be made on farm. However, past studies were based on relatively small groups of carryover cows (20-162 cows), that were comprised of a high proportion of Holstein-Friesian (55-76%) genetics and were located in one region of New Zealand (Canterbury) (Pangborn and Woodford, 2010; Pangborn and Woodford, 2013). For those reasons, the objective of Chapter 4 was to use linear modelling techniques to determine the milk production (MY, FY, PY and SCS) of carryover cows and compare this with heifers, lactation-matched and age-matched non-carryover cow groups from lactation records in a large dataset. Carryover cow milk production was to be determined and compared to non-carryover groups for the first carryover year (year when they returned to a milking herd), and for up to three carryover years, if the carryover cow remained in a herd.

## 4.2 Materials and Methods

### 4.2.1 Data

Dataset 1 (Chapter 3) was used to form Dataset 3 (Appendix C). Only cows that were categorised as Holstein-Friesian, Jersey or Holstein-Friesian x Jersey, according to the breed definition established in section 3.2.3.1, were retained (86% of Dataset 1) to simplify the linear modelling analysis. For each cow, breed 16$^{ths}$ were expressed as a proportion (decimal number) to match the format of the coefficient of heterosis that was calculated in section 3.2.3.1.

Lactation records that had June and July parturition dates were grouped together and lactation records that had October and November parturition dates were grouped together to balance the number of lactation records in each month. This gave four parturition month categories: June/July, August, September and October/November.

Each individual cow herd test record for SCC was transformed to somatic cell score (SCS), using $\log_2$(SCC) and averaged for each year. The average SCS for each year was matched to the cow's lactation record for that year. Lactation records with suspected recording errors were removed (<150 or >305 days in milk, <800 or >8000 litres milk, <40 or >400 kilograms of protein, <30 or >300 kilograms of fat).

#### *4.2.1.1 Carryover cow milk production in year one*

Carryover cow lactation records were identified according to the definition in section 3.2.2 and were marked as Carry 1 (first carryover year) records. Any subsequent lactation records for carryover cows were removed. This ensured that the milk production of Carry 1 and non-carryover records that had no carryover history were compared.

The dataset was grouped into seven sub-datasets: one for second-lactation carryover cow records and heifer lactation records; and the remaining six for carryover and non-carryover cows of the same lactation (second, third or fourth lactation) and the same age (four, five or six years old). For each sub-dataset, herd identification code (e.g. ABCD) and year (e.g. 2007) were combined to form contemporary herd-year groups (e.g. ABCD-2007). Cow lactation records were required to be part of a herd-year group that contained at least 50 lactation records and at least two carryover lactation records to be eligible for a data table. Therefore, for every carryover lactation record, a non-carryover lactation record existed for the same herd (same management conditions) and for the same year (same environmental conditions). Table 4.1 summarises the number of non-carryover and carryover records in each sub-dataset.

**Table 4.1** The total number of carryover (CO) cow and non-carryover (NCO) cow lactation records that were analysed in the milk production comparison between heifers and second-lactation carryover cows, as well as all lactation-matched (two, three and four) and age-matched (four, five and six) carryover and non-carryover groups.

| Group | CO | NCO |
|---|---|---|
| Heifers | 60,193 | 777,900 |
| Lactation two | 47,242 | 542,837 |
| Lactation three | 20,275 | 259,070 |
| Lactation four | 7,211 | 108,132 |
| Age four | 41,950 | 404,546 |
| Age five | 17,793 | 188,922 |
| Age six | 5,808 | 72,508 |

#### *4.2.1.2 Carryover cow milk production in first, second and third carryover year*

A total of 6868 second-lactation carryover records and their respective lactation-matched non-carryover cow records, and the second one contained 4117 four-year-old carryover cow records and their respective age-matched non-carryover cow records were selected from Dataset 3. To be selected carryover cows were required to maintain an annual, spring-calving parturition date for three subsequent years after they returned to a milking herd. Furthermore, across all years, the carryover cow was required to be part of a herd-year that contained at least 50 lactation records, and at least two carryover lactation records. Lactation records for carryover cows in their first, second and third carryover year were marked as Carry 1, Carry 2 and Carry 3, respectively. The dataset was grouped into six sub-datasets that contained both carryover and non-carryover lactation records; one for each of the lactation associated with the 6868 carryover cows (lactation two, three and four) and one for each of the age groups associated with the 4117 carryover cows (age four, five and six).

### 4.2.2 Statistical analysis

The Statistical Analysis System (SAS) software package version 9.4 (SAS Institute Inc., Cary, NC, USA) was used for the statistical analysis.

#### *4.2.2.1 Milk production model for carryover year one*

Linear models were used to obtain the least square means for milk production (MY, FY, PY) and average SCS of carryover and non-carryover lactation records for each group shown in Table 4.1. These were obtained by using the MIXED procedure of SAS. The model included the random effect of the herd-year contemporary group; the fixed effect of carryover year one (Carry 1) and parturition month class (June/July, August, September or October/November); and proportion of Holstein-Friesian, heterosis and days in milk as co-variates with linear effects.

#### *4.2.2.2 Milk production model for first, second and third carryover years*

The same model that was described above (section 0) was used to compare the milk production of carryover cows in their first, second and third carryover year with non-carryover cows of the same lactation and age (section 4.2.1.2). The model included the random effect of the herd-year contemporary group; the fixed effect of carryover year (Carry1, Carry2 or Carry3) and parturition month class (June/July, August, September or October/November); and proportion of Holstein-Friesian, heterosis and days in milk as co-variates with linear effects.

## 4.3 Results

### 4.3.1 Milk production in carryover year one

Second-lactation carryover cows (four years old) produced 4778.1 ± 6.3 L milk, 228.7 ± 0.3 kg fat, 182.0 ± 0.2 kg protein, and had an average SCS of 6.31 ± 0.01. These milk production traits were all greater ($P<0.01$) than those for two-year-old heifers that produced 3514.5 ± 5.9 L milk, 168.3 ± 0.3 kg fat, 134.0 ± 0.2 kg protein, and had a SCS of 5.89 ± 0.01. When milk production was expressed in terms of milksolids (kg MS), carryover cows produced an additional 108.4 kg MS than two-year-old heifers, which is equivalent to a 36% milksolid production advantage.

Carryover cows had greater milk production (MY, FY, PY) and average SCS in the year when they returned to a milking herd when compared to both age-matched and lactation-matched non-carryover groups (Table 4.2 and Table 4.3). Second-lactation (four years old) carryover cows had greater MY, FY, PY and SCS than second-lactation (three years old) non-carryover cows (Table 4.2). The milk production advantage for carryover cows was also evident when they returned to a milking herd in their third and fourth-lactation (Table 4.2). However, the milk production advantage decreased as the lactation that the carryover cow returned to a milking herd increased. The MY, FY and PY production advantage for carryover cow that returned to a milking herd in their fourth lactation was 50%, 57% and 44% lower than that of carryover cows that returned to a milking herd in their second lactation, respectively. When expressed as a milksolid production advantage the carryover cow produced an additional 54.6 kg MS (13%), compared to second-lactation non-carryover cows.

**Table 4.2** The least squares means (± SEM) for milk yield (MY), fat yield (FY), protein yield (PY) and somatic cell score (SCS) for carryover (CO) and non-carryover (NCO) cows that returned to a milking herd in their second, third and fourth lactation.

| Lactation number | Trait | Cow type | | |
|---|---|---|---|---|
| | | CO | NCO | P value |
| Two | MY (L) | 4740.6 ± 8.1 | 4175.2 ± 7.5 | <0.01 |
| | FY (kg) | 227.2 ± 0.4 | 199.5 ± 0.3 | <0.01 |
| | PY (kg) | 180.7 ± 0.3 | 160.8 ± 0.3 | <0.01 |
| | SCS | 6.29 ± 0.01 | 5.75 ± 0.01 | <0.01 |
| Three | MY (L) | 5032.0 ± 11.8 | 4635.4 ± 10.7 | <0.01 |
| | FY (kg) | 242.6 ± 0.5 | 222.0 ± 0.5 | <0.01 |
| | PY (kg) | 192.1 ± 0.5 | 179.3 ± 0.4 | <0.01 |
| | SCS | 6.43 ± 0.01 | 5.89 ± 0.01 | <0.01 |
| Four | MY (L) | 5164.0 ± 18.3 | 4879.9 ± 16.0 | <0.01 |
| | FY (kg) | 250.3 ± 0.8 | 234.4 ± 0.7 | <0.01 |

| | | | | |
|---|---|---|---|---|
| | PY (kg) | 198.4 ± 0.7 | 189.6 ± 0.6 | <0.01 |
| | SCS | 6.56 ± 0.02 | 6.04 ± 0.02 | <0.01 |

A carryover cow that returned to a milking herd at six years old (lactation-four) had higher MY, FY and PY, and SCS than six-year-old non-carryover (lactation five) cows (Table 4.3). The comparisons between each milk production trait (MY, FY, PY and SCS) were all significantly different (P<0.01) between carryover and non-carryover cow groups (Table 4.3). In contrast to lactation-matched cows, the production advantage for carryover cow MY, FY and PY increased as the age of the cow when they returned to a milking herd increased. The MY, FY and PY production advantage for six-year-old carryover cows was 68%, 64%, 59% greater than that for carryover cows that returned to a milking herd when they were four years old. When expressed as a milksolids production advantage, a four-year-old carryover cow produced an additional 21.4 kg MS (5%) than a four-year-old non-carryover cow.

**Table 4.3** The least squares means for milk yield (MY), fat yield (FY), protein yield (PY) and somatic cell score (SCS) for carryover (CO) and non-carryover (NCO) cows that returned to a milking herd when they were four, five and six years old.

| Age (years) | Trait | Cow type | | |
|---|---|---|---|---|
| | | CO | NCO | P value |
| Four | MY (L) | 4745.14 ± 9.1 | 4580.9 ± 8.4 | <0.01 |
| | FY (kg) | 227.6 ± 0.4 | 219.0 ± 0.4 | <0.01 |
| | PY (kg) | 181.4 ± 0.4 | 176.7 ± 0.3 | <0.01 |
| | SCS | 6.27 ± 0.01 | 5.94 ± 0.01 | <0.01 |
| Five | MY (L) | 5030.9 ± 13.2 | 4812.5 ± 12.0 | <0.01 |
| | FY (kg) | 242.8 ± 0.6 | 230.6 ± 0.5 | <0.01 |
| | PY (kg) | 192.7 ± 0.5 | 186.0 ± 0.5 | <0.01 |
| | SCS | 6.41 ± 0.02 | 6.10 ± 0.01 | <0.01 |
| Six | MY (L) | 5213.1 ± 21.5 | 4970.4 ± 18.9 | <0.01 |
| | FY (kg) | 250.4 ± 1.0 | 236.9 ± 0.8 | <0.01 |
| | PY (kg) | 200.3 ± 0.8 | 192.4 ± 0.8 | <0.01 |
| | SCS | 6.52 ± 0.03 | 6.26 ± 0.02 | <0.01 |

### 4.3.2 Milk production for first, second and third carryover year

The milk production (measured in MY, FY and PY) of carryover cows that retained a spring-calving parturition date and lactation records for three carryover years was consistently greater ($P<0.01$) than the milk production of non-carryover cows in the same lactation (Figure 4.1). Carryover cows produced 4810.0 ± 17.2 L milk in their first carryover year, which was greater ($P<0.01$) than the MY for lactation-matched (second-lactation) non-carryover cows that produced 4213.6 ± 15.2 L milk (Figure 4.1a). Carryover cow MY increased by 3% from first to second carryover year to 4954.0 ± 18.0 L milk, which was greater ($P<0.01$) than the MY for a lactation matched (third-lactation) non-carryover cow (4667.2 ± 15.9 L milk) (Figure 4.1a). Between second and third carryover year, milk yield increase plateaued (0.7% increase) to 4990.7 ± 18.0 L milk for carryover cows. This was greater ($P<0.01$) than the milk yield of lactation-matched (fourth-lactation) non-carryover cows that produced 4832.0 ± 15.8 L milk.

Carryover cows produced 231.7 ± 0.8 kg fat in carryover year one, and this increased by 3% and 0.8% to 238.8 ± 0.8 kg fat and 240.6 ± 0.8 kg fat, in second and third carryover year, respectively (Figure 4.1b). Lactation-matched non-carryover cows produced 202.0 ± 0.7 kg fat, 223.5 ± 0.7 kg fat and 232.1 ± 0.7 kg fat in second, third and fourth lactation (Figure 4.1b). All FY comparisons between carryover and non-carryover cow groups in first, second and third carryover year were significantly greater ($P<0.01$) for the carryover group.

Protein yield for carryover cows increased by 4% from 183.9 ± 0.7 kg protein to 191.2 ± 0.7 kg protein for first and second carryover year, respectively (Figure 4.1c). Between second and third carryover year carryover cow PY increased by 0.7% to 192.5 ± 0.7 kg protein (Figure 4.1c). Lactation-matched non-carryover cows produced 162.5 ± 0.6 kg protein, 180.1 ± 0.6 kg protein and 186.7 ± 0.6 kg protein in second, third and fourth lactation (Figure 4.1c). All PY comparisons between carryover and non-carryover groups in first, second and third carryover year were significantly greater ($P<0.01$) for the carryover group.

When milk production was expressed as milksolids, a carryover cow produced an extra 51.2 kg MS (13%), 26.3 kg MS (7%), and 14.3 kg MS (3%) in their first, second and third carryover year than non-carryover cows.

The average SCS for carryover cows was consistently greater ($P<0.01$) than the average SCS for lactation-matched non-carryover cows, regardless of the carryover year (Figure 4.1d). The average SCS for carryover cows reduced by 5% from 6.27 ± 0.02 in their first carryover year to 5.96 ± 0.02 in their second carryover year. Whereas, in the carryover cow's third carryover year, SCS increased to 6.13 ± 0.02. In contrast, the average SCS for lactation-matched non-carryover cows increased from 5.82 ± 0.01 in lactation two cows to 6.04 ± 0.02 in lactation four.

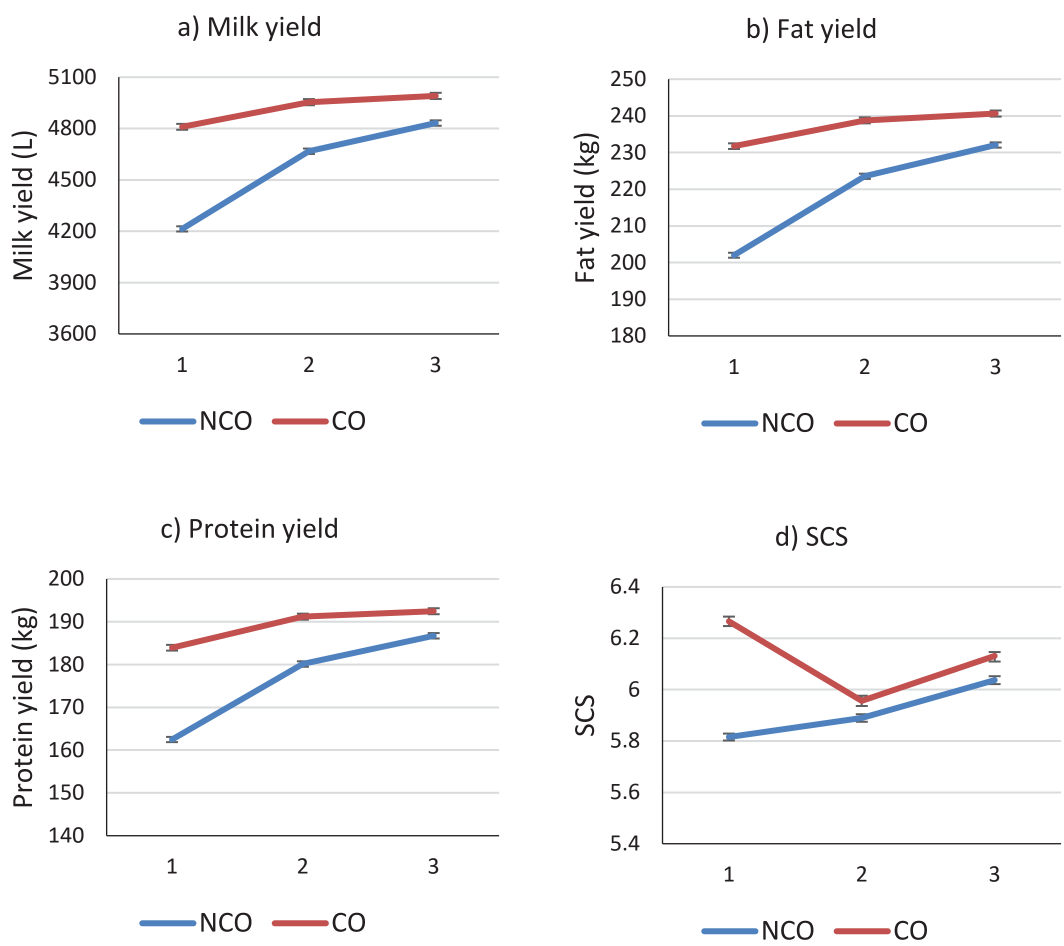


**Figure 4.1** Second-lactation carryover cow (CO) milk production ((a) milk yield (L), b) fat yield (kg), c) protein yield, d) somatic cell score (SCS)) for carryover year one (1), two (2) and three (3), compared to non-carryover cows (NCO) of the same lactation. All comparisons between CO and NCO groups were significantly (P<0.01) different.

Carryover cows that returned to a milking herd at four years old had greater (P<0.01) MY, FY and PY in their first, second and third carryover year than the MY, FY and PY of non-carryover cows of the same age (Figure 4.2). Four-year-old carryover cows produced 4838.6 ± 23.6 L milk in their first carryover year, which was greater (P<0.01) than age-matched non-carryover cows that produced 4654.9 ± 20.8 L milk (Figure 4.2a). Carryover cow MY increased by 3% to 5006.7 ± 24.1 L milk in their second carryover year, which was greater (P<0.01) than the MY of an age-matched non-carryover cow that produced 4895.8 ± 21.2 L milk (Figure 4.2a). Similar to the lactation-matched comparison, MY increase plateaued between second and third carryover year, increasing by a mere 0.03% for carryover cows to 5008.3 ± 24.2 L milk, but this was still greater (P<0.01) than the MY for age-matched (six years old) non-carryover cows (4921.3 ± 21.3 L milk) (Figure 4.2a).

Carryover cows produced 232.9 ± 1.1 kg fat in their first carryover year, and this increased by 4% in their second carryover year to 241.1 ± 1.1 kg fat (Figure 4.2b). Carryover cow FY increased an additional 0.2% between their second and third carryover year to 241.5 ± 1.1 kg fat (Figure 4.2b). All FY comparisons between carryover and non-carryover groups in first, second and third carryover year were significantly greater (P<0.01) for the carryover group. Carryover cows produced 222.6 ± 0.9 kg fat, 233.8 ± 1.0 kg fat and 235.6 ± 0.9 kg fat at age four, five and six years (Figure 4.2b).

Protein yield was greater (P<0.01) for carryover cows in their first carryover year (185.6 ± 0.9 kg protein) than for age-matched (four years old) non-carryover cows that produced 180.0 ± 0.8 kg protein (Figure 4.2c). Carryover cow PY increased by 4% between their first and second carryover year to 193.9 ± 0.9 kg protein, which was greater (P<0.01) than the PY for age-matched (five years old) non-carryover cows (188.9 ± 0.9 kg protein) (Figure 4.2c). Carryover cow PY decreased by 0.04% between second and third carryover year to 193.8 ± 0.9 kg protein, but was still greater (P<0.01) than the PY for age-matched (six-year-old) non-carryover cows that produced 190.0 ± 0.9 kg protein.

When FY and PY were accumulated (MS), carryover cows produced an additional 16.2 kg MS (4%), 12.4 kg MS (3%) and 9.75 kg MS (2%) in carryover year one, two and three, respectively, compared to age-matched non-carryover cows.

The SCS for carryover cows was different (P<0.01) than the SCS for non-carryover cows of the same age (Figure 4.2d). Somatic cell score reduced by 7% from 6.22 ± 0.03 for carryovers in their first carryover year to 5.92 ± 0.03 in their second carryover year, which was less (P<0.01) than the SCS for non-carryover cows of the same age (Figure 4.2d). Carryover cow SCS increased to 6.10 ± 0.03 in their third carryover year but this was still lower (P<0.01) than the SCS for non-carryover cows of the same age (6.25 ± 0.02) (Figure 4.2d).

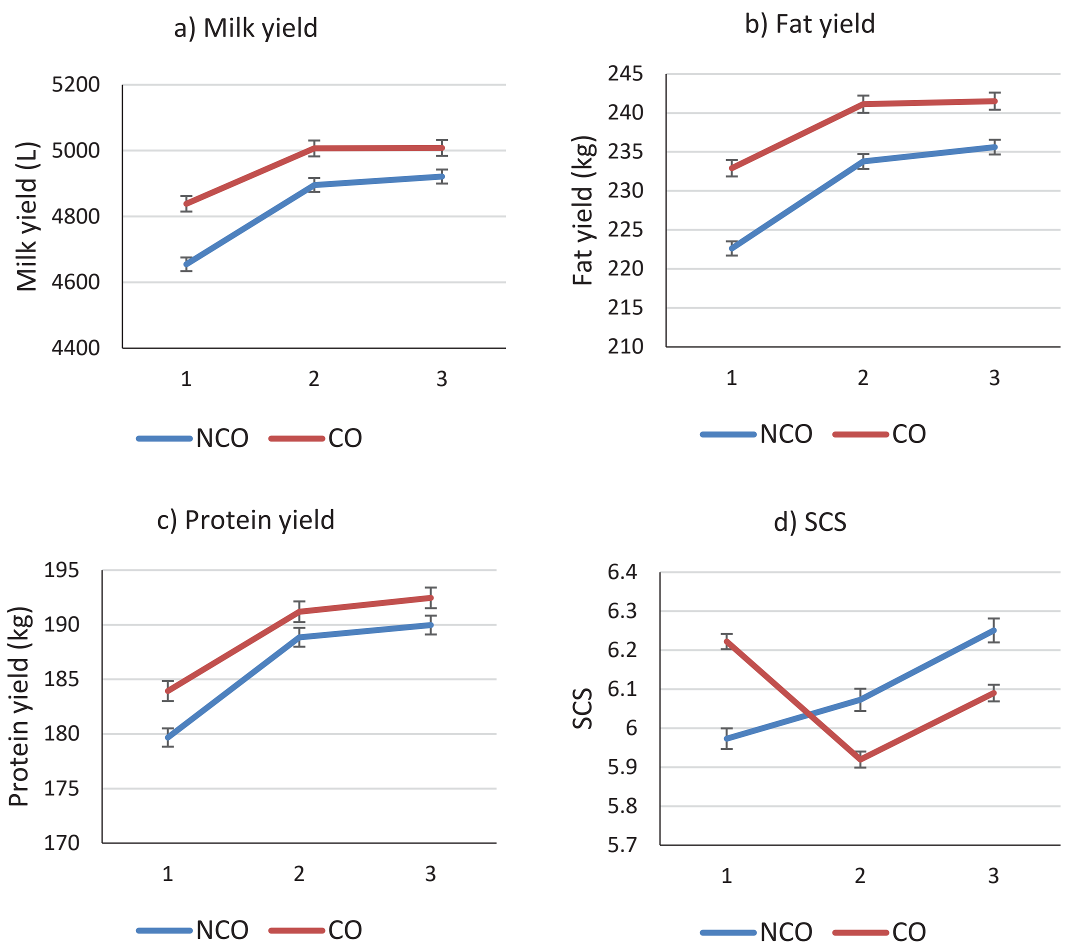


**Figure 4.2** Four-year-old carryover cow (CO) milk production ((a) milk yield (L), b) fat yield (kg), c) protein yield, d) somatic cell score (SCS)) for carryover year one (1), two (2) and three (3), compared to non-carryover cows (NCO) of the same age. All comparisons between CO and NCO groups were significantly (P<0.01) different.

## 4.4 Discussion

The main objective of this chapter was to determine and compare the milk production of carryover cows and non-carryover cows. The milk production of carryover cows in their first year when they returned to a milking herd was compared to that of heifers, lactation-matched and age-matched non-carryover cows. Further milk production comparisons were made between carryover cows that maintained an annual, spring-calving parturition date for three years when they returned to a milking herd and non-carryover cows of the same lactation or age.

The milk production advantage for carryover cows in the first year when they return to a milking herd, is consistent with two previous studies that were conducted on a herd in Canterbury (Pangborn and Woodford, 2010; Pangborn and Woodford, 2013). It was shown that carryover cow groups produced 128 kg MS more than two-year-old heifers (Pangborn and Woodford, 2010), which was greater than that that estimated in the current study (108.4 kg MS). However, when this milk production advantage was expressed as a percentage, the carryover cows had a greater advantage (36%) than the carryover cows in the previous work (27%) that was presented by Pangborn and Woodford (2010). According to the New Zealand dairy statistics, the average production advantage for a four-year-old compared to a three-year-old Friesian, Jersey or Holstein-Friesian x Jersey non-carryover cow is 24% (LIC and DairyNZ, 2016). Thus, the results of this study suggest that the age effect will be increased further if the cow is carried over and returned to a milking herd at four years old.

Carryover cows produced 41 kg MS (Pangborn and Woodford, 2010) and 81 kg MS (Pangborn and Woodford, 2013) greater than mature aged (greater than three years old) non-carryover herd-mates. It is difficult to compare the values found in Pangborn and Woodford (2010) and Pangborn and Woodford (2013) with the results of this study because milk production was compared between mixed-age carryover cows and mature-aged non-carryover cows in the former, rather than age-matched and lactation-matched groups used in this work. However, across all studies carryover cows consistently produced greater MY, FY and PY in their first carryover year than non-carryover groups.

When the milk production (MY, PY and FY) of lactation-matched carryover and non-carryover cows was compared the difference between the two groups decreased as lactation number increased. In contrast, when the milk production (MY, FY and PY) of age-matched carryover and non-carryover cows was compared the difference between the two groups increased as cow age increased. According to the New Zealand dairy statistics a four-year-old Holstein-Friesian x Jersey cow is expected to produce 372 L, 17 kg fat and 14 kg protein more than a three-year-old cow of the same breed (LIC and DairyNZ, 2016). Positive production differences also occur between four- and three-year-old cows, as well as five- and four-year-old cows, but at a decreasing rate (LIC and DairyNZ, 2016). It is likely that these milk-production age trends had an impact on the decreasing trend between the milk production of lactation-matched carryover and non-carryover cow that had a one-year age difference. However, regardless of these trends, carryover cows were shown to produce higher MY, FY and PY when compared to a non-carryover cow of the same age or lactation.

The carryover cow milk production advantage (MY, FY and PY) was maintained for up to three years, but at a decreasing rate, when compared to non-carryover cows of the same age and lactation. The production advantage decreased and plateaued in the second carryover year but remained greater ($P<0.01$) than non-carryover cows of the same lactation or age. The longitudinal milk production advantage shown in this study is consistent with the results shown in the Pangborn and Woodford (2013) study, where the performance of three carryover cow groups in the year when they returned to a milking herd was studied (either 2007, 2008 or 2009). On average, carryover cows produced an additional 81 kg MS, 38 kg MS and 41 kg MS compared to non-carryover cows in their first, second and third carryover year (Pangborn and Woodford, 2013). However, in some groups the difference was between carryover cow and non-carryover cow milksolids production was statistically insignificant due to small sample sizes (as low as 20 carryover cows). As established previously, it is difficult to compare values from relevant previous studies with this study, as the non-carryover comparison groups were not the same. However, the MS production advantage trend for lactation-matched and age-matched cows in this study is similar to that shown previously.

Furthermore, the use of a larger carryover cow group in this study resulted in all comparisons between statistically different.

In general, a carryover cow that has had a previous non-lactating year will be of higher body condition at parturition than a non-carryover cow (Pangborn and Woodford, 2010). Increased rate of lipolysis (fat breakdown) after parturition, not only provides long chain fatty acids for milk production, but also an energy substrate for non-mammary tissues, and therefore sparing glucose for lactose synthesis and increasing dairy cow milk production (Bauman and Currie, 1980; Garnsworthy and Topps, 1982). Thus, a cow of higher body condition has a greater supply of stored fat for lipolysis to provide energy for milk synthesis (Bauman and Currie, 1980; Domecq *et al.*, 1997) and this would contribute to the higher milk production for carryover cows.

Although, some studies have suggested that high body condition at parturition has a negative effect on milk production in early lactation (Garnsworthy and Topps, 1982; Treacher *et al.*, 1986), and from extensive research it has been suggested that cows and heifers should have a pre-calving BCS of 5.0 and 5.5, respectively (Roche *et al.*, 2004). Cows that are above these pre-calving BCS targets have a greater risk of losing large amounts of body condition after parturition, which has been shown to have a negative effect on the time before resumption of ovarian cycling, due to hormonal and blood metabolite concentration changes (Giuliodori *et al.*, 2011; Jeong *et al.*, 2015; Lucy, 2001; Reist *et al.*, 2000). Consequently, over conditioned cows can have lower first service conception rates and six-week pregnancy rates (Buckley *et al.*, 2003; Butler and Smith, 1989; Roche *et al.*, 2007b). Thus, if a farmer is to carryover a cow, achieving an appropriate pre-calving BCS is mandatory for the cow's productivity to be optimised once they return to a milking herd.

Higher body condition, in combination with higher genetic merit of carryover cows when compared to non-carryover cows, may account for some of the milk production advantage that was shown in this study. It was shown in Chapter 3 that carryover cows, prior to becoming non-pregnant, have greater EBVs for milk traits (MY, FY, PY), which led to a greater BW, regardless of their lower fertility EBVs, when compared to those for non-carryover cows. Carryover cow milk trait EBVs continued to be greater than those for non-carryover cows. Thus, carryover cows have a greater genetic merit for milk production, which led to them having greater milk production than non-carryover counterparts when they returned to a milking herd.

Somatic cell score (SCS) was consistently greater for carryover cows in their first carryover year compared to heifers, lactation-matched and age-matched cows. In subsequent carryover years, SCS remained higher for carryover cows compared to lactation-matched cows, but was lower than age-matched cows in second and third carryover year. Accordingly, farmers must monitor the SCS of carryover cows once they return to a milking herd. Further study is required to determine what may cause these differences and if the difference is of economic importance.

The results shown in this chapter have confirmed those that were previously presented (Pangborn and Woodford, 2010; Pangborn and Woodford, 2013). It provides further evidence that carryover cows have greater milk production than heifers, lactation-matched and age-matched non-carryover groups. It is evident that the production advantage can be maintained for up to three carryover years, provided that the cow becomes pregnant and therefore, survives in the herd and contributes in subsequent lactations. These results were determined from over 210,000 carryover lactation records, sourced throughout New Zealand, increasing the validity of the results. The survival of carryover cows is analysed in Chapter 5.

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# Chapter 5 Carryover cow survival

Paper: *'The milk production and survival of spring-calving carryover cows in New Zealand'* submitted to Journal of Dairy Science.

## 5.1 Introduction

Cow survival is often measured as the number of days between the cows first parturition date and last culling date (removal from the herd) (Ducrocq, 1994), or as a percentage of animals in the herd that survived from one lactation to the next (LIC and DairyNZ, 2016). Cow survival has been shown to decrease as lactation number and proportion of Holstein-Friesian genetics increase, for low producing cows, or when cow health or reproductive performance is compromised (Beaudeau *et al.*, 1995; Dillon *et al.*, 2003; Harris, 1989). A farm with a high cow survival rate has a reduced requirement for replacement heifers when compared to farms with low cow survival rates (Pritchard *et al.*, 2013; Vukasinovic *et al.*, 2001; Xu and Burton, 1996). Lower replacement rates, as well as a higher proportion of mature-aged cows that produce more milk than heifers have a positive impact on net farm revenue for herds that have higher cow survival rates (Lopez-Villalobos and Holmes, 2010; Pritchard *et al.*, 2013; Vukasinovic *et al.*, 2001). Furthermore, high culling rates, especially mortality and at what age this occurs for the cow, is an indication of animal welfare or the amount of herd wastage (Compton *et al.*, 2017; De Vries *et al.*, 2011). Pangborn and Woodford (2013) have shown that 83%, 82% and 71% of carryover cows survived from first to second, second to third, and third to fourth carryover year, respectively. However, in Pangborn and Woodford (2013), no comparison was made between the carryover cow survival and non-carryover herd-mates, due to a lack of data. No other known literature has estimated the probability of survival over time (days) for carryover cows once they have returned to a milking herd. This information is important to determine the amount of productive days that a carryover cow will have after the farmer has invested into carrying them over for a year. Accordingly, the objective of this chapter was to conduct a survival analysis to determine the probability of survival over time (days) for carryover cows that returned to a milking herd for their second lactation (four years old), compared to heifers and non-carryover cows of the same lactation.

## 5.2 Materials and Methods

### 5.2.1 Data

Dataset 1 (Chapter 3) was used to form Dataset 4a and 4b (Appendix D). Only cows that met the breed classification criteria (section 3.2.3.1) for Holstein-Friesian, Jersey and Holstein-Friesian x Jersey cows were retained. For each cow, breed was labelled as Holstein-Friesian, Jersey or Holstein-Friesian x Jersey, accordingly (section 3.2.3.1). Last transfer out date (last date of removal from a herd) was obtained from animal movement records and matched to each animal identification in Dataset 1.

Breed information, parturition month, herd identification key, year, parturition date and last transfer out date were retained. Herd identification key and year were combined to form contemporary herd-year groups. Lactation records with parturition dates in June and July were grouped together and lactation records with parturition dates in October and November were grouped together to balance the number of records in each month (June/July, August, September and October/November).

If a cow was part of a herd at data collection (which was conducted on the 01/07/2016), last transfer out date was set to this date and the record was marked as a censored value. All other records, for cows that had a transfer out date prior to the end of data collection were marked as uncensored values. The total survival days was calculated as: Survival (days) = LT – PD, where LT represented the last transfer out date for the cow and PD represented the parturition date for that record.

#### *5.2.1.1 Second-lactation carryover cow and heifer comparison*

The survival of carryover cows that returned to a milking herd in second-lactation (day 0) was compared to the survival of a heifer from their first parturition date (day 0). This comparison determined whether a carryover cow survived for more, or less days, than a replacement heifer.

Dataset 4a (Appendix D) contained records for carryover cows that returned to a milking herd in their second lactation and records from two-year-old heifers that had no subsequent history of being carried over. Records that had greater than 2555 days (seven-years/lactations) of survival were discarded to obtain sufficient data for the two groups (carryover cow and non-carryover cow heifer) for up to nine lactations.

To be eligible for Dataset 4a, each record was required to have a herd-year group that contained at least 50 records and two carryover cow records. This data restriction ensured that for each carryover record there was a non-carryover record in the same herd-year group. Once all data restrictions were imposed Dataset 4a contained a total of 857,155 non-carryover cow and 66,049 carryover cow survival records, respectively.

#### *5.2.1.2 Second-lactation carryover cow and second-lactation non-carryover cow comparison*

The process described in section 5.2.1.1 was repeated for carryover cows that returned to a milking herd in their second parturition (day 0) and for non-carryover cows after their second parturition (day 0). Records with less than 2555 total days of survival (ninth lactation) were retained for Dataset 4b (Appendix D). To be eligible for the Dataset 4b, each record was required to have a herd-year group that contained at least 50 records and two carryover cow records. Once all data restrictions were imposed Dataset 4b contained a total of 675,976 non-carryover cow and 62,028 carryover cow survival records, respectively.

### 5.2.2 Statistical analysis

The Statistical Analysis System (SAS) software package version 9.4 (SAS Institute Inc., Cary, NC, USA) was used for the statistical analysis.

A histogram that showed the distribution of total survival days for second-lactation carryover and non-carryover cows was produced using the UNIVARIATE method of SAS to gauge the spread of total survival days.

The LIFETEST procedure (Kaplan-Meier method) of SAS was used to produce proportional-hazard survival curves for each comparison described in section 5.2.1.1 and 5.2.1.2. This determined the probability of survival at any point in time (days) for second-lactation carryover cows and heifers, as well as carryover and non-carryover cows after their second parturition. Chi-square analysis of the LIFETEST procedure was used to test the significance ($P<0.01$) between different strata (class) groups.

One survival curve was produced to compare the probability of survival for heifers and second-lactation carryover cows over time (days). The probability of survival at 365 days, 730 and 1095 days was determined from the curve to estimate the probability of survival for carryover cows to second, third and fourth carryover year.

Five additional survival curves were produced for carryover cows and non-carryover cows after their second lactation: firstly, where carryover class (carryover or non-carryover), parturition month or cow breed were fitted as strata levels; and later, both carryover class and breed, as well as carryover class and parturition month were added as strata levels.

For all survival curve comparisons, both censored values (cows still alive) and uncensored values were included. It was appropriate to include censored values as the probability of culling is assessed at each consecutive day of life, given that the animal is still alive just prior to this time (the day) (Allison, 2010, Vukasinovic, 1999).

## 5.3 Results

The distribution of survival days for both second-lactation carryover and non-carryover cows is shown in Figure 5.1. In general, the frequency of cows decreased as total survival days increased up to lactation nine (2555 days). However, it is evident there is a seasonal culling pattern in spring-calving herds in New Zealand. The frequency of culling is greatest before the end of each year (365 days).

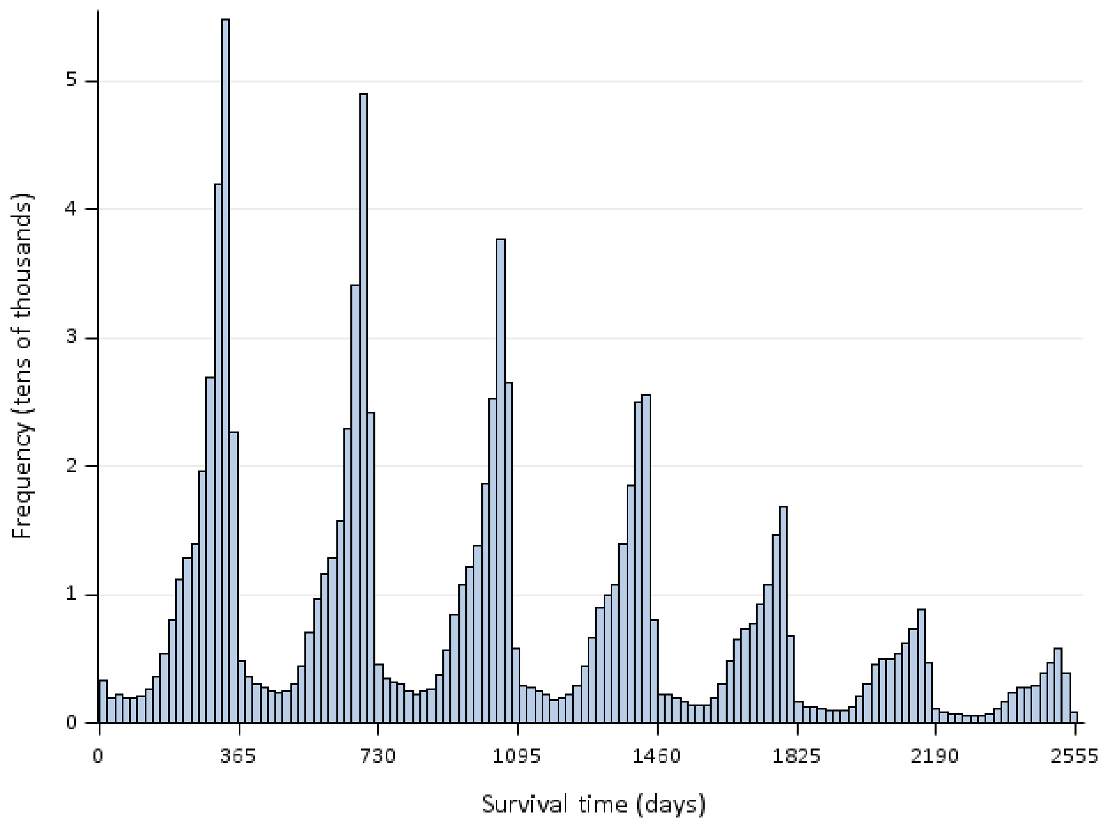


**Figure 5.1** The distribution of survival (days) for carryover and non-carryover cows after their second parturition date (Day 0).

### 5.3.1 Survival of second-lactation carryover cows and heifers

The probability of survival for second-lactation carryover cows was lower (P<0.01) than two-year-old heifers Figure 5.2. The probability of survival from first to second carryover year (365 days) was 82%, and this reduced to 63% and 45% for survival from second to third (730 days) and third to fourth (1095 days) carryover years, respectively. Whereas, the probability of heifer surviving from first to second, second to third and third to fourth-lactation was 90%, 79% and 68%, respectively.

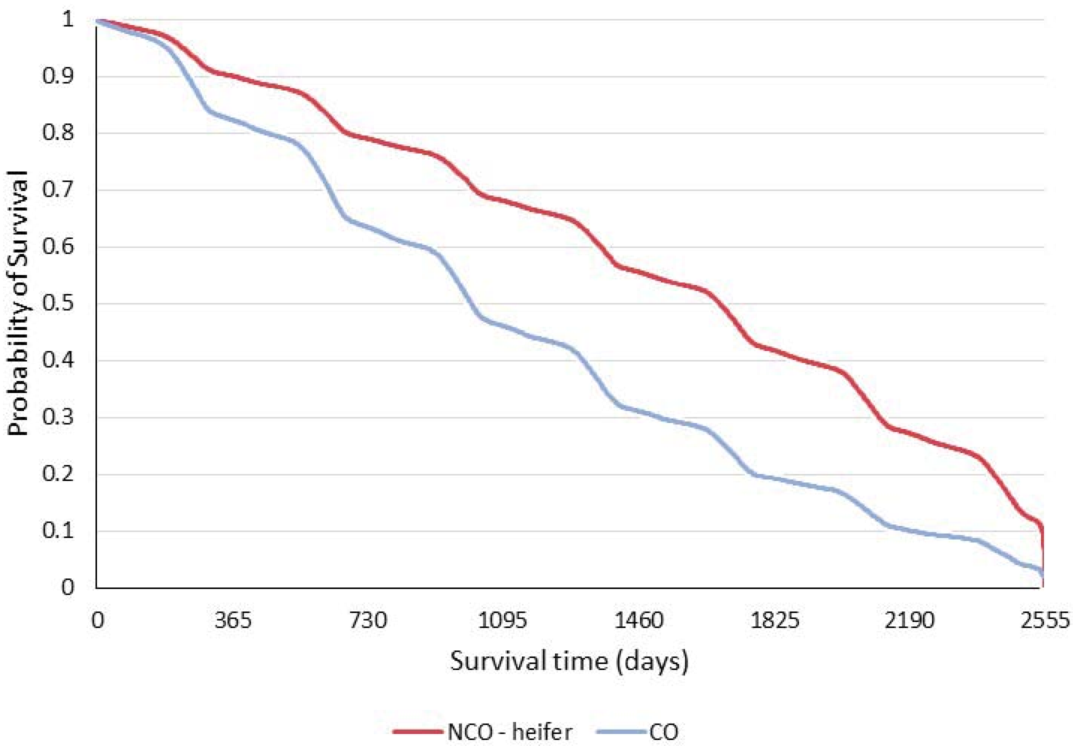


**Figure 5.2** The probability of survival for carryover (CO) cows after their second parturition date (day 0) and non-carryover heifers (NCO – heifer) after their first parturition date (day 0).

Table 5.1 shows that a higher percentage of carryover cows survived to less days than for non-carryover cows. For example, 50% of carryover cows survived to 1010 days, which was less than for heifers, where 50% survived to 1680 days.

Carryover cows survived an average of 1140.74 ± 3.2 days after their second parturition date, which was lower (P<0.01) than that for heifers, which survived 1553 ± 0.1 days from first parturition date. Therefore, if a second-lactation carryover cow and heifer are in the same herd, the heifer is expected to survive approximately 413 days longer (1.1 years).

**Table 5.1** The percentage of second-lactation carryover (CO) cows and heifers (NCO heifer) cows that survived to a specific time (days) and the 95% confidence interval.

| Cow type | Percentage | Survival time (days) | 95% confidence interval | |
|---|---|---|---|---|
| | | | Lower | Upper |
| CO | 75% | 1695 | 1689 | 1701 |
| | 50% | 1010 | 1006 | 1014 |
| | 25% | 582 | 579 | 586 |
| NCO –heifer | 75% | 2290 | 2282 | 2299 |
| | 50% | 1680 | 1678 | 1682 |
| | 25% | 942 | 940 | 944 |

### 5.3.2 Survival of second-lactation carryover cows and second-lactation non-carryover cows

Carryover cows that returned to a milking herd in second-lactation had a lower ($P<0.01$) probability of survival, when compared to non-carryover cows of the same lactation (Figure 5.3). Table 5.2 shows that more carryover cows (as a percentage) were removed from herds before non-carryover cows.

Carryover cows had an average survival of 1131 ± 3.3 days, which was less ($P<0.01$) than non-carryover cows that had an average survival of 1460 ± 1.1 days. As a result, a carryover cow is expected to survive an average of 329 days (0.9 years) less than a lactation-matched cow once they return to a milking herd.

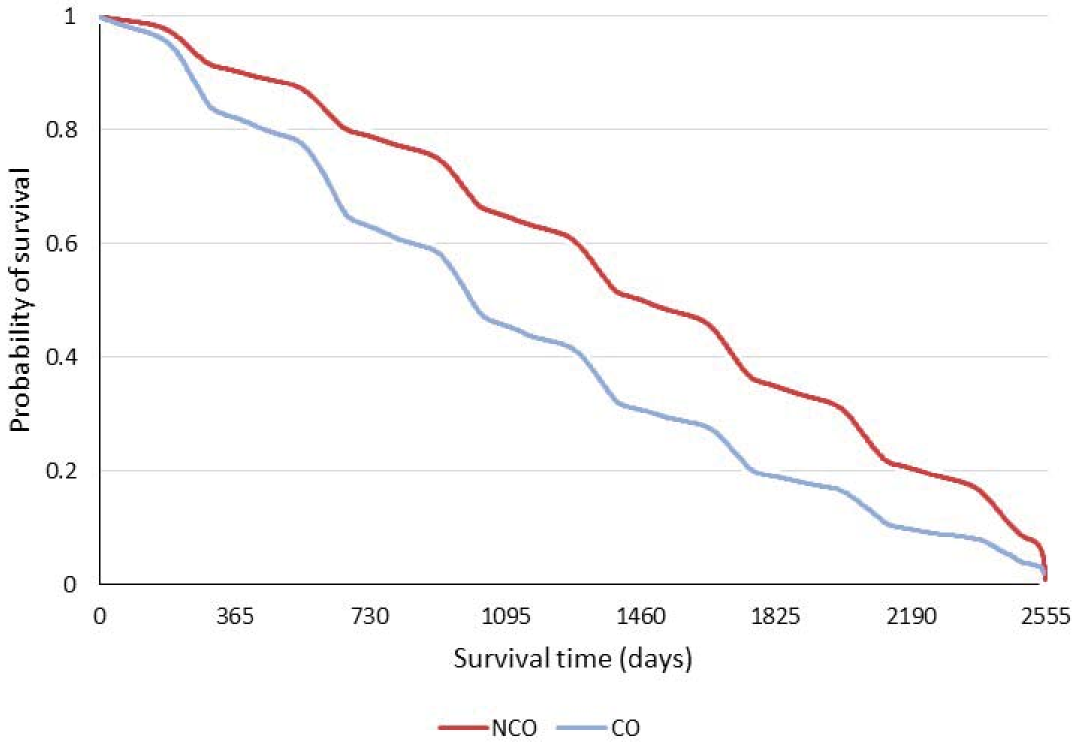


**Figure 5.3** The probability of survival for carryover (CO) and non-carryover (NCO) cows after their second parturition date (day 0).

**Table 5.2** The percentage of carryover (CO) and non-carryover (NCO) cows that survived to a specific time (days), after their second lactation, and the 95% confidence interval.

| Cow type | Percentage | Survival time (days) | 95% confidence interval | |
|---|---|---|---|---|
| | | | Lower | Upper |
| CO | 75% | 1691 | 1685 | 1698 |
| | 50% | 1004 | 1000 | 1008 |
| | 25% | 579 | 575 | 582 |
| NCO | 75% | 2079 | 2077 | 2081 |
| | 50% | 1462 | 1455 | 1469 |
| | 25% | 910 | 908 | 913 |

Both cow breed and parturition month at second-lactation influenced the probability of survival for both carryover and non-carryover cows. The average survival days for all (non-carryover and carryover cows) Holstein-Friesian, Jersey and Holstein-Friesian x Jersey cows was 1469 ± 1.5 days, 1434 ± 2.9 days and 1382 ± 1.7 days, respectively. Figure 5.4 shows this trend, where the survival rate of Holstein-Friesian cows is lower (P<0.01) than both Jersey and Holstein-Friesian x Jersey cows. Fifty percent of Holstein-Friesian x Jersey, Jersey and Holstein-Friesian cows survived to 1477 days, 1398 days and 1350 days, respectively (Table 5.3).

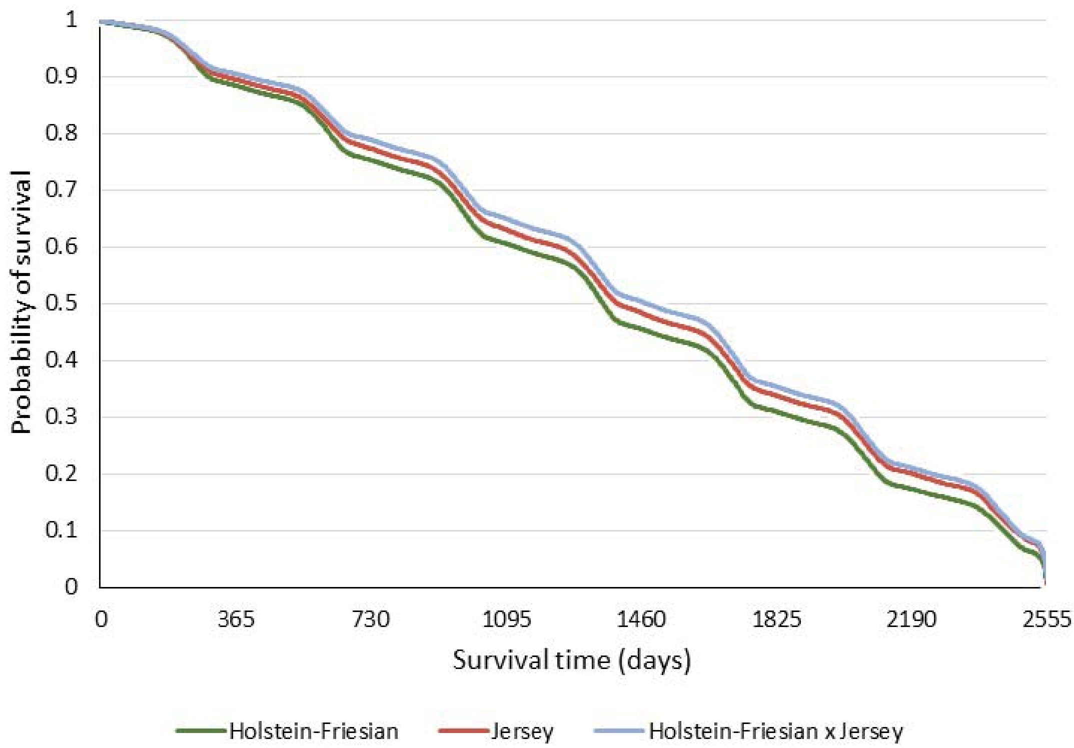


**Figure 5.4** The probability of survival for Holstein-Friesian, Jersey and Holstein-Friesian x Jersey cows after their second parturition date (day 0).

**Table 5.3** The percentage of Holstein-Friesian, Jersey and Holstein-Friesian x Jersey cows that survived to a specific time (days) and the 95% confidence interval.

| Breed | Percentage | Survival time (days) | 95% confidence interval | |
|---|---|---|---|---|
| | | | Lower | Upper |
| Holstein-Friesian | 75% | 2039 | 2036 | 2041 |
| | 50% | 1358 | 1356 | 1360 |
| | 25% | 747 | 738 | 754 |
| Jersey | 75% | 2071 | 2066 | 2076 |
| | 50% | 1398 | 1390 | 1408 |
| | 25% | 850 | 830 | 865 |
| Holstein-Friesian x Jersey | 75% | 2087 | 2084 | 2090 |
| | 50% | 1477 | 1469 | 1485 |
| | 25% | 914 | 911 | 918 |

Figure 5.5 shows the probability of survival was greatest for cows that had a parturition date in July and lowest for cows that had parturition date in October. Cows whose second parturition was in July survived an average of 1506 ± 2.5 days, which was greater (P<0.01) than cows whose second parturition was in August (1454 ± 1.4 days), September (1379 ± 2.1 days) and October (1225 ± 4.6 days). Fifty percent of cows that calved in July, August, September and October survived to 1546 days, 1423 days, 1344 days and 1231 days, respectively (Table 5.4).

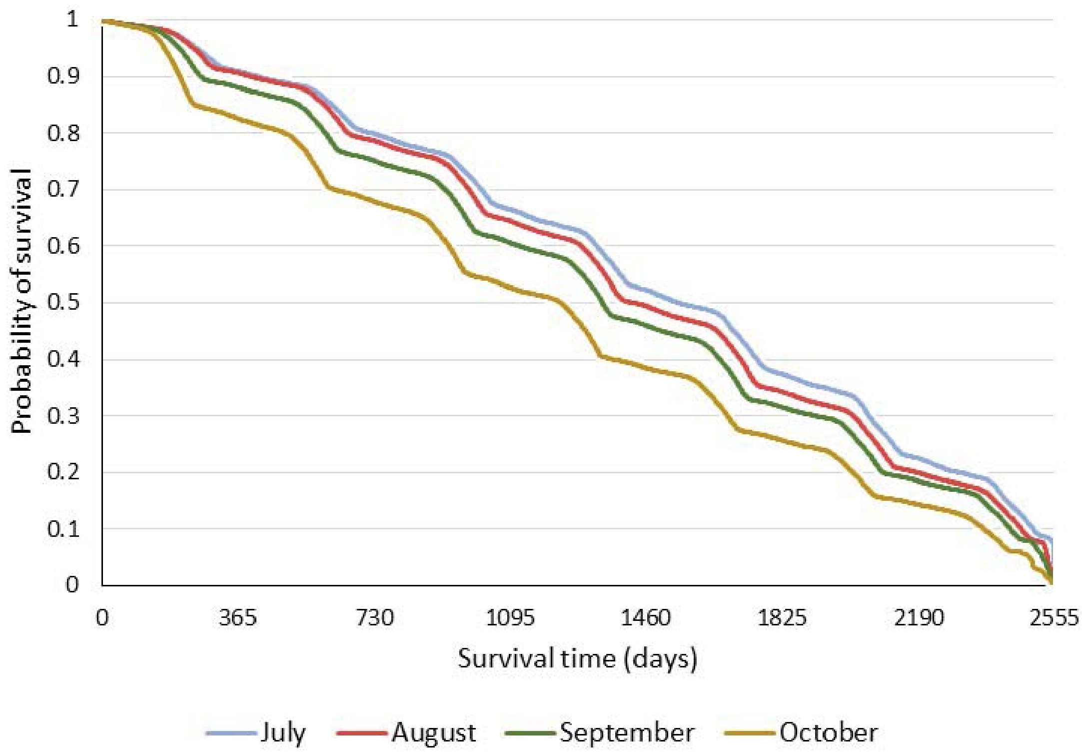


**Figure 5.5** The probability of survival for cows that calved in July, August, September and October for their second parturition date.

**Table 5.4** The percentage of July, August, September and October calving cows that survived to a specific time (days) and the 95% confidence interval.

| Type | Percentage | Survival time (days) | 95% confidence interval | |
|---|---|---|---|---|
| | | | Lower | Upper |
| July | 75% | 2122 | 2117 | 2127 |
| | 50% | 1546 | 1530 | 1565 |
| | 25% | 947 | 943 | 951 |
| August | 75% | 2079 | 2076 | 2082 |
| | 50% | 1423 | 1411 | 1438 |
| | 25% | 912 | 908 | 916 |
| September | 75% | 2035 | 2031 | 2039 |
| | 50% | 1344 | 1342 | 1346 |
| | 25% | 735 | 726 | 745 |
| October | 75% | 1861 | 1826 | 1900 |
| | 50% | 1231 | 1216 | 1243 |
| | 25% | 566 | 561 | 571 |

Carryover cows had lower ($P<0.01$) survival than lactation-matched non-carryover cows regardless of breed, and this was lowest for Holstein-Friesian carryover cows (Figure 5.6). The average survival for Holstein-Friesian carryover cows was 1088 ± 4.9 days, which was lower ($P<0.01$) than the average survival for Jersey carryover cows (1148 ± 9.2 days), and Holstein-Friesian x Jersey cows (1168 ± 5.1 days). Fifty percent of Holstein-Friesian, Jersey and Holstein-Friesian x Jersey carryover cows survived to 984, 1017 and 1024 days, respectively (Table 5.5).

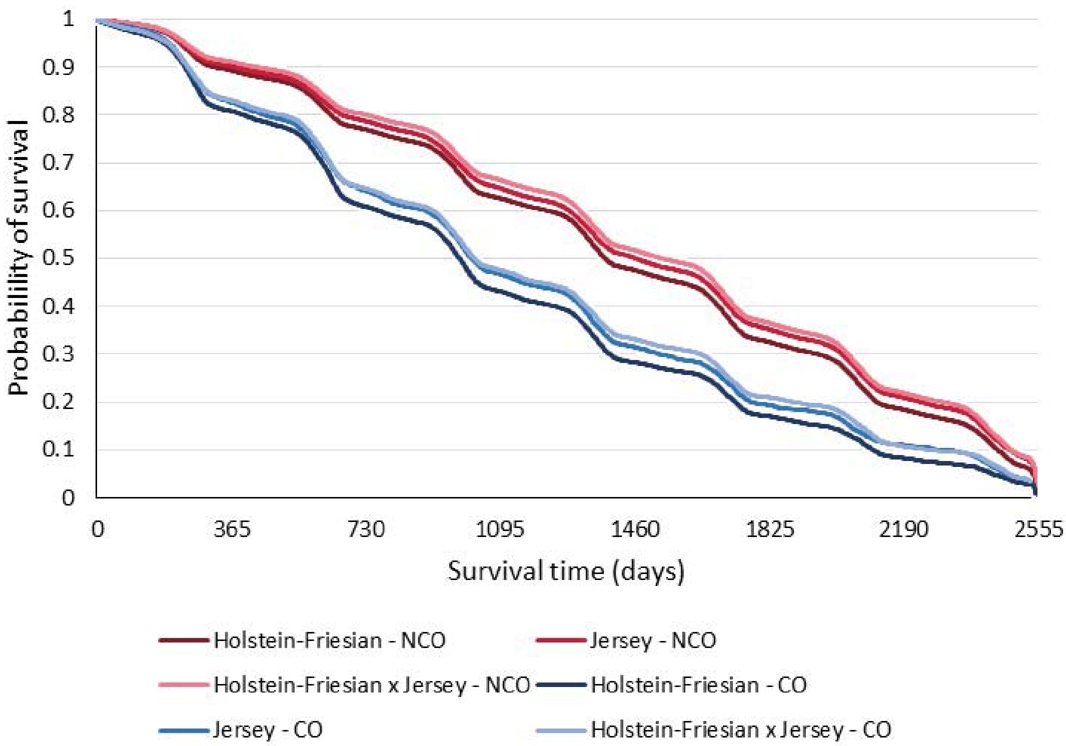


**Figure 5.6** The probability of survival for Holstein-Friesian, Jersey and Holstein-Friesian x Jersey carryover (CO) and non-carryover (NCO) cows after their second parturition date (day 0).

The probability of survival for non-carryover Friesian cows was greater (P<0.01) than for all carryover breed groups but lower (P<0.01) than for Jersey and Friesian x Jersey non-carryover cows. The average survival days for Friesian non-carryover cows was 1415 ± 1.7 days, which was lower (P<0.01) than Jersey non-carryover cows that had an average survival of 1462 ± 3.0 days, and Friesian x Jersey non-carryover cows that had an average survival of 1492.3 ± 1.53 days. Fifty percent of Friesian, Jersey and Friesian x Jersey non-carryover cows survived to 1379, 1463 and 1543 days, respectively (Table 5.5).

**Table 5.5** The percentage of Holstein-Friesian, Jersey and Holstein-Friesian x Jersey carryover (CO) and non-carryover cows (NCO) that survived to a specific time (days) and the 95% confidence interval.

| Cow type | Percent | Survival (days) | 95% confidence interval | |
|---|---|---|---|---|
| | | | Lower | Upper |
| Holstein-Friesian – CO | 75% | 1652 | 1634 | 1669 |
| | 50% | 984 | 978 | 990 |
| | 25% | 564 | 557 | 571 |
| Jersey – CO | 75% | 1697 | 1680 | 1718 |
| | 50% | 1017 | 1003 | 1032 |
| | 25% | 581 | 569 | 593 |
| Holstein-Friesian x Jersey - CO | 75% | 1719 | 1709 | 1728 |
| | 50% | 1024 | 1016 | 1033 |
| | 25% | 591 | 586 | 595 |
| Holstein-Friesian – NCO | 75% | 2055 | 2052 | 2058 |
| | 50% | 1379 | 1376 | 1382 |
| | 25% | 824 | 814 | 836 |
| Jersey – NCO | 75% | 2084 | 2079 | 2089 |
| | 50% | 1463 | 1448 | 1478 |
| | 25% | 903 | 895 | 910 |
| Holstein-Friesian x Jersey - NCO | 75% | 2097 | 2094 | 2101 |
| | 50% | 1534 | 1523 | 1546 |
| | 25% | 936 | 934 | 938 |

The probability of survival for carryover and non-carryover cows that calved in July, August, September or October were different (P<0.01). Carryover cow survival was lower (P<0.01) than that for all non-carryover groups (Figure 5.7). The average survival of carryover cows that calved in July, August, September and October was 1214 ± 6.6 days, 1135 ± 4.3 days, 1016 ± 8.5 days and 879 ± 19.8 days, respectively. Fifty percent of carryover cows that calved in July, August, September and October survived to 1075 days, 1008 days, 927 days and 615 days, respectively (Table 5.6).

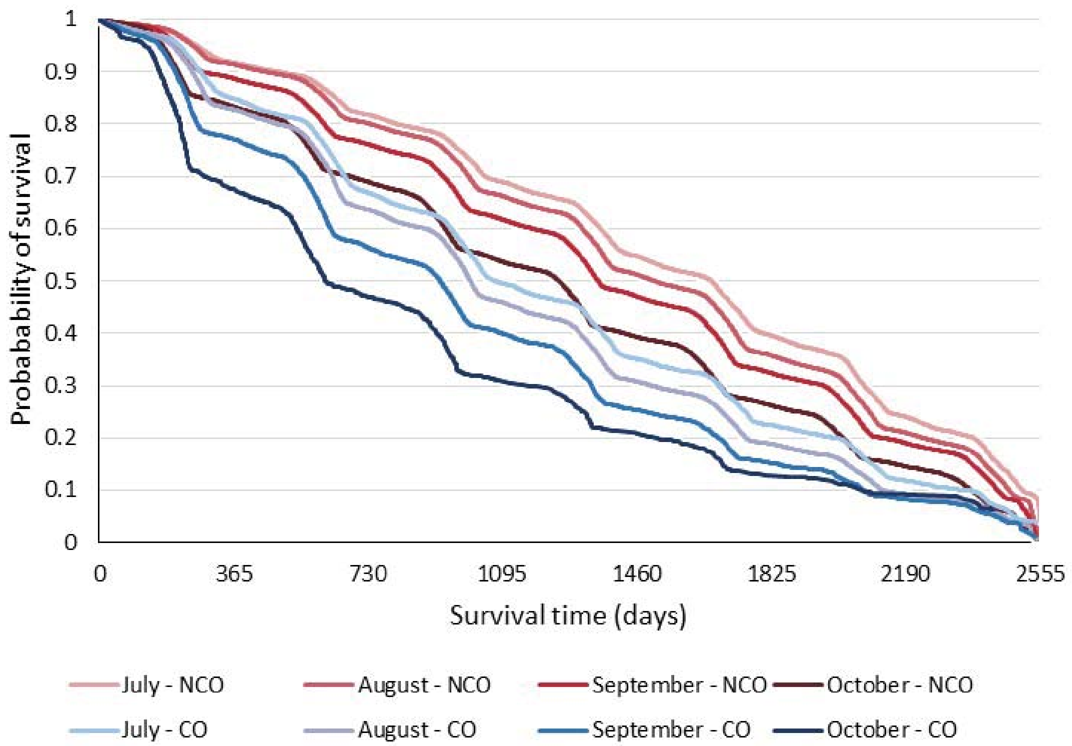


**Figure 5.7** The probability of survival for July, August, September and October calving carryover (CO) and non-carryover (NCO) cows after their second parturition date (day 0).

The average survival days for non-carryover cows that had parturition dates in July, August, September, and October were 1547 ± 2.7 days, 1486 ± 1.46 days, 1398 ± 2.2 days and 1241 ± 4.7 days, respectively. Fifty percent of non-carryover cows that calved in July, August, September, and October survived for 1662 days, 1508 days, 1355 days, and 1249 days, respectively (Table 5.6).

**Table 5.6** The percentage of July, August, September and October calving carryover (CO) and non-carryover (NCO) cows that survived to a specific time (days) and the 95% confidence interval.

| Type | Percent | Survival time (days) | 95% confidence interval | |
|---|---|---|---|---|
| | | | Lower | Upper |
| July – CO | 75% | 1754 | 1741 | 1765 |
| | 50% | 1075 | 1052 | 1119 |
| | 25% | 622 | 615 | 628 |
| August – CO | 75% | 1691 | 1683 | 1699 |
| | 50% | 1008 | 1003 | 1012 |
| | 25% | 590 | 584 | 594 |
| September – CO | 75% | 1484 | 1408 | 1558 |
| | 50% | 927 | 914 | 938 |
| | 25% | 439 | 403 | 481 |
| October – CO | 75% | 1311 | 1268 | 1337 |
| | 50% | 615 | 595 | 711 |
| | 25% | 235 | 228 | 242 |
| July – NCO | 75% | 2143 | 2137 | 2157 |
| | 50% | 1662 | 1655 | 1668 |
| | 25% | 979 | 974 | 984 |
| August – NCO | 75% | 2092 | 2089 | 2094 |
| | 50% | 1508 | 1500 | 1516 |
| | 25% | 942 | 940 | 944 |
| September - NCO | 75% | 2044 | 2041 | 2048 |
| | 50% | 1355 | 1352 | 1358 |
| | 25% | 783 | 771 | 796 |
| October – NCO | 75% | 1896 | 1858 | 1939 |
| | 50% | 1249 | 1238 | 1258 |
| | 25% | 575 | 570 | 580 |

## 5.4 Discussion

The survival of a dairy cow, or the longevity of their productive life, is a major factor influencing farm profitability. Poor survival rates are an economic cost to dairy systems due to the requirement to raise or purchase replacements (Pritchard *et al.*, 2013; Vukasinovic *et al.*, 2001; Xu and Burton, 1996). The decision to keep a cow, rather than replacing her is based on the expectation that she will produce profit in following years (Van Arendonk, 1988). The objective of this chapter was to determine the probability of survival over time (days) of carryover cows and compare this to non-carryover cows. This was achieved by firstly comparing the survival of second-lactation carryover cows with that of two-year-old heifers. Following this, the survival of carryover and non-carryover cows, after their second lactation was compared, without accounting for the cows breed or parturition month. Lastly, survival curves for breed and parturition month as an additional class to carryover type were produced.

From the results, it is evident that carryover cow survival is inferior to that of non-carryover cows. When second-lactation carryover cows were compared, the average survival of carryover cows was 413 days or 1.1 years less than a heifer. Although this is a comparison between two groups cows that are of different age and lactation, the results provide evidence to a farmer that carryover cows will survive at least one year less than a heifer that would be introduced if the non-pregnant cow had not been carried over.

Second-lactation carryover cows survived 329 days (0.9 years) less than non-carryover cows of the same lactation. This comparison was made between carryover cows and non-carryover cows in lactation two (day 0) that were four years old and three years old, respectively. New Zealand survival statistics show that cows of different age groups have different survival probability to next lactation, and this is greatest for cows between four and five years old (LIC and DairyNZ, 2016). Although the one-year age difference between the lactation-matched carryover and non-carryover cows may account for some of the survival differences shown, Beaudeau *et al.* (1995) reported the risk of being culled increased with lactation number but was only significantly greater when the survival of lactation five cows was compared to lactation two cows (three-year age difference).

Pangborn and Woodford (2013) have shown that 83%, 82% and 71% of carryover cows survive from their first to second, second to third and third to fourth lactation, respectively. The results of the study presented here show that the probability of carryover cows to survive from first to second, third and fourth lactation is similar in the first year, but much lower for the two subsequent lactations. However, it is unclear if the survival rates presented in Pangborn and Woodford (2013) were the percentage of cows from each lactation that survived to the next lactation or whether it was a percentage of the original number of carryover cows.

Breed was identified as a significant factor that influenced cow survival in this study. Holstein-Friesian x Jersey and Jersey cows had longer median and average survival days when compared to Holstein-Friesian cows. This is consistent with other studies that have shown that Holstein-Friesian cows have lower survival than other breed types (Brownlie and McDougall, 2014; Dillon *et al.*, 2003). The current study provides additional evidence to suggest that carryover cow survival is lower than all non-carryover cows of Holstein-Friesian, Holstein-Friesian x Jersey and Jersey breed, and is lowest for Holstein-Friesian carryover cows. It has been suggested that part of these breed differences are accounted for by the lower fertility, especially lower pregnancy rate and longer calving to conception rate, for Holstein-Friesian cows in New Zealand (Dillon *et al.*, 2003). Some of this lower fertility may be influenced by Holstein-Friesian cows having a greater incidence (19%) of anouestrous issues at mating, when compared to Jersey (13%) and Holstein-Freisian x Jersey (14%) cows (Xu and Burton, 2003).

Furthermore, part of these breed differences for cow fertility may be influenced by crossbreeding (Holstein-Friesian x Jersey); whereby two breeds are crossed to exploit heterosis, which removes negatives effects of using the same breed (inbreeding) and complements favourable traits from two or more breeds (Lopez-Villalobos and Garrick, 2006). Studies have shown that the proportion of cows pregnant to first service, cows in-calf during the first six weeks and conception rate were higher, as well as days to first oestrus were lower for Holstein-Friesian x Jersey cows, compared to Holstein-Friesian and Jersey straightbred cows (Prendiville *et al.*, 2011; Vance *et al.*, 2013). It has been suggested that the reproductive decline, and therefore, lower survival for Frieisan cows may be influenced by increased levels of inbreeding (Lucy, 2001). It could be speculated that the lower fertility of carryover cows may impact the fertility of the overall national herd, as you are breeding less fertile animal. However, one way to minimise this effect, while reducing herd wastage would be to breed non-replacement animals from the carryover cows (e.g. beef cross calves).

New Zealand dairy farm managers aim to have their herd's calving period between 10 and 14 weeks to match the beginning of the grass growing season with the cows increased energy requirements (Holmes *et al.*, 2002). The findings presented in the current study, cows with parturition dates in July had a higher probability of survival than cows with parturition dates in August, September and October, respectively. This is consistent with the findings in an Irish study that showed survival rate decreased as parturition month increased (Evans *et al.*, 2006). The probability of survival was lower for carryover cows for all parturition months, when compared to non-carryover cows, and was lowest for carryover cows that calved in October. It must be acknowledged that only the cows second parturition month is accounted for. However, cows that calve late in one year, are likely to calve late in the following year (Blackwell *et al.*, 2010; Firk *et al.*, 2002). The seasonal nature (365 calving interval) of New Zealand dairy systems requires cows to calve, resume ovarian cycling, display oestrus, be mated and conceive within approximately 83 days after the farm's planned start calving date (Blackwell *et al.*, 2010). A cow that calves later (September or October) has less time to resume ovarian cycling and conceive. Consequently, the likelihood of them conceiving during the mating period and their survival is reduced.

The greater breed proportion of Holstein-Friesian and higher EBVs for milk traits, as well as lower EBVs for fertility for the carryover group that was shown in Chapter 3 may contribute to the lower survival of carryover cows in the present chapter. During early lactation, cows with high milk yields are unable to consume enough pasture to meet their energy requirements, and as a result, enter a period of negative energy balance (Bauman and Currie, 1980). To counteract this energy imbalance, body fat reserves are broken down (lipolysis) to provide energy to the cow (Bauman and Currie, 1980). Studies have shown that the hormonal changes and increased blood metabolite concentrations during negative energy balance have a negative effect on the production of the reproductive hormones that are required for ovulation and therefore, the cow's resumption of ovarian cycling is delayed (Giuliodori *et al.*, 2011; Jeong *et al.*, 2015; Lucy, 2001; Reist *et al.*, 2000).

The increased number of Holstein-Friesian cows in New Zealand arose from selection of overseas Holstein-Friesian cows that were selected for high milk yields while fed concentrate diet and therefore, once placed in New Zealand pasture-based systems they experience a period of severe negative energy balance in early lactation (Harris and Kolver, 2001). The fertility of these overseas Holstein-Friesian cows has been shown to be lower but as discussed in Chapter 3, it appears that these cows fail to conceive, rather than fail to resume ovarian cycling after parturition and this contributes to the poorer reproductive performance of these animals (McNaughton, 2003).

The adverse effect of negative energy balance on the resumption of ovarian cycling, the higher proportion of Holstein-Friesian, as well as the potentially higher body condition of carryover cows, which is shown to depress feed intake (Garnsworthy and Topps, 1982; Rukkwamsuk *et al.*, 1999) may account for the lower survival of carryover cows when they return to a milking herd. Research findings have led to the recommendation of a pre-calving BCS of 5.0 and 5.5 for cows and heifers, respectively. Beyond this target, extra body condition has been shown to negatively impact first service conception rate, and six-week pregnancy rates (Buckley *et al.*, 2003; Butler and Smith, 1989; Roche *et al.*, 2007b). Diet has been shown to have no effect on the rate of BCS loss in early lactation, and therefore, appropriate management of cow BCS prior to parturition is mandatory to optimise carryover cow productivity once they return to a milking herd (Roche *et al.*, 2006; Roche *et al.*, 2007a; Ruegg and Milton, 1995).

Further research could be conducted on the reasons why carryover cows were culled once they returned to a milking herd. Carryover cows may have underlying health problems that resulted in a lower survival when compared to non-carryover cows. In

Chapter 4, it was shown that SCS was generally higher for carryover cows, compared to non-carryover groups. Therefore, it may be suspected that carryover cows are more prone to mastitis issues. Cows infected with mastitis have been shown to require more services per conception and have a greater number of non-pregnant days (Ahmadzadeh *et al.*, 2009). This reduced reproductive performance, as well as the requirement to maintain a low bulk SCC may increase the likelihood of a carryover cow being culled once they return to a milking herd. Carryover cows may have a greater incidence of diseases, such as, *Neospora caninum,* which is transmitted to cows by dogs and infects the cows for their lifetime by causing mid-pregnancy abortion (Anderson *et al.*, 2000), or *Bovine viral diarrhea* (BVD) virus, which has also been shown to cause early abortion (Olafson *et al.*, 1946) and more recently shown to reduce the reproductive performance (e.g. conception rate) of infected cows (Larsson *et al.*, 1994; McGowan *et al.*, 1993). Furthermore, uterine health and the rate of uterine involution, which is negatively affected by retained placentas and dystocia may contribute to the reduced reproductive performance and survival of carryover cows (Sheldon and Dobson, 2004; Sheldon *et al.*, 2008). External factors, such as poor hoof conformation, lameness and/or poor udder conformation may also influence the decision to retain a cow that has already carried over. However, further investigation is required before the impact of these factors can be determined.

Longevity reflects a cow's fertility and reproductive performance, health, and overall fitness (Beaudeau *et al.*, 1995; Vukasinovic *et al.*, 2001), but is also influenced by the environment and farm management practices (Beaudeau *et al.*, 1995; Weigel *et al.*, 2003). An American study on cow survival showed that herds with fewer cows per employee, and herds that had the whole herd artificially inseminated, rather than part of the herd artificially inseminated and part of the herd mated to the bull, had lower risk of involuntary culling (Weigel *et al.*, 2003). In New Zealand, other factors such as grazing management, reproduction management (oestrus detection, anoestrus treatment), stocking rate and feed types (pasture versus alternative forage types) not only affect cow milk production directly, but reproduction and survival indirectly (Baudracco *et al.*, 2010; Lucy *et al.*, 2004; Macmillan and Watson, 1973; Woodward *et al.*, 2003). With the data provided in the current study, it is difficult to determine if any of these management factors influenced the survival of carryover and non-carryover cows. However, data was only selected from herd-year groups that contained both carryover and non-carryover records to reduce bias and account for some of these management and environment factors that could influence carryover cow survival.

The data analysis method for this Chapter (Kaplan-Meyer SA) did not adjust for confounding factors. Future work may consider using a model (e.g. Cox-PH model) that allowed testing for interactions between carryover and non-carryover cows, breed or month.

The results of this chapter have shown that carryover cows had lower survival when they returned to a milking herd, when compared to two-year-old heifers and non-carryover cows in the same lactation. For carryover and non-carryover cows in their second lactation, this trend was evident regardless of cow breed or parturition month, but carryover cows that were Holstein-Friesian or had a parturition month in October had a higher risk of being culled earlier (less days). Although it was identified in Chapter 4 that carryover cows had a milk production advantage, it is clear that carryover cow survival is inferior to non-carryover cows.

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# Chapter 6 General Discussion and Conclusion

## 6.1 Introduction

The primary aims of this thesis were to identify spring-calving carryover cows, using calving interval as a tool and to describe their population (Chapter 3); to compare the milk production of carryover cows with non-carryover cow groups in the first carryover year, and for up to three subsequent carryover years (Chapter 4); and lastly, to compare the probability of carryover cow survival over time (days) with that of non-carryover groups (Chapter 5). A total of 20 million lactation records (MY, FY, PY and SCC) as well as breed proportions, ancestry information, animal movement and parturition dates for each animal were extracted from LIC's animal recording database. Data restrictions were imposed to obtain well-recorded spring-calving lactation records. Sub-populations were developed for each aim and analysed accordingly. The results from this study provides new information on the carryover population, and adds to the current knowledge surrounding carryover cow productivity, which was previously investigated in New Zealand by Pangborn and Woodford (2010) and Pangborn and Woodford (2013).

## 6.2 Main findings

### 6.2.1 Carryover cow population

The results in Chapter 3 show that a proportion of non-pregnant spring-calving cows are carried over each year. Furthermore, this chapter provided evidence that the carryover cow population is different to the non-carryover cow population, in terms of breed and genetic merit. The results showed that each year, approximately 2.5% of spring-calving dairy cows had a carryover period in the previous year. To the authors knowledge, this figure had not been directly estimated for the New Zealand dairy industry. Annual fluctuations in milk price, cull cow price and rearing costs influence farm profit and cash flow and therefore, culling decisions (Lehenbauer and Oltjen, 1998), in two years prior to the year when the cow returns to a milking herd may influence the percentage of carryover cows. For example, the greatest percentage of carryover cows in spring-calving dairy herds was in the 2009/10 year and this is likely to be influenced by a relatively high milk price ($7.67 per kg MS) two years prior to this (LIC and DairyNZ, 2016).

A large proportion (43%) of carryover cows returned to milking herds at four years old, after failing to conceive during their first lactation. The percentage of carryover cows returning to dairy herds decreased as cow age increased. This age trend may be influenced by dairy cow's reaching peak milk production between five and six years old and cow survival from one lactation to the next decreasing beyond this age (LIC and DairyNZ, 2016). Non-pregnant cows that are carried over just prior to, or during this peak age, will return to a milking herd after their optimum milk production age and therefore, the decision to cull, or retain, the non-pregnant cows may favour the former.

The results showed that on average, 17%, 69% and 14% of dairy herds contained zero, less than 5%, and greater than 5%, carryover cows, respectively. It is likely that management differences occur between farms in each category, but from the data provided for each animal, this cannot be confirmed. Some differences were identified between the percentage of carryover cows in herds with high and low milk production performance. This was different for Holstein-Friesian and Holstein-Friesian x Jersey dominant herds. Further research is required to determine what management practices and cow factors influence the decision to carryover a non-pregnant cow.

The carryover cow population was comprised of a greater breed proportion of Holstein-Friesian than the non-carryover population. The carryover cow EBVs for milk traits (MY, FY and PY) were greater than for the non-carryover group. After the carryover cow period, milk traits EBVs decreased but remained greater than for the non-carryover cow group. Fertility EBVs were significantly lower for carryover cows than non-carryover cows, prior to their carryover period. Some of this variation may be accounted for by a lower 21-day submission rate for carryover cows. For instance, a carryover cow may be less likely to be submitted for mating in the first 21 days after planned start of mating than cows that did conceive, and consequently, reducing their fertility EBV (NZAEL, 2016a). Aside from this, after failing to conceive and being carried over, fertility EBVs for carryover cows reduced further, while the non-carryover cow fertility EBVs increased due to the success of maintaining an annual parturition. The high EBVs of carryover cows for milk traits lead to higher BW in the year prior to being carried over when compared to non-carryover cows. However, as carryover cow fertility and milk trait EBVs decreased, their BW was lower than non-carryover cows in the year when they returned to a milking herd.

### 6.2.2 Carryover cow milk production

Chapter 4 focussed on the milk production of carryover cows and compared this to that of heifers, lactation-matched and age-matched non-carryover cows. A linear mixed model that included the random effect of the herd-year contemporary group; the fixed effect of carryover (Carry 1, Carry 2 or Carry 3) and parturition month class (June/July, August, September or October/November); and proportion of Holstein-Friesian, heterosis and days in milk as co-variates with linear effects was used to determine least square means for MY, FY, PY and SCS. The potential milk production of a carryover cow is an important productive aspect that impacts farm profitability and therefore, will influence the decision to carryover, or cull, a non-pregnant cow.

The greater milk EBVs for carryover cows, compared to non-carryover cows, shown in Chapter 3 were reflected in the results of Chapter 4. The milk production of second-lactation carryover cows was greater ($P<0.01$) than for two-year-old heifers, as well as lactation-matched and age-matched non-carryover cows. The current results were consistent with the milk production advantage shown in Pangborn and Woodford (2010).

If a carryover cow was to survive for three consecutive years, the milk production advantage for carryover cows was maintained, but at a decreasing rate. This confirms the longitudinal milk production advantage for carryover cows that was shown in Pangborn and Woodford (2013)'s study. However, in the current study, a larger study population resulted in all comparisons for milk traits between carryover and non-carryover cow groups being statistically different ($P<0.01$).

Some of the milk production advantage for carryover cows may be influenced by the greater BCS of these cows that is expected after one non-lactating year (Pangborn and Woodford, 2010). Cows with higher body condition have larger lipid stores, which provide a source of long chain fatty acids and glucose for lactose synthesis and milk production (Bauman and Currie, 1980). These factors in combination with the higher EBVs for milk traits that were shown in Chapter 3, may have contributed to the higher milk production for carryover groups. However, cows with very high body condition, and/or cows that produce large amounts of milk, are at risk of losing large amounts of body condition and entering a severe state of negative energy balance in early lactation (Bauman and Currie, 1980). The hormonal changes and increased blood metabolite concentrations during negative energy balance can have a negative effect on the production of the reproductive hormones that are required for ovulation and therefore, the resumption of ovarian cycling can be delayed (Giuliodori *et al.*, 2011; Jeong *et al.*, 2015; Lucy, 2001; Reist *et al.*, 2000).

Body condition score targets of cows and heifers having a pre-calving BCS of 5.0 and 5.5, respectively, have been based on research that suggests the positive effects of BCS are non-linear (Roche *et al.*, 2007a). Cows with greater than the optimum BCS have been shown to have lower conception rates to first service and six-week pregnant rates (Buckley *et al.*, 2003; Butler and Smith, 1989; Roche *et al.*, 2007b). Diet has been shown to have no significant effect on BCS loss after parturition (Roche *et al.*, 2006; Roche *et al.*, 2007a; Ruegg and Milton, 1995), and therefore, achieving an appropriate BCS prior to parturition and ensuring carryover cows do not become over conditioned during their extended lactation is important. In this study, there was no data for BCS, but future work that investigates appropriate carryover cow management would be valuable to ensure carryover cow productivity is optimised once they return to a milking herd. These BCS factors, as well as the metabolic changes and lower genetic value of carryover cows (Chapter 3) may have influenced the survival results shown in Chapter 5.

### 6.2.3 Carryover cow survival

Chapter 5 focussed on carryover cow survival once they returned to a milking herd and compared this with heifers and lactation-matched non-carryover cows. Carryover cow survival and milk production (Chapter 4) are two important aspects that impact farm revenue. The Kaplan-Meier method (life-test procedure) of SAS was used to produce proportion-hazard survival curves for each comparison. Carryover class was included as strata levels for both the heifer and lactation-matched cow comparisons, and breed and parturition month were included as an additional comparison for lactation-matched cows.

The results in estimated that a two-year-old heifer will survive in a herd for 1.1 years longer than a carryover cow that returned to a milking herd in her second lactation. The probability of survival to second carryover year (365 days) was 82%, which was similar to the survival percentage presented in Pangborn and Woodford (2013) (83%). In the current study, probability of survival was reduced to 63% and 46% for carryover cows surviving from second to third carryover year (730 days) and third to fourth carryover year (1095 days), respectively. These probabilities of survival are lower than the survival percentages presented in Pangborn and Woodford (2013)'s longitudinal study. However, it is unclear if the survival rates shown in Pangborn and Woodford (2013) represent the percentage of cows that survived to the next lactation from the previous lactation or as a percentage of the original number of carryover cows. If so, it is difficult to compare the results of the current study.

In this study, second-lactation carryover cows were expected to survive 0.9 years less than a non-carryover cow after their second parturition. This trend was consistent even when cow breed and parturition month were considered. Survival was lowest for carryover cows that had a second parturition date in October or for Holstein-Friesian cows. Carryover cow survival was greatest when cows had a second parturition date in July or were Holstein-Friesian x Jersey, but survival was still lower than all non-carryover groups for parturition month and breed. Previous studies have presented similar breed (Brownlie and McDougall, 2014; Dillon *et al.*, 2003) and parturition month (Evans *et al.*, 2006) trends, but the current study provides evidence that carryover cow survival is lower than non-carryover cows, even when these aspects are accounted for.

The lower survival of carryover cows may be influenced by their low EBVs for fertility (Chapter 3). The lower fertility EBVs indicate that the population of carryover cows is inherently less fertile, with reduced survival when compared to non-carryover cows under the same management conditions (i.e. within the same herd). Furthermore, cows of higher body condition, which may be the case for carryover cows, have been shown to have reduced feed intakes (Rukkwamsuk *et al.*, 1999). To counteract these effects, the rate of lipolysis (fat breakdown) is increased, and as discussed in section 6.2.2, the metabolic hormone and metabolite concentration changes can negatively affect the resumption of ovarian cycling. Thus, the cow may not resume ovarian cycling or conceive within the herds mating period and as a consequence, the risk of being culled before the next year is greater.

In New Zealand's seasonal, pasture-based dairy systems it is important for herd calving interval to remain close to 365 days to align the grass growing season with the cows increased energy requirements. To maintain an annual calving interval, cows are required to resume ovarian cycling, display oestrus behaviour, be mated and conceive within approximately 83 days after the farm's planned start calving date (Blackwell *et al.*, 2010). Cows that calve in September or October will have less than a month before the herds planned start of mating for these events to occur and once the average post-partum anoestrus interval (25 days and 50 days) (McDougall, 1994) is accounted for, it is unlikely that the cow will conceive and therefore, may be culled.

## 6.3 Limitations

### 6.3.1 Data

In this study, data was provided for herds that recorded their information with LIC. Although it was only for herds that recorded their information with LIC, the number of records (total of 20 million records from cows that were born between 2003 and 2013) was sufficient and provided a good representation of spring-calving cows in New Zealand.

Data was only sourced from herds that conducted at least three herd tests per year. Selecting data from herds that conducted regular herd tests may create some bias towards farmers using this service for data and information capture, and therefore, it could be speculated that they are higher performing, well managed herds. However, this data restriction was essential to provide accurate estimates of milk production and to minimise the amount of poorly recorded data.

Much of the data stored in the animal recording database at LIC is input by farmers, farm technicians, and relies on the accuracy of herd testing equipment and software for processing records. It has been assumed that data, including parturition dates and animal movement information has been input correctly, however, it is likely that there are recording errors. The size of the datasets should minimise the impact of recording errors, but some errors cannot be eliminated.

### 6.3.2 Methods

Calving interval was used as a tool to identify carryover cows. This was an effective tool to identify cows that had extended calving intervals. However, it did not capture heifers that failed to conceive at their first mating (at approximately 15 months) or non-pregnant cows that were carried over but failed to conceive after their carryover period so never returned to a milking herd.  Pregnancy diagnosis information, in conjunction with herd exit dates, may be used in future projects to identify heifers that are carried over, or cows that are carried over, but never returned to a milking herd.

The study was limited to spring-calving cows that had parturition dates between June and November (inclusive). Carryover cows can also be utilised, and potentially more frequently, in split-calving herds. The role of carryover cows in split-calving herds could be investigated in future work.

Furthermore, the milk production and survival analysis results were limited to Holstein-Friesian, Holstein-Friesian x Jersey and Jersey cows. However, these breeds represent most dairy cows in New Zealand (90%) and this data restriction only reduced the size of the datasets by less than 15% of the original size.

The data that was available did not contain information on specific management practices that could be influencing the performance or prevalence of carryover cows. This information would be valuable, however, incorporating herd-year as a contemporary group should have minimised these effects in the current analysis.

## 6.4 Research implications

The success of the New Zealand dairy industry is driven by the favourable environment (climate and soils) for pasture growth. As established in section 2.3, the success of these pastoral-based dairy systems relies on maintaining a 365-day calving interval and a condensed calving pattern during the spring period. This ensures that the increased pasture growth rates are synced with the increased animal energy requirements after parturition. Cows that fail to maintain seasonality are generally culled from the herd, but this comes with a considerable economic loss if the cow is relatively young and yet to reach its optimum productivity. Furthermore, consumer demand for sustainable products is likely to drive the dairy industry to reduce cow wastage.

Accordingly, it seems appropriate that alternative options for non-pregnant cows are investigated. Prior to this study, it was known that some non-pregnant cows were carried over in the industry, but the scale of the practice had not been determined. The results from the current study provide evidence that some non-pregnant cows are carried over as an alternative to culling them and introducing a heifer. The milk production advantage and lower survival rates for carryover cows provide further evidence to support the on-farm results that were presented by Pangborn and Woodford (2010) and Pangborn and Woodford (2013). The results can be directly used by farmers and industry professionals as an indication of the potential productivity and survival of carryover cows once they return to a milking herd when compared to an alternative, non-carryover cow (an equivalent mature-aged cow or heifer). Furthermore, the results may be incorporated into a comprehensive economic simulation to determine whether carrying over a non-pregnant cow is an economically feasible management practice.

## 6.5 Further study

The current study focussed on carryover cows that were part of spring-calving dairy herds. Although this captured the majority of cows (95%), non-pregnant cows in split-calving (autumn and spring-calving herds) are often carried over for six-months before being mated and returned to the other herd (e.g. a spring-calving cow switches to an autumn-calving cow). It would be valuable to investigate the use, prevalence, and productivity of carryover cows in these types of systems.

The results of this study showed that carryover cows had a production advantage for up to three years once they had returned to a milking herd. Further work could investigate the lifetime production of the carryover cow, compared to non-carryover counterparts.

As discussed previously, a comprehensive economic simulation study that determines the economic feasibility of carrying over a non-pregnant cow as an alternative to raising a replacement heifer or purchasing an age-matched cow would help aid culling decisions made on farm. The results from this study, as well as further information regarding the cost of each option would be required. The scope of this type of study could include decision rules for the maximum cow age and minimum PW and BW where the management practice remains profitable alternative to culling the cow.

Investigation on the genetic parameters (heritability, genetic correlation) for carryover cows, and how these may impact their survival would be valuable. Such information may be used for livestock selection schemes to reduce the number of these low fertility and survival cows.

Lastly, investigation of the management factors that influenced a carryover becoming non-pregnant in the first place such as pre-calving BCS, reproductive performance, underlying diseases (e.g. *Neospora caninum*) and factors that influenced a farmer's decision to carryover a non-pregnant cow would be valuable for the New Zealand dairy industry. This could be conducted with on-farm, longitudinal studies, as well as qualitative techniques such as surveys and case studies. Results from such trials may help reduce the number of potential carryover cows.

## 6.6 Conclusion

This study used calving interval as a method to identify spring-calving carryover cows that had failed to conceive and had an extended, non-lactating period, before being mated and returned to a milking herd in the following year. Each year, 2.5% of spring-calving cows had a carryover period in the previous year. Forty-three percent of these carryover cows returned at four years old after failing to conceive in their first lactation. The majority (69%) of New Zealand spring-calving herds contained less than 5% carryover cows and 17% contained no carryover cows.

Average breed proportions for Holstein-Friesian were greater for the carryover group compared to the non-carryover group. Carryover cows had greater milk trait (MY, FY, PY and SCC) EBVs, but lower fertility EBVs than non-carryover cow groups. Carryover cow BW and PW were higher than those for non-carryover cows prior to their carryover period, but were either lower, or equal to, non-carryover cow groups in the year when they returned to a milking herd.

Carryover cow milk production (measured as MY, FY and PY) was greater than the milk production of two-year-old heifers, lactation-matched (two, three and four) and age-matched (four, five and six-year-old) non-carryover cows in carryover year one. This milk production advantage for carryover cows was retained for up to three years, if the carryover cow survived for this length of time once they had returned to a milking herd. The milk production advantage was greatest in carryover year one and decreased from thereafter.

The survival of carryover cows that returned to a milking herd in their second lactation was lower than the survival for two-year-old heifers and lactation-matched non-carryover cows. Carryover cow survival was lowest for cows that had a parturition date in October or for Holstein-Friesian cows, and was highest for cows that had a partition date in July or were Holstein-Friesian x Jersey cows. The probability of survival for carryover cow groups was consistently lower than for non-carryover cow groups, regardless of breed and parturition month.

This study quantified the prevalence of spring-calving carryover cows in the New Zealand dairy industry. It shows that carryover cow milk production is superior, but carryover cow survival is inferior to non-carryover cows. This information will aid on-farm culling decisions to ensure New Zealand's low-cost, pasture-based dairy systems .

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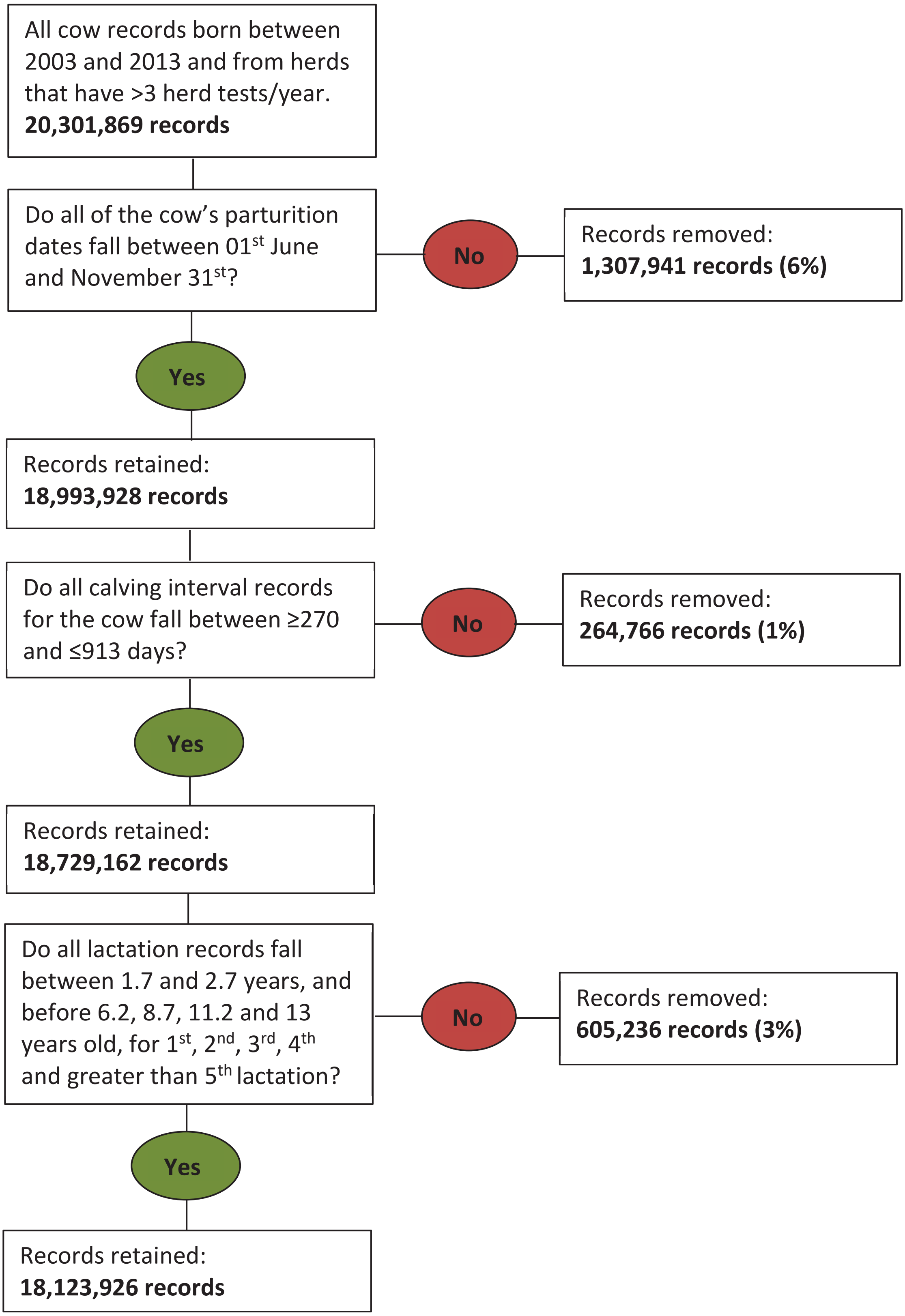
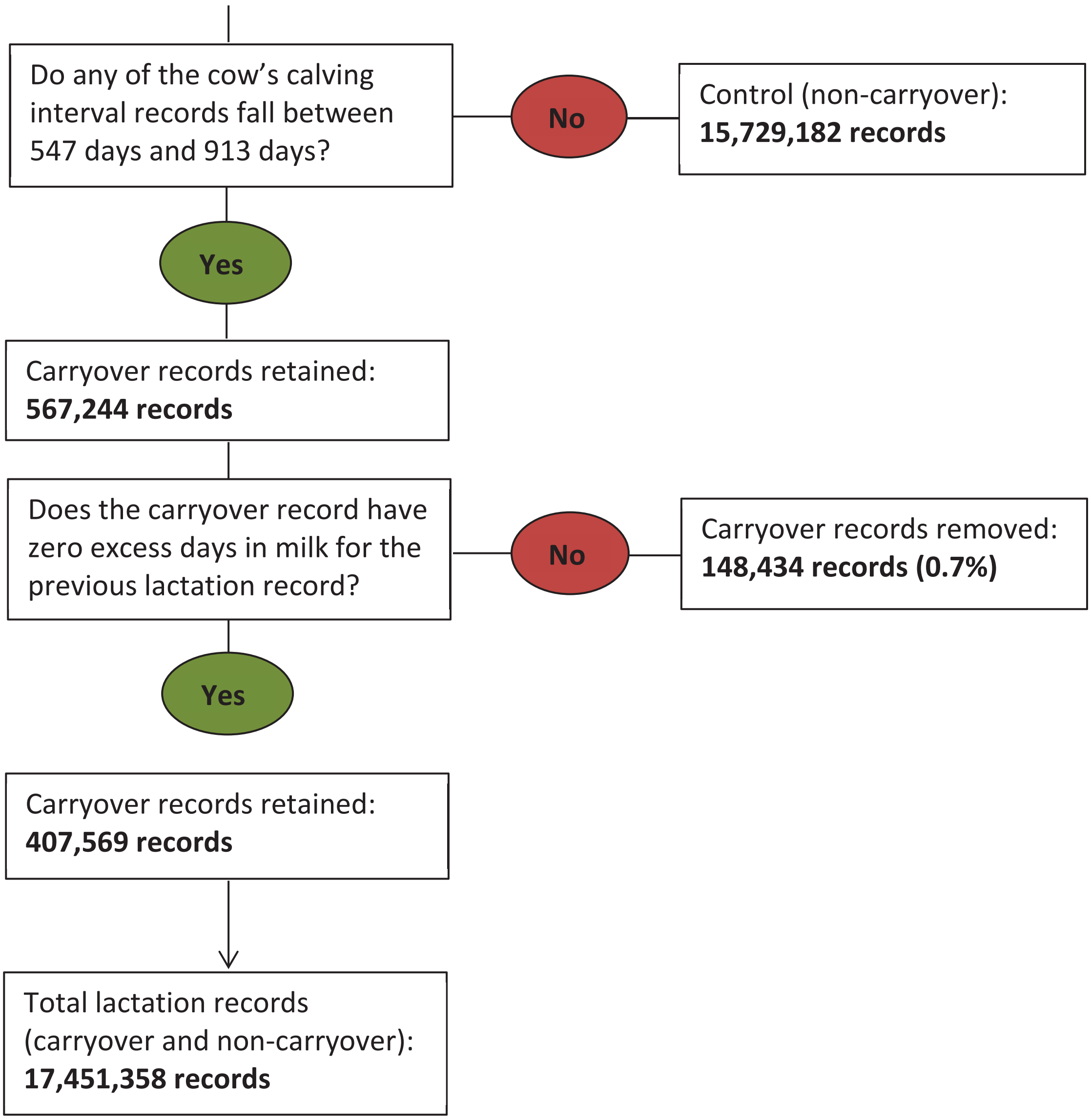
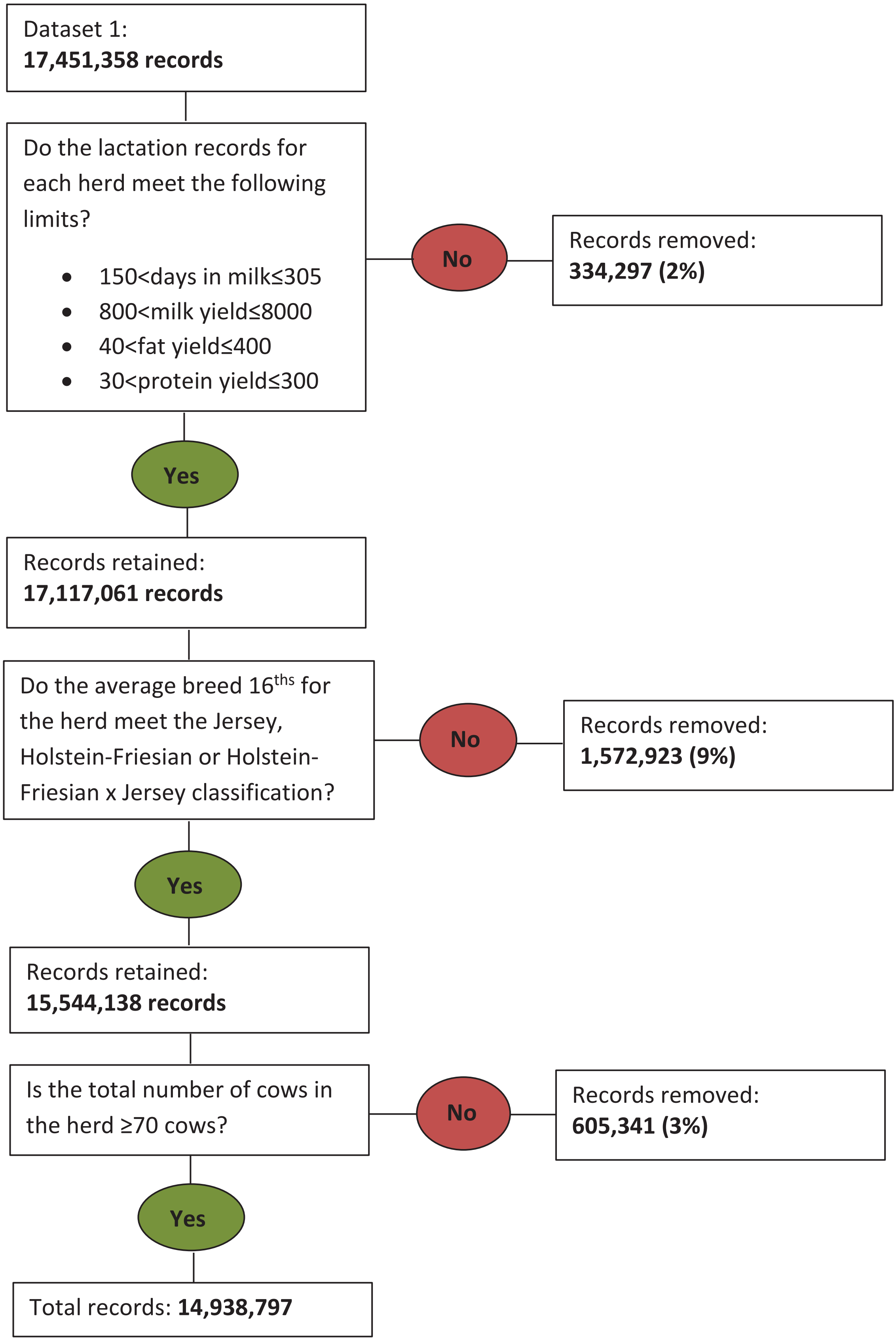
# Appendices

## Appendix A: Data exclusion process for Dataset 1 (section 3.2.2 and 3.2.3)

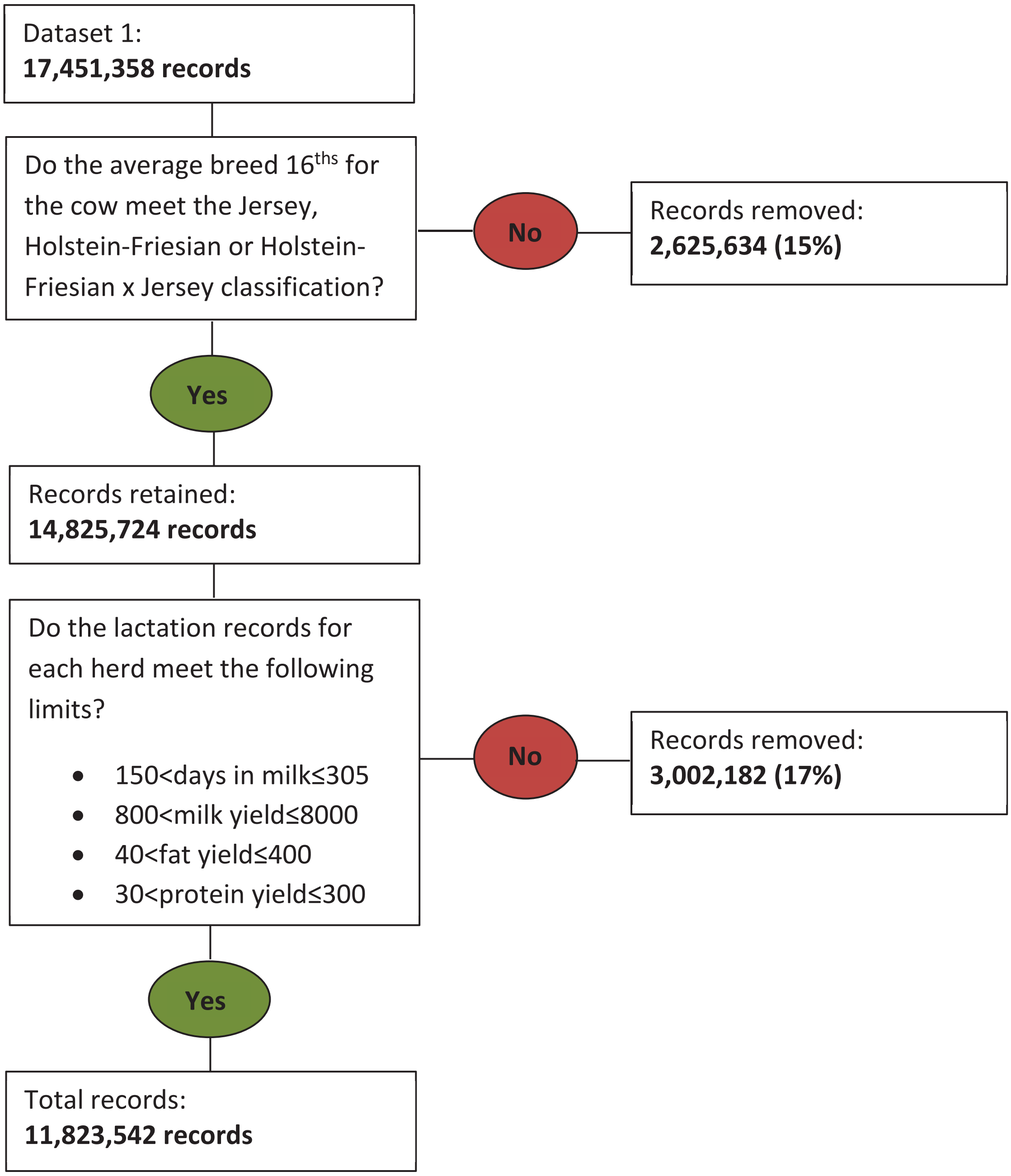



Do any of the cow's calving interval records fall between 547 days and 913 days?
No
Control (non-carryover): **15,729,182 records**
Yes
Carryover records retained: **567,244 records**
Does the carryover record have zero excess days in milk for the previous lactation record?
No
Carryover records removed: **148,434 records (0.7%)**
Yes
Carryover records retained: **407,569 records**
Total lactation records (carryover and non-carryover): **17,451,358 records**

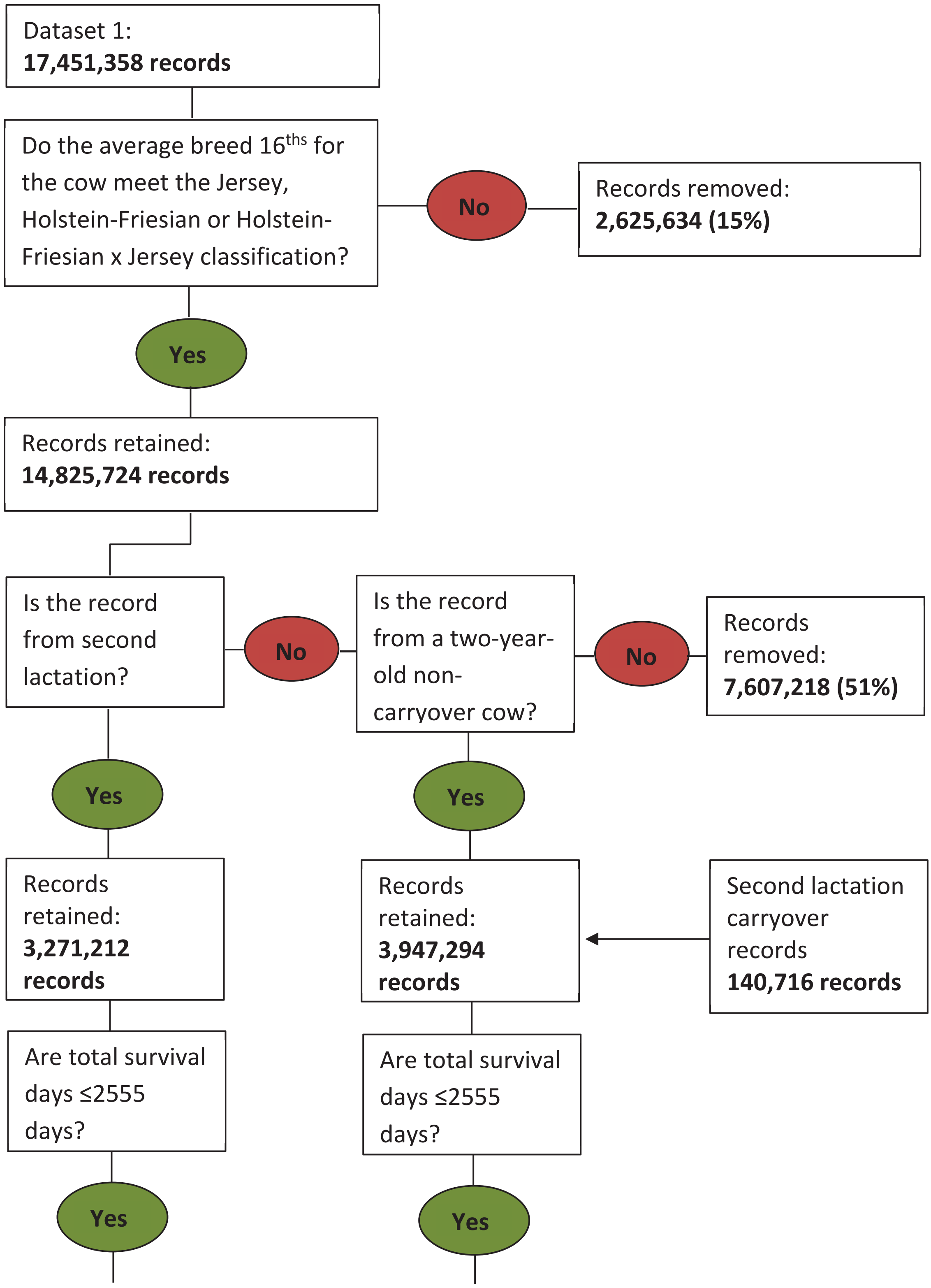
# Appendix B: Data exclusion process for Dataset 2 (section 3.2.4.2)

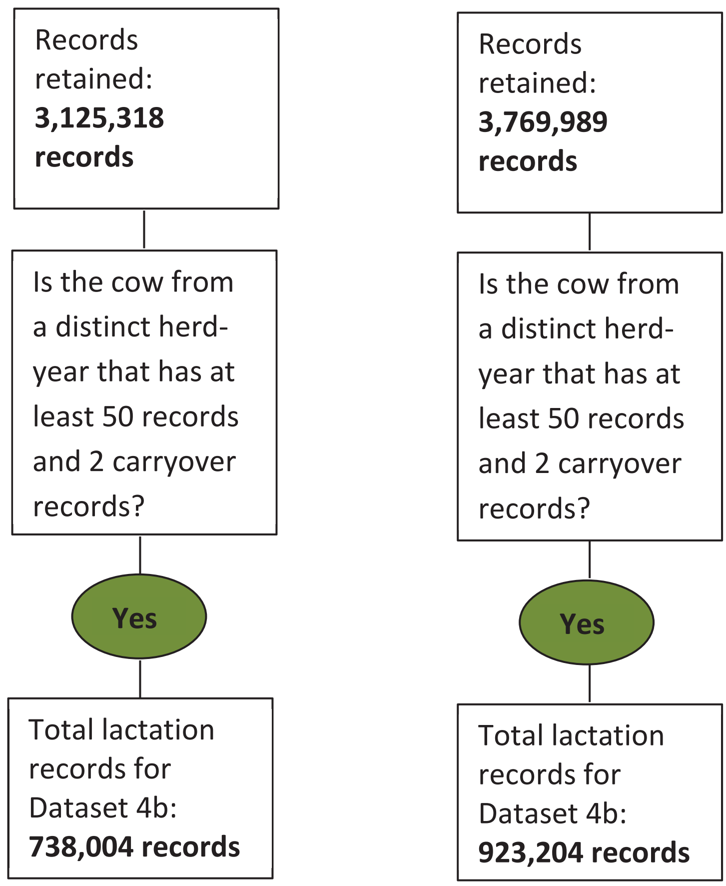


# Appendix C: Data exclusion process for Dataset 3 (section 4.2.1)



## Appendix D: Data exclusion process for Dataset 4a and 4b (section 5.2.1, 5.2.1.1 and 5.2.1.2)




Records retained: 3,125,318 records
Is the cow from a distinct herd-year that has at least 50 records and 2 carryover records?
Yes
Total lactation records for Dataset 4b: 738,004 records
Records retained: 3,769,989 records
Is the cow from a distinct herd-year that has at least 50 records and 2 carryover records?
Yes
Total lactation records for Dataset 4b: 923,204 records