Biophysical implications and economic considerations when changing from spring to autumn calving in pasture-based dairy systems

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Jake William Marshall Jarman

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Abstract

For a farmer considering changing their herd's calving season from spring to autumn, one approach is to extend the herd's calving interval (CI) and undertake an extended lactation. The objective of this thesis was to quantify the biophysical and economic implications of this approach. Two randomised and balanced farmlets were established on 1 October 2017 on an existing spring-calving research farm in South Taranaki, New Zealand. One farmlet (SPR; 301 cows, 104.0 ha) maintained a 12-month CI, spring-calving pattern, while the other farmlet (AUT; 301 cows, 104.8 ha) changed to autumn calving by delaying mating and extending the CI to 20 months. This resulted in an extended lactation, followed by a 12-month CI autumn-calving pattern for the remainder of the experiment. The experimental period was 1 June 2017 to 31 January 2020, and included two and a half lactations for the SPR farmlet and two lactations for the AUT farmlet. Weather, animal and pasture performance, supplementary feed use, and economic data were analysed for differences between farmlets, and used to model potential outcomes over a 10-year investment horizon, where the investment was to either remain spring calving or to use this approach to change to autumn calving.

Throughout the experimental period, total milksolids (MS) production was similar between the AUT and SPR farmlets (1,194 vs. 1,174 kg MS/cow), but AUT farmlet cows were offered more supplementary feed (2,371 vs. 1,936 kg dry matter/cow). Cows in the AUT farmlet varied in their ability to sustain an extended lactation [488 mean days in milk (DIM,) 577 max DIM]. Implications from extending the CI in the AUT farmlet were: a greater winter feed deficit, which increased supplementary feed requirements; a greater summer feed surplus, which required more pasture conservation; greater BCS gain, above an optimal pre-calving level, for cows during the later stages of their extended lactation; an improvement in reproductive performance during the extended lactation; and greater grazing costs for replacement heifers, although this also meant that heifers were older when they entered the milking herd and produced more MS. There were also carry-over effects from the extended lactation on the first autumn-calving lactation. Cows in the AUT farmlet had more DIM and produced more MS during their first complete autumn-calving lactation compared with either of the two complete lactations from SPR farmlet cows.

Extending the CI resulted in greater net costs during the first three years that had to be recouped by a relatively more profitable, steady-state autumn-calving system in subsequent years for the change to autumn calving to be a better investment than remaining spring calving. During the transition period AUT farmlet profit was $289–1,452/ha less compared with the SPR farmlet. Less annual MS production due to the extended lactation and required capital expenditure were major drivers of this relative difference in profitability in the AUT farmlet. Conversely, the availability of the winter milk premium, and greater MS production in the AUT farmlet, with

good cost control, once a steady-state autumn-calving pattern had been achieved, were critical to the AUT farmlet recouping the relative profitability difference. Greater MS production and the availability of the winter milk premium meant profit was greater in the steady-state AUT farmlet compared with the SPR farmlet after the transition period. With the current winter milk premium available, the NPV of the AUT farmlet was $38,212/ha compared with $26,040/ha for the SPR farmlet, however the NPV of the AUT farmlet reduced to $25,723/ha with no winter milk premium, and this was less than the NPV of the SPR farmlet. This led to the recommendation that only farmers who can operate an economically-sustainable autumn-calving system without a winter milk premium, should consider changing calving season.

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List of Abbreviations

18-CI	Eighteen-month calving interval
APC	Average pasture cover
AUT	Autumn-calving farmlet
BCS	Body condition score
BW	Breeding worth
CI	Calving interval
CP	Crude protein
DIM	Days in milk
DM	Dry matter
DMI	Dry matter intake
GDD	Growing degree days
GHG	Greenhouse gas
HF	Holstein Friesian
L1	Lactation one
L2	Lactation two
L3	Lactation three
LWT	Liveweight
ME	Metabolisable energy
MJ ME	Megajoules of metabolisable energy
MMPR	Marginal milksolids production response
MP	Metabolisable protein
MS	Milksolids (fat + protein)
NA HF	North American Holstein Friesian
NPV	Net present value
NZ HF	New Zealand Holstein Friesian
PGR	Pasture growth rate
PSC	Planned start of calving
PSM	Planned start of mating
S1	Scenario one
S2	Scenario two
SCC	Somatic cell count
SD	Standard deviation
SE	Standard error
SED	Standard error of the difference
SPR	Spring-calving farmlet
SR	Stocking rate
TMR	Total mixed ration
VCSN	Virtual climate station network
Y1	Year one
Y2	Year two
Y3	Year three
Y4	Year four
Y5	Year five
Y10	Year 10

Chapter 1 General Introduction

The New Zealand (NZ) dairy industry is a globally-competitive supplier of milk. Most NZ dairy farmers use a pasture-based production system that aims to maximise the production of milksolids (MS; fat + protein) from in-situ harvested, homegrown feed (i.e., pasture). Large quantities of pasture in the diet reduce the cost of MS production, allowing NZ dairy farmers to be cost leaders in the global dairy market.

In NZ, and other temperate regions of the world, pasture grows in a temporal pattern that peaks in spring and early summer, and reaches a nadir in winter. To align herd feed demand with pasture feed supply, the majority of NZ dairy herds calve in late winter and early spring (i.e., spring calving). A spring-calving herd consumes the majority of their diet as in-situ harvested pasture, with some conservation of surplus pasture and importation of supplementary feed when required.

However, in some NZ regions, spring calving does not provide an alignment of herd feed demand with pasture feed supply due to variations in climatic drivers of pasture growth. Unpublished data from experimental research farms indicate that pasture growth in South Taranaki, NZ, is becoming more variable during summer, and winter pasture growth rates (PGR) are increasing relative to summer PGR. Greater summer rainfall variability and warmer winter air temperatures are hypothesised as causing this change in PGR. Changing the season of calving from spring to autumn is one strategy farmers have used to optimise this alignment and attempt to minimise the impact of variable summer rainfall on PGR, and subsequently MS production. Winter milk premiums offered by milk processing companies for MS supplied during the winter months (May–July) are also incentivising farmers to change their herd's milk supply curve.

Farmers contemplating changing the season of calving from spring to autumn can initiate the change in several ways. Each approach will be unique to each farming business and the specific goals they have. Farmers can view the decision to change calving season and the approach they utilise as an investment decision for their business.

Literature has detailed comparisons between spring- and autumn-calving pasture-based dairy systems. However, there is little literature describing the process over which a farm system changes from spring calving to autumn calving. There are different implications that affect the farm system during this period of change that have not been previously reported. Therefore, the primary objective of this thesis is to investigate biophysical and economic implications on the farm system as it changes from a spring-calving system to an autumn-calving system within the context of an investment decision in South Taranaki.

Chapter 2 Literature Review

The background and justification for the primary objective of this thesis is presented in the following chapter. The chapter describes the NZ dairy industry, draws focus to seminal research comparing spring- and autumn-calving systems in pasture-based dairying (Garcia & Holmes, 1999), and highlights why further review is required since the publication by those authors. The principles of pasture-based dairy systems are explained to provide reasoning as to the implementation of spring-calving systems. Alternative calving systems to spring calving are described, with particular focus on autumn-calving systems. Reasoning for recent farmer interest in changing to autumn-calving systems is described and on-farm approaches to achieving this change are detailed. A focus is made on the extended lactation approach to changing calving season. Changing calving season is presented as an investment concept and literature described regarding analysis of agricultural investment decisions. Finally, drawing on the literature review, the primary objectives for the current thesis are formalised and hypotheses presented.

2.1 Pasture-based dairying in New Zealand

The NZ dairy industry plays an important role in the NZ economy. In 2017, the industry contributed 3.5% to gross domestic product (NZIER, 2017), and in the most recently-completed dairy season (2018/2019), dairy export revenue exceeded NZ$18 billion (Ministry for Primary Industries, 2019). The dairy industry employed over 27,000 people on farm and a further 13,000 in milk processing, and paid over $2 billion in wages in 2015 (NZIER, 2017).

The Taranaki region is a significant dairying region in NZ and is home to 14% of NZ dairy farms and 9% of NZ dairy cows (DairyNZ, 2018). Dairying in Taranaki contributes 8% to Taranaki's gross domestic product (NZIER, 2017). The Fonterra Co-operative Group Ltd, the largest milk processing company in NZ (accounting for 84% of raw milk collection; MBIE, 2017), was formed in 2001 through the amalgamation of Kiwi Co-operative Dairies, based in Taranaki, and the NZ Dairy Group, based in the Waikato (Trechter et al., 2003).

New Zealand is a significant international dairy exporting country (Table 2.1), reflected in Fonterra being the fourth largest international dairy company by turnover (Pawson & Perkins, 2017). Considering that only 8.8% of global milk production is exported, NZ dairy farms produce 25% of the world's total exported milk (FAO, 2019). This occurs because NZ produces substantially more milk than the local market consumes, demonstrated by per capita milk production being three times greater than that of closest rival, Ireland (Table 2.1), therefore requiring large scale export of milk and milk products to overseas markets (NZIER, 2017).

Table 2.1 Total milk exports and milk produced per capita by some large milk producing countries. From FAO (2019) and NZIER (2017), respectively. "-" = data not reported.

	Milk exports		Per capita production
Country/Union	000' tonnes	Global rank	(kg/person)
New Zealand	18,748	2nd	4,742
EU 28[1]	20,504	1st	
Australia	3,055	5th	404
United States of America	11,778	3rd	293
United Kingdom	Both included in EU 28		234
Ireland			1,244

[1] EU 28 = 28 member states of the European Union

Dairy production systems vary globally, from extensive, outdoor, pastoral grazing systems characterised by a seasonal calving pattern, relatively low production costs and low non-land capital investment costs, to intensive, completely housed, total-mixed-ration (TMR) systems characterised by year-round calving, high costs of production and high non-land capital investment requirements, or any combination in between (Dillon et al., 2005).

The NZ dairy industry is based on a pastoral grazing production system, with pasture forming the majority of the herd's diet, which is relatively unique compared with dairy production systems in Europe and North America (Figure 2.1). Due to NZ's temperate climate, pasture can grow almost all year round, providing a nutritionally-complete feedstuff for lactating animals (Holmes et al., 2007). In addition, the temperate climate minimises the need to house cows to protect them from extreme weather events. Grain-based supplementary feeds can be more expensive than pasture as a result of the small, local grain industry and cost of importing grain over long distances (mainly from Australia). This causes the base milk produced from pasture to be cheap, relative to the marginal milk produced from supplementary feeds, which can be very expensive (Roche et al., 2018). Disruption to the NZ milk industry, firstly when the United Kingdom (UK) entered the European Economic Community in 1973, and secondly when domestic agricultural subsidies were removed by the NZ Government in 1984, mean that the NZ dairy industry operates in a deregulated environment. For NZ milk exports to be competitive in global markets, where subsidies are commonly provided to domestic producers, the NZ milk price needs to be comparatively low (Figure 2.2). Furthermore, exporting to global markets exposes the NZ milk price to fluctuations in foreign exchange rates and international market volatility (Evans, 2004; Dillon et al., 2005).

Figure 2.1. Country comparison of the relationship between the total cost of production [euro cents (€ c)/L] and the proportion (%) of grass in the diet. From Dillon et al. (2008; pg 24).

As the milk price to supplement price ratio is small, the NZ milk industry relies on cheap, home-grown pasture as the main feed source to underpin the low cost strategy for its competitive advantage in the global market place (Figure 2.1). However within NZ, individual farm systems can vary substantially from complete reliance on in-situ harvested pasture, to importation of >50% of the diet as supplementary feed and partial housing of cows (Hedley et al., 2006; Holmes et al., 2007). New Zealand's temperate climate drives a temporal pattern of pasture growth. Growth peaks in spring and early summer, with a nadir in winter. To optimise the quantity of pasture that can be harvested in situ, NZ farmers block calve their herds in late winter and early spring (Roche et al., 2017b). This 'spring calving' aims to optimally align feed supply (i.e., pasture growth) with feed demand (i.e., herd feed requirements). As a result, spring calving is the default calving system in NZ (Holmes et al., 2007).

Figure 2.2. Milk price [United States (US) dollars per hundredweight] trends for New Zealand (NZ), US and European Union (EU) milk producers, adjusted for historical exchange rates and to US milksolids and fat content. From Newton (2016; pg 60).

Within certain regions of NZ, however, spring calving does not optimally align feed supply with feed demand. Variations in climate and soil type cause variations in the pasture growth curve, causing spring calving to be suboptimal. In particular, summer pasture growth can be extremely variable and increases production risk. Autumn calving is an alternative seasonal calving system adopted by some farmers in these regions (Holmes et al., 2007). By autumn calving, feed demand is shifted to avoid this risky period, and better align with expected supply of pasture. Climate change predictions indicate that these risky summer-dry periods will intensify and impact on larger regions in the future (Ministry for the Environment, 2018). Furthermore, changing global dairy market demand has resulted in milk processors offering a 'winter milk premium' for milk supplied during the winter months (May–July). Therefore, there has been increased interest from NZ dairy farmers to change from spring to autumn calving.

The timing of calving has previously been reviewed, with considerable focus on spring- and autumn-calving systems (Garcia & Holmes, 1999). Those authors concluded that autumn-calving systems required more supplementary feed and could produce greater MS yields than spring-calving systems. However, they did not review the economic aspect of calving season. The recent increased interest from NZ dairy farmers in autumn calving, along with additional research undertaken since the review by Garcia & Holmes (1999), justifies a review of the literature to explore and describe:

1. Spring- and autumn-calving systems,
2. The implications of changing from a spring-calving system to an autumn-calving system.

The aim of this review is to evaluate the current literature pertaining to pasture-based dairy systems, and review the impact of different seasonal calving systems, with particular focus on spring- and autumn-calving systems and the implications of changing between those calving systems. The review will be divided into four key areas:

- The relationship between feed supply and feed demand in pasture-based systems and key factors that influence this, both between and within seasons;
- Spring calving as the default calving season, the risks of traditional spring-calving systems and potential alternatives;
- Autumn-calving systems and impacts on cow, pasture and economic performance; and
- Risks and unique systems implications during the period of change when changing from spring- to autumn-calving systems.

2.2 Principles of pasture-based dairy systems

In profitable pasture-based dairy systems, grazing cows efficiently convert large quantities of in-situ harvested pasture into large quantities of MS, while minimising farm working expenses (Coffey et al., 2018). To be profitable, milk revenue must be greater than farm working expenses. Specifically, because pasture is cheap relative to supplementary feeds (Verkerk, 2003), and because operating expenses are positively associated with supplement feed use (Ramsbottom et al., 2015; Neal & Roche, 2020), feed supply consisting of predominantly pasture is likely to improve profit. In order for directly-grazed pasture to form the major portion of the herd's diet, the supply of pasture must, as close as practical, match the demand for feed across the season. During periods when pasture supply and feed demand do not match, the average pasture cover (APC) acts as a store of feed that can be utilised to offset the mismatch, which ensures that directly-grazed pasture continues to form the major portion of the diet instead of requiring importation of supplementary feed. Matching pasture feed supply with feed demand and using APC as a feed bank when mismatches do occur optimises the production and profitability of the system.

2.2.1 Overview of feed supply

Perennial ryegrass (*Lolium perenne*) and white clover (*Trifolium repens*) are the main plant species in temperate pasture-based dairy systems (Verkerk, 2003; Kemp et al., 2011). Both are chosen due to their productivity, resilience to treading damage, low growing points, and persistence, which is due to the stoloniferous regrowth of white clover and the tillering ability of perennial ryegrass (Kemp et al., 2011). Furthermore, white clover, being leguminous, is capable of fixing 100–350 kg of nitrogen (N)/ha/year into the soil which is available for subsequent growth by both the white clover and perennial ryegrass, and can increase total pasture production (Brock & Hay, 2001).

Total pasture production is constrained by the climate, grazing management, irrigation management, soil fertility, and pests and diseases (Rawnsley et al., 2007). Of these, climate is the most limiting factor to pasture production and the only factor not under the direct control of the farmer. The climatic factors most strongly correlated with pasture growth are sunlight hours and evapotranspiration, and evapotranspiration is underpinned by rainfall, prevailing temperatures and relative humidity (Roche et al., 2009d). Sunlight hours determine the potential maximum seasonal pasture production, however, during the season, actual pasture production is constrained by the soil moisture level (Valentine & Kemp, 2007). As total available soil moisture decreases, due to a combination of drainage, evapotranspiration, and plant uptake, pasture requires greater energy to extract moisture from the soil (Allen et al., 1998). As a result, perennial ryegrass decreases leaf size, the appearance of new leaves and the number of tillers,

resulting in a decrease in total biomass when growing under conditions of soil moisture stress (Tozer et al., 2017). Similarly, soil moisture stress restricts white clover growth in the short term and its persistence in the long term (Lane et al., 2000). Furthermore, growth is suboptimal when temperature is outside 5–18°C for perennial ryegrass and 18–30°C for white clover (Lane et al., 2000; Kemp et al., 2011). Due to the temperate oceanic climate (Cfb Koppen-Geiger climate classification; Kottek et al., 2006) that provides adequate soil moisture and mild temperatures in NZ, pasture grows nearly year round, but growth can be restricted at certain times of the year because of unfavourable climatic conditions.

Pasture growth exhibits a temporal growth curve which peaks in spring and reaches nadir in winter (Roche et al., 2009c). The greatest pasture growth occurs during spring due to a combination of mild temperatures, adequate soil moisture and plant physiology (e.g., peak tillering and seeding), whereas suboptimal growth occurs during winter due to cold temperatures, low sunlight hours and excessive soil moisture, and during summer due to hot temperatures and restricted soil moisture. Furthermore, variations in latitude, topography, altitude, aspect and coastal proximity influence climatic variables, causing regional variation in pasture growth in NZ (McKenzie et al., 2011). Pasture growth curves for five different regions of NZ are displayed in Figure 2.3.

Cold winter temperatures and lower sunlight hours in Southland result in reduced winter growth rates (Hutchinson et al., 2000). Conversely, in more northerly-situated regions, like Northland, with warmer temperatures and greater sunlight hours during winter, PGR are higher. Taranaki experiences greater maximum PGR than the other dryland regions during spring, however both the West Coast and Southland experience higher autumn pasture growth than Taranaki due to a tendency for more consistent rainfall. The influence of irrigation on PGR is demonstrated by the Canterbury pasture growth curve (Figure 2.3). High levels of growth can be maintained throughout summer and autumn because soil moisture is no longer the most limiting factor to growth.

Within regions, large variations in pasture growth can occur both within and between seasons. Due to inherent variability in the critical drivers of pasture growth, actual pasture growth can vary significantly weekly, monthly and annually, compared to the mean PGR for that region (Chapman et al., 2013). In a study undertaken between 1973 and 1981 with no N fertiliser applications (which differs from present day management), Roberts & Thomson (1984) reported a significant variation in monthly PGR in South Taranaki, with the greatest variation occurring during January–March (Figure 2.4). More recently, PGR variation was reported to be the greatest during late spring and summer in the West Coast, Southland and Otago (Dalley & Gardner, 2012; Dalley & Geddes, 2012).

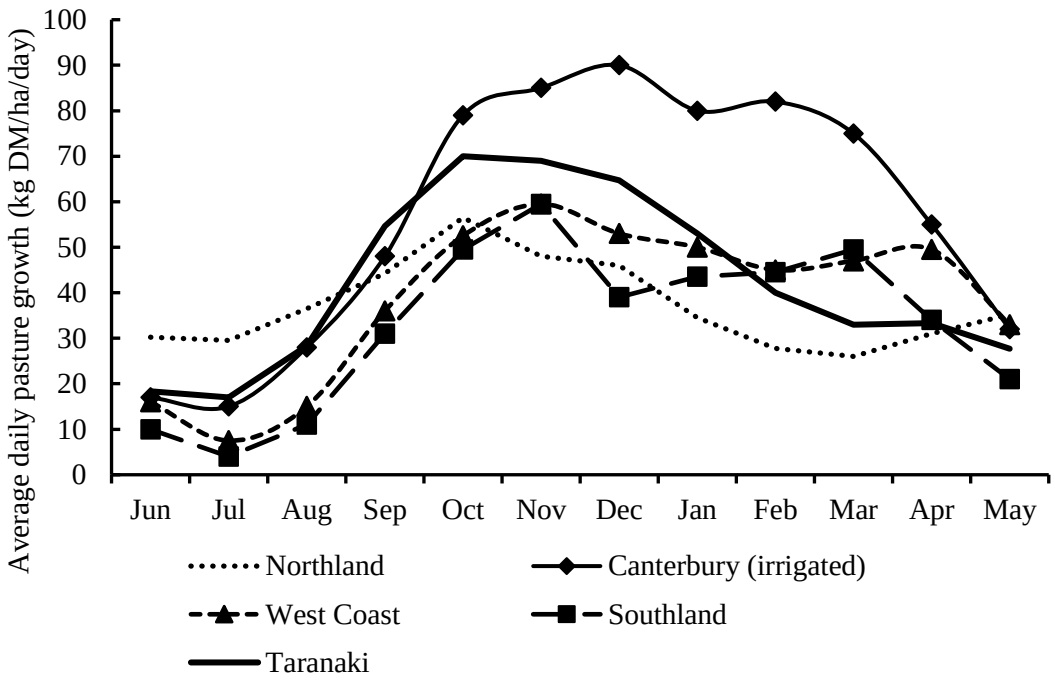

Figure 2.3. Average daily pasture growth [kg dry matter (DM)/ha/day] for five geographically and climatically diverse regions of New Zealand. Adapted from DairyNZ (2010).

Similarly, average (±standard deviation) total pasture growth during December–April was 7.0 ±1.2 t dry matter (DM) over a 41-year period in the Waikato, greater than any other period of the year (Glassey, 2011). Further, Glassey (2011) reported that an additional 849 kg DM/ha of pasture grew for every additional 100 mm of rainfall during December–April, confirming the impact of rainfall on the variability of pasture growth during the summer months.

Pasture quality [megajoules of metabolisable energy (MJ ME)/kg DM] also varies within and between seasons. Within a season, pasture quality peaks during late winter and early spring, then decreases to nadir during late summer and early autumn (Roche et al., 2009c). Seasonal changes in temperature and sunlight cause variation in plant production of carbohydrates, which, combined with plant physiological changes during the season, increase concentrations of less-digestible plant tissues (lignin and cellulose; Roche et al., 2009c).

These variations in pasture growth and quality impact the management decisions that are made in pastoral grazing systems to balance the feed supply and feed demand. Profitable dairy systems manage these variations by implementing operational, tactical and strategic decisions that minimise the impact on current and future production (Chapman et al., 2013).

Figure 2.4. Monthly distribution of mean pasture growth rates [kg dry matter (DM)/ha/day] and standard errors (SE) over eight years at the Waimate West demonstration farm, South Taranaki. No nitrogen fertiliser was applied during this experiment. From Roberts & Thomson (1984; pg 86).

2.2.1.1 Alternative feeds to pasture

Matching feed supply with feed demand in pasture-based systems when both pasture quantity and quality vary, can be overcome by utilising alternative feeds. There can be both acute and prolonged deficits of pasture supply compared to feed demand within a season, which can result in an immediate decrease in MS production, as a consequence of decreased dry matter intake (DMI), plus decreases in lactation persistency in late lactation (Harris et al., 1998), relatively short lactation lengths (Holmes et al., 2007), and long periods of body condition score (BCS) loss (Roche et al., 2006). Alternative feeds to pasture are broadly described as supplementary feeds and include any feedstuff that is not in-situ harvested pasture, and that could be grown or produced either on or off the milking platform. Supplementary feeds are further categorised as either grazed forage, conserved forage or concentrates (including by-products; de Ruiter et al., 2007). Supplementary feeds are fed to increase DMI when there is a pasture deficit, and to manipulate rotation length and control post-grazing residuals (Clark & Woodward, 2007).

Incorporating supplementary feed into the pasture-based system would ideally lead to an increase in profit. To generate additional profit, the marginal cost of supplementary feeding, which includes both the direct and indirect costs, must be less than the marginal increase in milk revenue generated from the marginal increase in MS production. Multiple factors determine the additional MS production, indicated in Figure 2.5, and are discussed in detail in subsequent sections. The direct cost of supplementary feeding refers to the cost of purchasing and

delivering the supplementary feed to the farm. For reference, the direct costs of selected supplementary feeds compared to the cost of pasture are demonstrated in Table 2.2. Indirect costs are costs of feeding and storage of supplementary feed (e.g., machinery, labour, fuel and repairs and maintenance; Ramsbottom et al., 2015). Farm database analysis in NZ, Ireland and the UK concur that indirect costs are approximately 60% of the direct cost of the supplementary feed (Table 2.3), which is consistent with Macdonald et al. (2017). Profitability is a critical pillar of a resilient pasture-based system that is able to cope with fluctuating farm input and output prices (Roche & Horan, 2015; Neal & Roche, 2020). Therefore, supplementary feeding decisions must be profit focussed and consider all costs of supplementary feed.

Figure 2.5. Factors associated with utilising supplementary feed in a pasture-based system. BCS = body condition score. From Kay (2017; pg 3).

Table 2.2. Direct cost [NZD cents/kg dry matter (DM)] of maize silage, pasture silage and palm kernel expeller compared with pasture.

Feedstuff	Direct cost (c/kg DM)	Source
Pasture	15[1]	Verkerk (2003)
Maize silage	32	Fausett et al. (2015)
Pasture silage	35	Macdonald et al. (2017)
Palm kernel expeller	29	Neal & Cooper (2016)

[1] Includes capital cost of land

Table 2.3. Indirect cost of supplementary feeding as a proportion of the direct cost of the supplementary feed from farm database analysis in three countries. n = number of farms in the database.

Country	n	Indirect cost as a proportion of the direct cost	Source
New Zealand	1,119	53-66%	Neal & Roche (2020)
Ireland	1,561	53%	Ramsbottom et al. (2015)
United Kingdom	330	62%	AHDB (2013)

Alongside the supplementary feeding cost, the marginal MS production response (MMPR) is the major determinant of the incremental increase in profitability from supplementary feeding. The MMPR describes the marginal MS (g MS) produced per marginal kg DM of supplementary feed fed (Kellaway & Harrington, 2004), with literature reporting MMPR to be 50–90 g MS/kg DM in pasture-based dairy experiments (Bargo et al., 2003; Roche et al., 2017b). However, wastage, pasture substitution and partitioning to BCS mean that the MMPR on commercial dairy farms is usually <50 g MS/kg DM (Ramsbottom et al., 2015; Roche et al., 2017a). Marginal revenue generated from supplementary feeding is dependent on the MMPR and the milk price (Laborde et al., 1998), so profitable supplementary feeding is less likely with a small MMPR, therefore, supplementary feeding must be incorporated into the system such that the MMPR is relatively large. However, even when the MMPR is large (~120 g MS/kg DM), incorporating supplementary feed into a pasture-based system is only more profitable than a solely pasture-based system 70% of the time (McCahon, 2019). Furthermore, that author also reported that any reduction in MMPR from this above-average level reversed the profitability advantage of supplementary feeding.

2.2.1.2 Wastage of supplementary feed

Wastage of supplementary feed prior to the cow consuming it, decreases the MMPR and increases the cost of the feed. Wastage occurs when there is a loss in the amount of total DM, as well as when there is a decrease in the quality of the supplementary feed, between harvest or purchase and when it is consumed. Poor harvesting and storing techniques of supplementary feed contribute to wastage (Ruppel et al., 1995), however the method of feeding has the greatest impact. In a review of supplementary feed wastage, Stockdale (2010) reported that average wastage of supplementary feed was between 9 to 45% depending on storing technique and feeding method. Greater wastage is associated with in-paddock feeding compared with feed pads or in-shed feeding (DairyNZ, 2010). When less capital infrastructure is utilised, supplementary feed wastage increases because cows are able to defecate, urinate and trample the feed (Stockdale, 2010). Furthermore, the weather can adversely impact wastage; for example there is substantial wastage when supplementary feed is exposed to mud (Stockdale, 2010). Hence, supplementary feeding wastage is greater during the winter months compared

with the summer months. When wastage is high, the MMPR decreases because there is an increased proportion of supplementary feed that has been offered that is not consumed by the herd. It follows that the marginal cost of supplementary feeding increases with greater wastage (Stockdale, 2010).

2.2.1.3 Substitution

Beyond the impact of wastage, substitution of pasture for supplementary feed is the most important factor determining the MMPR and eventual profitability of marginal supplementary feeding (Clark & Woodward, 2007). An unintended yet unavoidable effect of supplementary feeding is that a cow will substitute a portion of her pasture DMI with supplementary feed so that her total DMI is less than the combined total of offered pasture and supplementary feed (Holmes & Mathews, 2001). This substitution effect is displayed in Figure 2.6, and when grazing management is not optimal, can result in wastage of pasture. Substitution rate ranges from 0.3 to 0.9 kg pasture DM/kg supplementary feed DM, with the range determined by two key factors that are under farmer control; the relative feed deficit (RFD) and the quantity of supplements fed (Bargo et al., 2003; Kellaway & Harrington, 2004). Therefore, profitable supplementary feeding requires minimising the substitution rate by effective control of the RFD and the quantity of supplements fed.

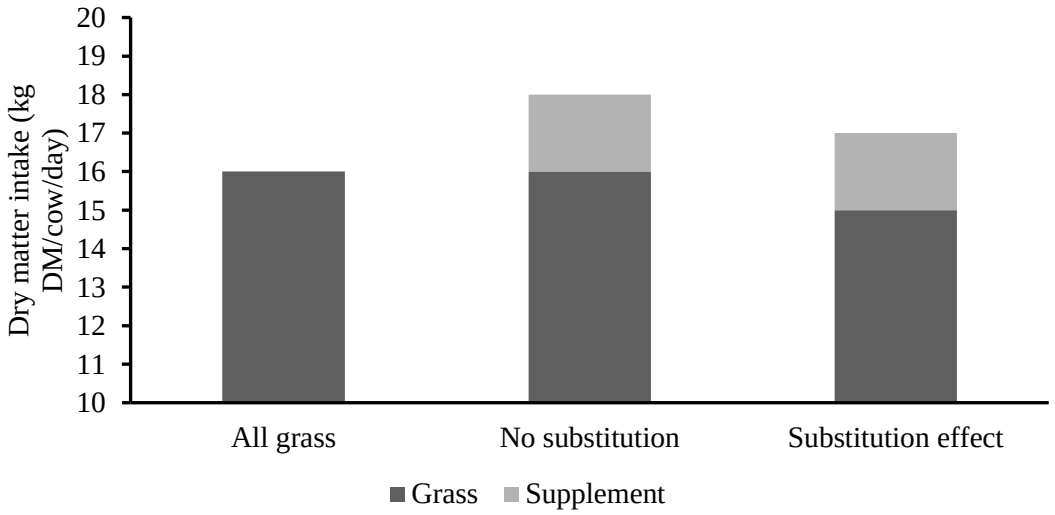

Figure 2.6. The impact of substitution on the total dry matter (DM) intake when supplementary feeding. Adapted from Kay (2017).

2.2.1.3.1 Relative feed deficit

The RFD is the greatest controlling factor of substitution rate and consequently the MMPR. Relative feed deficit refers to the difference between the nutrient supply of the current diet, before the addition of supplementary feeds, to the nutrient requirements of the cow to produce its potential MS production, determined by genetic merit and physiological state (Penno et al.,

2001; Poole, 2018). A greater RFD describes a cow that is 'hungrier', so there is an inverse relationship between RFD and substitution rate, because the cow with greater RFD forgoes less pasture when offered supplementary feed (Stockdale, 2000). It follows that there is a positive relationship between RFD and MMPR, due to the total diet DMI decreasing by less, which results in greater energy partitioned to milk production (Penno, 2002).

2.2.1.3.2 Quantity of supplementary feed

The quantity of supplementary feed offered is the second greatest controlling factor of substitution rate, with a positive relationship existing between the quantity of supplementary feed offered and the substitution rate of pasture. Substitution rate increased from 0.63 to 0.75 when concentrate-based supplementary feed increased by 3 kg DM/cow/day to 6 kg DM/cow/day (Kolver et al., 2005). Similarly, substitution rate increased from 0.31 to 0.48 when grazed forage supplementary feed increased by 4 kg DM/cow/day to 8 kg DM/cow/day (Harris et al., 1998). A reduction in grazing time is the main process by which substitution rate increases as the quantity of supplementary feed offered increases (Bargo et al., 2003; Garcia & Holmes, 2005; Baudracco et al., 2010). A review of the literature reported that daily grazing time reduced by 12 minutes/kg DM of supplementary feed offered (Bargo et al., 2003), with Roche et al. (2007c) suggesting that supplementary feeding decreases blood concentration levels of ghrelin, an appetite-inducing hormone, reducing the cows 'hunger-drive'.

2.2.1.3.3 Partitioning to body tissue

Partitioning of energy from supplementary feeding to body tissue (i.e., fat or muscle), instead of milk production, decreases the MMPR, if the tissue is not catabolised later in lactation. Depending on the quantity of supplementary feed offered and the stage of lactation, a portion of supplementary feed energy is partitioned to body tissue gain instead of milk production, which can result in an increase in BCS (Kellaway & Harrington, 2004). A deferred MMPR occurs when the cow catabolises the marginal increase in body tissue later in the lactation, after the supplementary feeding period has ceased, and partitions that energy to lactation. Cows partition more energy to body tissue reserves as the quantity of supplementary feed offered increases, because the difference between current and potential milk production decreases (Kellaway & Harrington, 2004). Furthermore, pasture-fed cows increase body tissue reserves, resulting in increased BCS, in late lactation as milk production concurrently declines, reflecting a change in dietary energy partitioning (Roche et al., 2009a). Therefore, MMPR decreases in late lactation because less energy is partitioned to milk production. However, increasing body tissue reserves in late lactation, in preparation for the following lactation, is important in pasture-based systems, so although there is no MMPR in the current lactation, stored body tissue can be catabolised in the following lactation and can positively affect reproduction and MS yield (Roche et al., 2009a).

2.2.2 Overview of feed demand

Pasture-based systems are predominantly seasonal-calving systems, which require the cow to have a 365-day calving interval (CI) and calve around the same time of the year (Roche et al., 2018). As a result, the herd calves in a condensed period and then must be rebred relatively quickly, approximately 80 days after calving, as shown in Figure 2.7. Seasonal calving is practiced because it creates a seasonal herd feed demand curve that matches the seasonal pasture growth curve, allowing pasture growth to meet feed demand and pasture to be the main source of feed (Roche et al., 2017b). In contrast, TMR systems can have a stable year-round feed supply, and therefore calving can occur year round to maintain a stable feed demand. In seasonal calving pasture-based systems stocking rate (SR), calving date and spread, drying-off date and culling are levers the farm manager can use to synchronise feed demand and feed supply.

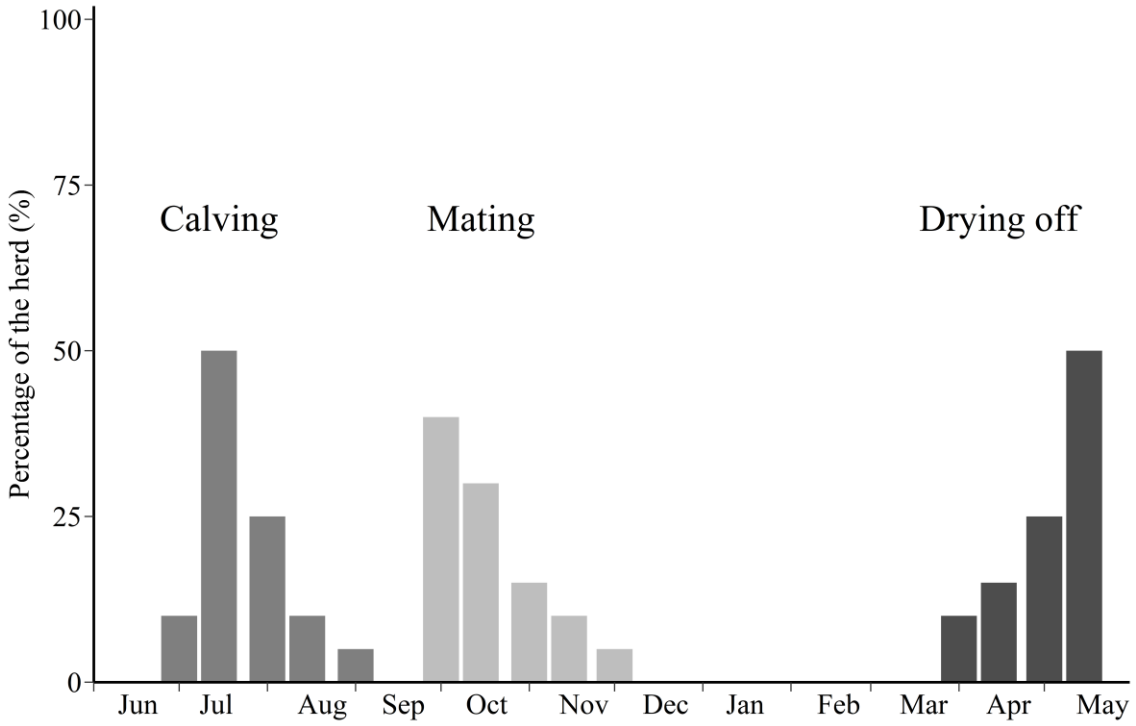

Figure 2.7 Timing of calving, mating and drying off within a season for a southern-hemisphere, 12-month calving interval, pasture-based dairy system. Adapted from Roche et al. (2017b).

2.2.2.1 Stocking rate

At a seasonal level, SR is the most important decision tool to manipulate herd feed demand so that it matches feed supply. Stocking rate is a tactical management decision made in the previous season that determines the allocation of resources for the upcoming season (Shadbolt & Bywater, 2005). Stocking rate simply describes the feed demand of the herd (as the number of animals), divided by the feed supply of the farm [as the number of effective hectares (ha)],

and is reported as the number of cows per ha (cows/ha). Research has consistently identified the importance of employing the correct SR on milk production (McMeekan, 1961; Bryant, 1984; Coffey et al., 2017), pasture production and utilisation (Glassey et al., 2012; McCarthy et al., 2013), and profitability (Penno, 1999; Macdonald et al., 2001; Macdonald et al., 2017). Stocking rate is the most important decision lever because it is the starting point of all other interactions between the biophysical and economic aspects of the pastoral-grazing system.

However, SR is too simplistic to use as a comparison tool within the dairy industry. Stocking rate does not accurately detail the total feed supply in the system because dairy farmers are increasingly importing feed from off the milking platform (Penno & Kolver, 2000), pasture growth per ha differs due to variations in soil type, climate, fertility and grazing management (Coffey et al., 2018), and feed demand per cow differs due to breed, liveweight (LWT), production level and metabolic state (Spaans et al., 2018). Therefore, Penno (1999) proposed an alternative measure, comparative stocking rate (CSR), that more accurately reflects the balance between total feed demand and supply.

With CSR, the LWT of the cows is used to describe feed demand, and is divided by feed supply, expressed as total DM (in tonnes; t DM) offered per effective ha, resulting in CSR as kg LWT/t DM. The advantages of CSR over the more simplistic SR are the inclusion of purchased supplementary feed (imported feed) into the calculation and the ability to accurately compare between farms with different breeds and different LWT (Penno, 1999; Speight, 2002). Research has indicated that optimum profitability occurs at a CSR between 70 to 90 kg LWT/t DM (Macdonald et al., 2008; Macdonald et al., 2011). Because CSR accounts for greater than 80% of variation in milk production and pasture harvested per cow (Macdonald et al., 2017), manipulating the CSR is the most important lever to optimise the farm system.

Unfortunately, limitations also exist for CSR. Accurate LWT are rarely recorded on NZ dairy farms, and total pasture production is often back-calculated from milk production data, therefore on commercial dairy farms, CSR can be an unreliable measure (M. Neal, personal communication, December 19, 2019). However, overall, regardless of the measurement, manipulation of the SR is the most important decision lever in pasture-based systems.

2.2.2.2 Calving date and pattern

Individual cow feed demand dramatically increases over the parturient period as she transitions from a non-lactating to a lactating physiological state. Pregnant non-lactating (i.e., dry) cow DMI is ~2% of LWT, and decreases to ~1.5% in the final week of gestation (Agenäs et al., 2003), however during the first week post-calving, DMI increases 30–50% in response to the several-fold increase in demand for energy, protein and minerals (Roche et al., 2013a). Dry matter intake continues to increase up to 10 weeks post-calving (Kertz et al., 1991), and at peak

lactation, DMI is approximately 3.3–4% of LWT (Kolver & Muller, 1998). Therefore, the date of calving signals the onset of a substantial increase in feed demand for the individual cow. As calving occurs over a condensed period in pasture-based systems, feed demand in the system rapidly increases.

The magnitude of the increase in feed demand at a system level is determined by the calving spread of the herd (Clark et al., 2009), which describes the temporal spread over which cows calve, demonstrated in Figure 2.8. New Zealand best-practice targets are for 67% and 88% of the herd to have calved within three weeks and six weeks, respectively, after the planned start of calving (PSC) date (Blackwell et al., 2017). These targets are set to ensure that cows have a 365-day CI and to maximise the mean lactation length of the herd (Roche et al., 2017a). Therefore, during early lactation, feed demand is driven by calving date and calving spread, with a large increase in feed demand occurring within six weeks after PSC.

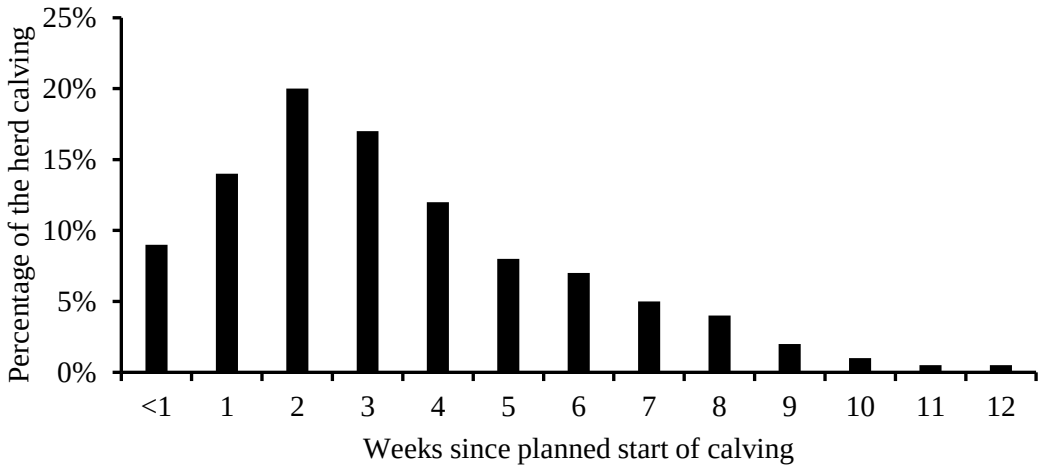

Figure 2.8. Best-practice calving pattern displayed as the percentage of the herd calving in each week after the planned start of calving. Adapted from Macmillan et al. (1990) and Blackwell et al. (2017).

2.2.2.3 Drying-off date

Because feed demand is driven primarily by the energy requirements of the cow for lactation (Dillon, 2006), herd feed demand decreases in mid- and late lactation as milk yield decreases. This decrease in milk yield after peak lactation is described as lactation persistency, and the magnitude of this decrease in lactation persistency is predominantly dependent on the genetics of the cows and partially dependent on their feeding level (Horan et al., 2005). Hence, feed management decisions cannot substantially minimise the decrease in milk yield after peak lactation.

Conversely, drying-off date is under the farmer's direct control and can be optimised for the system. Drying off describes when the cow transitions from a lactational to non-lactational physiological state, and is implemented by discontinuing milking of that cow for the season.

The subsequent decrease in energy requirements of the cow due to the removal of the milking stimulus, results in an acute decrease in feed demand. As drying off is under farmer control, its implementation is a tactical decision that can be made at both a cow and herd level (Holmes et al., 2007).

Deciding on a drying-off date requires balancing the conflicting aims of maximising per cow lactation length, and so per cow milk production, whilst minimising negative impacts on the subsequent lactation. At a cow level, best practice advocates that a cow should be dried off, at minimum, 50 days prior to calving, to replenish and replace mammary tissue before the next lactation (Macdonald & Penno, 1998; Bachman & Schairer, 2003). Hence, to achieve maximum per cow MS production, lactation length should be ~315 days. However, short dry periods reduce the timeframe that the cow has to increase BCS before calving, and low BCS at calving is associated with poor reproductive performance (Roche et al., 2009a). In addition, long lactation lengths reduce the ability to transfer pasture grown in autumn and winter to the calving period, reducing the amount of feed on hand when calving begins. Therefore, the best-practice drying-off date is earlier than it theoretically could be in pasture-based systems, in order to ensure that reproductive performance and feed levels in the following lactation is not compromised. These concepts have been extensively described and broadcast to the industry in a number of publications (Macdonald & Penno, 1998; Macdonald et al., 2010; Roche et al., 2017a). Briefly, those authors advise that drying-off decisions should include drying off non-pregnant, low producing or low BCS cows from mid-lactation onwards, to allow sufficient time to for those animals to gain body condition, and also advise that grazing rotation length should be extended in late lactation to reduce pasture allowance and subsequently reduce herd feed demand. They conclude that lactation performance is optimised when APC of the farm and BCS of cows at the PSC are >2000 kg DM/ha and 5.0–5.5 (1–10 scale; Roche et al., 2009a), respectively.

2.3 Calving systems in pasture-based dairy systems

Pasture-based dairy systems are predominantly seasonally calving and target a 365-day CI for each cow (Roche et al., 2017b). This section describes why spring calving is the predominant system in pasture-based dairying, outlines limitations to spring calving, and discusses alternative calving options.

2.3.1 Spring calving

The pasture growth curve in temperate regions drives the implementation of spring calving. To ensure that peak lactation of the herd, and so peak feed demand, is synchronised with the peak pasture growth period, dairy farm systems calve two months prior to this peak, during late

winter and early spring and displayed in Figure 2.9, and so are called ‘spring-calving’ systems (Roche et al., 2017b).

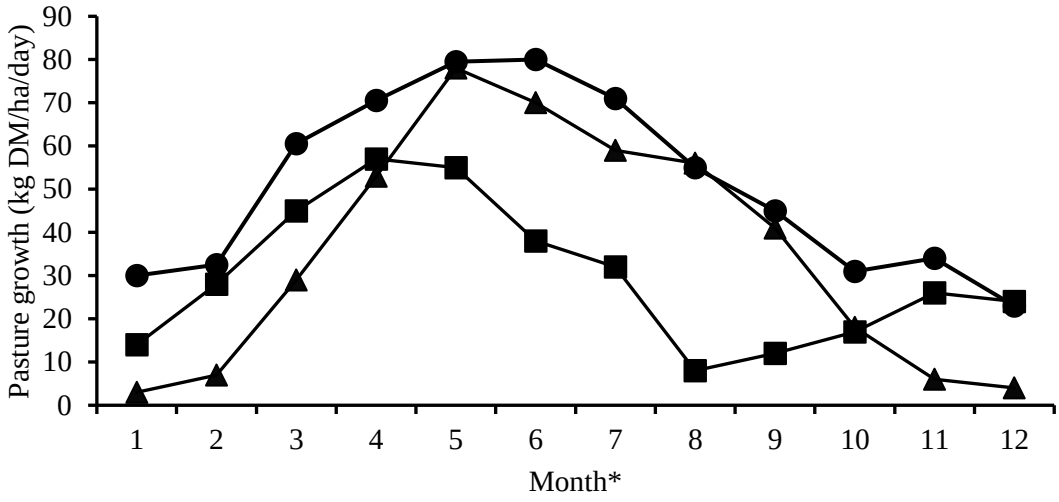

Figure 2.9. New Zealand (●, NZ), Irish (▲, IRE), and Australian (■, AUS) average monthly pasture growth rates [kg dry matter (DM)/ha/day]. NZ is the average between Ruakura, North Island, and Lincoln, South Island; IRE is for Moorepark, Co. Cork; AUS is for Ellinbank, Victoria. *Month 1 is July in the southern hemisphere and January in the northern hemisphere. Adapted from Dillon et al. (2005).

Spring calving is the most common seasonal calving system on dairy farms in NZ and Ireland (Blackwell et al., 2010; Tratalos et al., 2017). Specific data on spring calving in Australia are not reported, however 43% of all Australian dairy farms seasonally calve (includes both spring- and autumn-calving systems), and this increases to 57% in Tasmania where the climate is more temperate (ABARES, 2019).

A consequence of matching feed supply with feed demand is that milk production exhibits a similar curve to pasture growth in spring-calving systems. In NZ, Ireland and Australia, maximum MS production occurs during spring and is lowest during winter (Figure 2.10). The flatter milk production curve exhibited in Australia, relative to NZ and Ireland, occurs because spring calving is not as popular in the Mediterranean or humid subtropical climatic states of Queensland, Western Australia, New South Wales and South Australia, and irrigated regions of northern and south eastern Victoria, therefore milk supply is relatively more consistent year round (ABARES, 2019).

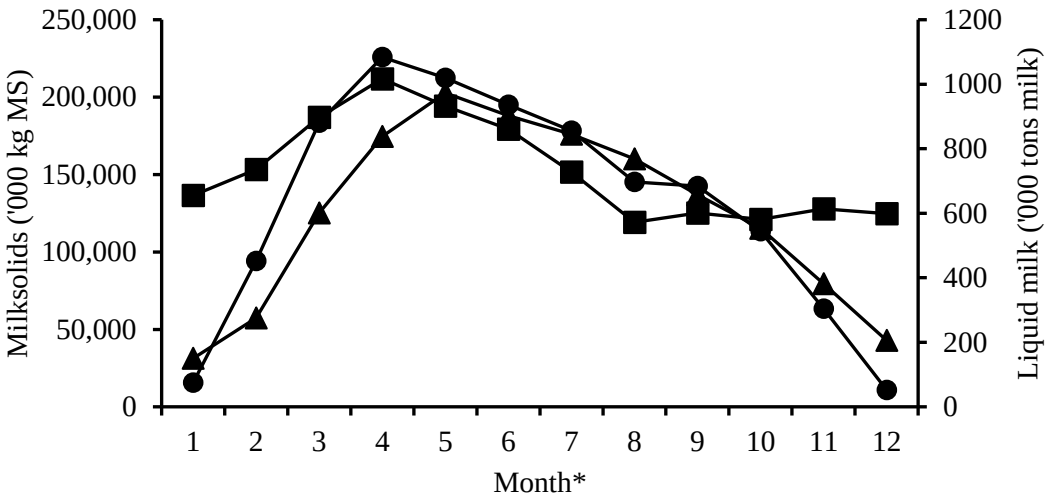

Figure 2.10. New Zealand (●, NZ) average monthly milksolids production (kg MS; left-hand axis), and Irish (▲, IRE) and Australian (■, AUS) average monthly liquid milk production (t milk; right-hand axis). *Month 1 is July in the southern hemisphere and January in the northern hemisphere. Period of data and their source are as follows: NZ, 2003–2019, DCANZ (2019); IRE, 2015–2019, Central Statistics Office (2019); AUS, 2018, Dairy Australia (2019).

A seasonal milk production curve negatively impacts manufacturers' capital utilisation. Processing infrastructure must be able to process milk supplied during the peak of the season, meaning the infrastructure is underutilised for the remainder of the season (Heinschink et al., 2016). Alternative calving systems could increase plant utilisation by achieving a flatter milk supply curve, however increased profit achieved by milk processors may be offset by increased expenses incurred by dairy farms operating alternative calving systems, therefore the dairy industry as a collective may not be better off (Davis & Kirk, 1985; Keane, 2010; Heinschink et al., 2016). Hence spring calving persists in pasture-based systems because it optimises both producer and processor profitability (Heinschink et al., 2016).

2.3.1.1 Climatic limitations on spring-calving systems

Spring calving pasture-based systems are dependent on climatic conditions for productivity and profitability. Climatic factors control pasture growth, quality and mineral concentrations which in turn dictate feed (i.e., energy) supply and ultimately MS production (Holmes et al., 2007; Roche et al., 2009e). During early lactation (spring and early summer), pasture growth is typically not constrained climatically, and so herd milk production is at potential. In contrast, in summer and autumn, pasture growth and quality can both be highly variable (Figure 2.11), which leads to a decrease in feed supply and quality. There are many options during this period for the farmer to either reduce feed demand to match feed supply, including selectively drying off or once-a-day milking (OAD), or increasing feed supply to match feed demand by importing supplementary feed (Gray & Lockhart, 1996; Neal et al., 2017). Furthermore, achieving BCS and APC targets for the following calving forces systems-level decisions to be made during the

summer and autumn, which are dependent on the climate over that period (Macdonald et al., 2010). As a result, milk production can decrease, and the cost of production can increase, hence poor climatic conditions create downside risk in spring-calving systems.

Figure 2.11. Monthly pasture growth rate [kg dry matter (DM)/ha/day] distributions from climatic inputs (NZ; 1976–2006 and AUS; 1907–2006) modelled in DairyMod. From Chapman et al. (2013; pg 799).

2.3.1.2 Lactation length

When unfavourable climatic conditions reduce pasture supply during summer and autumn, drying off part or all of the herd is an accepted management decision in spring-calving systems (Macdonald et al., 2017). To fill the feed deficit created during winter due to seasonal low PGR, autumn-grown pasture is deferred by extending the grazing rotation during the later stages of the lactation, with the overall aim of achieving APC and BCS targets prior to, and at calving. However, if autumn PGR are restricted by hot and dry weather there will be little or no autumn-grown pasture to 'carry forward'. In these situations, feed demand is reduced by drying off cows prior to fulfilling their MS production potential so that APC and BCS targets for the following calving can be met, thus, forgoing days in milk (DIM) and MS production (Holmes et al., 2007).

2.3.1.3 Supplementary feed

Alternatively, supplementary feed can be imported into the system to fill late lactation feed deficits. Supplementing the pasture diet with an additional feedstuff allows total DMI to be maintained, while allowing pasture time to regrow in the autumn, in order to achieve APC targets and for cows to increase BCS. Supplementary feeding options in late lactation have been

well documented, and there are a range of forage and conserved crops, and concentrates utilised in spring-calving systems (Harris et al., 1998; Thomson et al., 1998; Kolver et al., 2001; Dias et al., 2008). However, due to the milk price to supplement price ratio being small, the profitability of supplementary feeding to fill feed deficits in late lactation has been frequently questioned (Dias et al., 2008; Anderson & Ridler, 2010; Neal et al., 2017; Ho et al., 2018).

2.3.2 Alternative seasonal-calving systems

Spring calving, although synonymous with pasture-based systems, is one of four main calving systems implemented in pasture-based dairying. Other calving systems include autumn calving, split calving and 18-month CI. These alternatives to spring calving exist in response to the aforementioned limitations in spring-calving systems, as well as market forces and to reduce costs. The following sections briefly describe the main features of each system, their relative popularity, and reasons why they exist.

2.3.2.1 Autumn calving

Autumn-calving systems are analogous to spring-calving systems, except calving occurs during autumn (March–May). Autumn-calving systems are still seasonally based with a 365-day CI, however, mating occurs during winter (June–July) and drying off during summer (December–February). As with spring calving, the whole herd calves and is subsequently mated during a condensed period.

Older research indicated approximately 3–10% of NZ dairy herds calved in autumn (Blair, 1999; Harris et al., 2006), however more recent NZ data are limited. Edwards (2017) reported that during the 2015/16 season ~3% of NZ dairy herds calved in autumn, and the majority of these autumn-calving herds were located in Northland, Auckland and Hawkes Bay. Accurate autumn-calving statistics are limited from other pasture-based systems in other countries.

The decision to adopt an autumn-calving system is mainly driven by climate and market forces. A detailed review of the drivers causing the change to autumn calving, as well as an overview of spring- versus autumn-calving systems literature is found in section 2.4.

2.3.2.2 Split calving

In split-calving systems, cows calve at two different times of the year, with a portion of the herd calving during spring and a portion calving during autumn. Both groups maintain a 12-month CI, but one group begins their lactation while the other group is in late lactation, resulting in a flatter feed demand curve compared with spring- or autumn-calving systems.

Split calving is implemented in response to climate variability and suitability, market forces and cow physiology. The flatter feed demand curve can more closely align with the flatter feed

supply curve caused by variable summer pasture growth and reliable winter pasture growth (Taylor, 1996), milk produced in winter can earn a winter milk premium (Chikazhe et al., 2017), and cows that do not conceive during their normal mating period can be 'recycled' into the other group in the herd, reducing replacement rates (Patton, 2010).

As split-calving herds produce milk year round, split calving is popular in regions with relatively large markets for year-round liquid milk. Fresh milk demand from large local population centres mean that ~18% of dairy herds in Western Australia, South Australia and Tasmania split calve (ABARES, 2019). Similarly, the majority of the ~2,700 'winter milk' herds in Ireland (17% of the total dairy herds; Teagasc, 2017), contracted to supply the fresh milk market year round, split calve, with 20–50% of the overall herd calving in autumn (Patton & Lawless, 2019). Conversely, the relatively small domestic market in NZ means split calving is not as popular, with ~8% of NZ dairy herds split calving (P. Edwards, personal communication, December 3, 2019).

2.3.2.3 18-month calving interval

Calving every 18 months (18-CI) is a novel alternative to the 365-day CI utilised in spring-, autumn- and split-calving systems. In the 18-CI system, the herd calves during the spring of one year and then calves during the autumn of the third year, so that there are only two calving events and two dry-off events every three years (Borman et al., 2004). The 18-CI system is advocated as a method to negate infertility constraints, characteristic of Holstein Friesian (HF) cows (Harris & Kolver, 2001; Evans et al., 2006) while fulfilling their milk production ability, by reducing the number of lifetime calving periods (Knight, 2005). Reduced involuntary culling, normally caused by infertility, results in a lower replacement rate and consequently reduced cost of rearing replacement heifers (Borman et al., 2004). In addition, 60% of animal health costs are incurred during early lactation, therefore the 18-CI system can also reduce total farm expenses (Knight, 2005).

Limited literature exists describing the relative popularity of 18-CI in pasture-based systems. Borman et al. (2004) detailed the potential of an 18-CI system in Victoria, Australia, and Auldist et al. (2007) compared variations in CI to the 18-CI system in the same region. In NZ, research instead focussed on a 24-month CI, and in particular the suitability of NZ and North American HF (NA HF) strains to extended CI (Kolver et al., 2007; Kay et al., 2009). However, overall, no accurate data exists on the implementation of 18-CI in pasture-based systems.

2.4 Autumn calving as an alternative calving system to spring calving

Autumn calving is the focus of this literature review instead of split calving or 18-CI, because of the current popularity and likely future suitability of autumn calving for certain NZ dairy farmers. The following sections detail the main similarities and differences reported between autumn- and spring-calving systems, describe the recent drivers of changing from spring calving to autumn calving in a NZ context, describe the period over which a farm changes from a spring- to autumn-calving system, and identify the gaps in the literature regarding this topic.

2.4.1 Autumn- vs spring-calving systems

Literature in this section is sourced from systems experiments, with modelling studies and survey studies referenced in support as appropriate. Unfortunately, due to the complexity of systems experiments, there are few studies that have reported robust comparisons between autumn- and spring-calving systems managed similarly in pasture-based regions.

2.4.1.1 Milk production

The lactation length of autumn-calving cows tends to be greater than spring-calving cows in systems experiments (Table 2.4). Autumn-calving cows were milked on average for 50, 26, 28 and 15 days longer than spring-calving cows, reported by Garcia et al. (2000), Spaans et al. (2019), Manjala (2000), and Ryan et al. (1998), respectively. However, the statistical significance of these results are inconsistent and confounded by differences in SR and supplementary feed use between farmlets.

Seasonal influences on management decision rules are postulated as the reason for the trend towards longer lactations by autumn-calving cows. Dry-off date determines lactation length and is a management tool to achieve APC and BCS targets at calving. Compared with spring-calving cows, pasture quality and quantity are both greater during late lactation for autumn-calving cows due to the corresponding time of the year (i.e., summer and early autumn vs. late spring and early summer; Garcia et al., 1998). As a result, autumn-calving cows may be able to partition greater dietary energy to BCS gain during late lactation compared with spring-calving cows. Pasture growth is also lower during summer and early autumn compared with late spring and early summer (Figure 2.3), meaning less can be offered to spring-calving cows so that APC targets at calving can be achieved. Therefore, there are different pressures on BCS and APC

Table 2.4. Per cow and per ha total lactation yield [kg milksolids (MS)], peak daily milk yield [kg MS/cow/day or *litres (L)/cow/day*] and lactation length (days) of autumn-calving (A) and spring-calving (S) systems. "-" = data not reported; SR = stocking rate (cows/ha); NZ = New Zealand; IRE = Ireland; AUS = Australia.

		SR	Total lactation yield		Peak daily milk yield	Lactation length
Source, location & date	Calving system (month of calving)	cows/ha	kg MS/cow	kg MS/ha	kg MS/cow/day or *L/cow/day*	days
Garcia et al. (2000)	S (July)	2.4	309	750	*20*[1]	241
Manawatu, NZ	A (March)	2.0	361	723	*18*[1]	291
1996/97–1998/99						
Spaans et al. (2019)	S (July)	3.0	361	1,083	2.16[2]	261
Waikato, NZ	A (April)	3.0	314	942	1.59[2]	287
1998/99–2000/01						
Manjala (2000)	S (-)	3.0	312	936	1.72	257
Northland, NZ	A (-)	2.4	364	864	1.55	285
1997/98–2000/01						
Patton & Lawless (2019)	S (-)	2.9	489	1,467	-	-
Co. Wexford, IRE	A (-)	2.9	561	1,683	-	-
-						
Ryan et al. (1998)	S (February)	2.5	460	1,150	-	304
Co. Tipperary, IRE	A (August)	2.5	495	1,238	-	316
1995–1998						
Fulkerson et al. (1987)	S (August)	1.6	264	493	*24*	-
Tasmania, AUS	A (April)	1.5	256	425	*17.5*	-
1983/84–1986/87						

[1] Data from companion paper (Garcia & Holmes, 2001).

[2] Data obtained through personal communication (O. Spaans, January 7, 2020).

between autumn- and spring-calving systems due to differences in feed quality and quantity, which can lead to differences in drying-off date and subsequent lactation length.

However, the confounding factors of SR, supplement use and supplement quality may exert greater influence on lactation length than season of calving alone (Spaans et al., 2019). Stocking rate was 0.4 and 0.6 cows/ha less in the autumn-calving farmlet herd compared with the spring-calving farmlet herd in experiments by Garcia et al. (2000) and Manjala (2000). Autumn-calving cows were also offered greater quantities of supplementary feed. This lower SR, combined with greater supplementary feed, would have resulted in the autumn-calving cows being allocated a greater total DMI per cow compared with the spring-calving cows. Although not measured in these studies, this is turn would have resulted in those cows partitioning greater energy to BCS, and APC would increase due to less grazing pressure. Hence, these factors may confound the impact of calving season on lactation length.

The peak milk yield of spring-calving cows is higher than that of autumn-calving cows (Table 2.4). For example, the peak milk yield of spring-calving cows was 40% (7 L/day), 11% (0.17 kg MS/day), 13% (2.3 L/day), and 36% (0.57 kg MS/day) greater than that of autumn-calving cows (Fulkerson et al., 1987; Manjala, 2000; Garcia & Holmes, 2001; O. Spaans, personal communication, January 7, 2020; respectively). Peak milk yield occurs four to eight weeks after calving (Silvestre et al., 2009), therefore its occurrence differs in calendar date between spring- and autumn-calving cows.

Relative differences in diet during the peak lactation period can cause differences in peak milk yield between autumn- and spring-calving cows. Supplementary feeds are required in the diet of autumn-calving cows during early lactation because it corresponds to a period of low pasture growth (i.e., winter) when feed demand exceeds pasture supply. During early lactation, the diets of autumn-calving cows included 6 kg DM of maize silage, 1 kg DM of pasture silage or 8 kg DM of pasture silage, and cows consumed less fresh pasture, compared with the diets of spring-calving cows, in the experiments reported by Garcia & Holmes (2005), Spaans et al. (2019), and Fulkerson et al. (1987), respectively. The quality of these supplementary feeds is lower than pasture, so milk production would be lower than if pasture was the sole diet (Penno et al., 1996).

Differences in day length (i.e., photoperiod) between autumn-calving systems and spring-calving systems may also be a driver of the difference in peak lactation yield. Peak lactation in autumn-calving systems occurs during the relatively short-day lengths during early winter; conversely, peak lactation for spring-calving systems occurs as day length is increasing. The effect of photoperiod on milk production was extensively reviewed by Dahl et al. (2000), however they focussed on TMR systems where day length can be artificially manipulated in housed barns, so it may not be applicable to pasture-based systems. Nonetheless, Dahl et al.

(2000) recommended that short-day lengths during the dry period followed by long-day lengths during the lactation period, will increase milk production in dairy cows. The photoperiod effect was reported in NZ conditions by Auldist et al. (2006), who reported a 23% decrease in milk production, compared to the control herd, 12 weeks after first subcutaneously implanting melatonin to induce the effects of a short-day length in the treatment herd. However, in that experiment, the melatonin implantation caused a physiological response more akin to complete darkness, compared to actual diurnal variation in melatonin concentration, so the results may not accurately reflect a photoperiod effect. Alternatively, a positive association between sunlight hours and milk yield during six years of experiments was reported by Roche et al. (2009e). Therefore, photoperiodic differences may explain some of the difference in peak lactation yield between autumn- and spring-calving systems, but further research needs to be undertaken to confirm this.

Although autumn-calving cows had lower peak milk yields, their greater lactation lengths resulted in mostly greater milk production per cow, compared with spring-calving cows (Table 2.4). Milk production was 35, 52, 52 and 72 kg MS/cow greater in autumn-calving cows compared with spring-calving cows, reported by Ryan et al. (1998), Garcia et al. (2000), Manjala (2000), and Patton & Lawless (2019), respectively. However Spaans et al. (2019) and Fulkerson et al. (1987) reported that autumn-calving cows produced 47 and 8 kg MS/cow less milk compared with spring-calving cows, respectively. However, when taking into account differences in SR, the MS per ha in autumn-calving herds was lower than in spring-calving herds in all experiments, except for Patton & Lawless (2019) and Ryan et al. (1998). In support of these results, autumn-calving systems (calving during March) were modelled in four different locations in the Waikato and Northland, and also displayed greater MS production per cow than spring-calving systems, but this did not translate into greater MS production per ha because SR was reduced (Chikazhe et al., 2017). Therefore, in these experiments, when SR was reduced, autumn-calving herds tended to produce greater MS per cow, indicating an increase in quantity of feed offered, but this did not compensate for the reduction in SR, so MS per ha was reduced.

2.4.1.1.1 Lactation curves

The lactation curve of an autumn-calving cow has been described as being flatter, with a lower peak and greater persistence, than that of a spring-calving cow [Figure 2.12; Garcia & Holmes (2001)]. In turn, the MS production profile differs between the two calving systems. Autumn-calving cows produced significantly ($P < 0.01$) greater MS between peak lactation and drying off (mid- to late lactation) than spring-calving cows, due to autumn-calving cows displaying greater lactation persistency (Garcia & Holmes, 2001). Interestingly, in some literature, greater lactation persistency manifests as a second, smaller peak in the lactation curve in mid- to late lactation (Ryan et al., 1998; Garcia et al., 2000; Auldist et al., 2002). As the second peak

coincides with spring for autumn-calving cows, an increase in feed quality and quantity has been hypothesised by the authors of the aforementioned studies as the cause of this second peak.

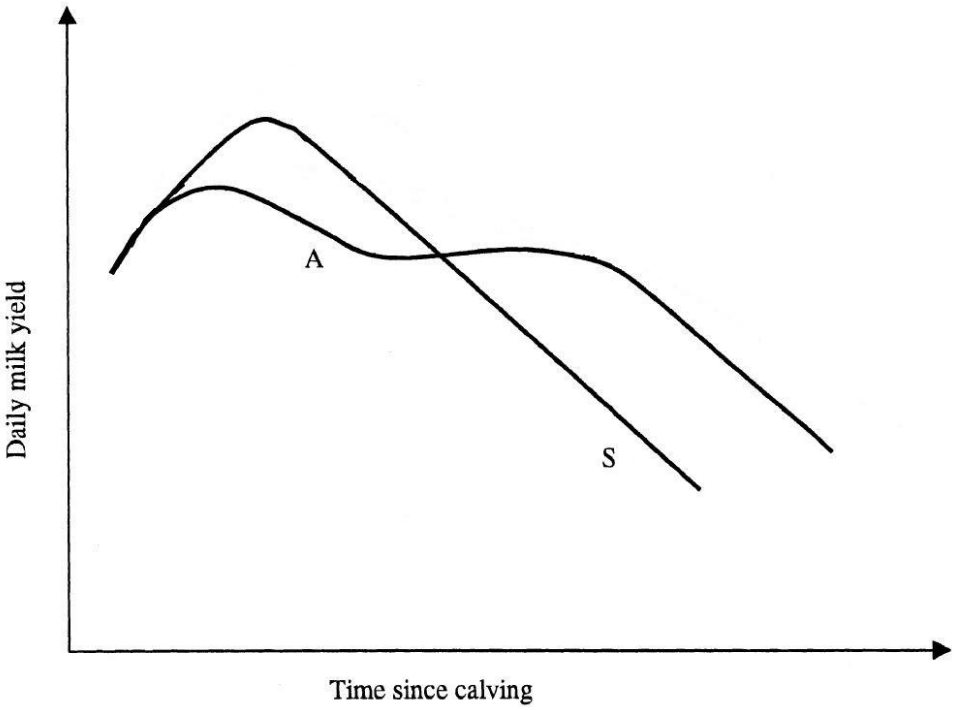

Figure 2.12. Hypothetical diagrammatic representation of the lactation curves of autumn-calving (A) and spring-calving (S) herds. From Garcia & Holmes (2001, pg 201).

2.4.1.2 Feed supply

Annual pasture growth is reported to be similar between autumn- and spring-calving systems (Fulkerson et al., 1987; Garcia & Holmes, 2005; Spaans et al., 2019). Interestingly, average PGR during summer was reported to be greater ($P < 0.1$) in the autumn-calving system due to greater farm area being conserved for silage (discussed further in section 2.4.1.4), but this did not materially affect annual pasture growth (Garcia & Holmes, 2005). However, the timing of feed supplied to spring- and autumn-calving herds differs, due to their relative alignment of feed demand with feed supply.

Dry matter intake normally matches feed supply in spring-calving systems, whereas for autumn-calving systems, early lactation (i.e., increasing DMI), occurs at time of decreasing pasture growth during winter, and late lactation (i.e., decreasing DMI), occurs at a time of increasing pasture growth during spring and summer (Garcia & Holmes, 2005). As a result, pasture grown during early and mid-lactation can be lower in autumn-calving systems compared to the same stages of lactation for spring-calving systems (Spaans et al., 2019). To overcome the deficit in pasture supply during these periods, autumn-calving systems may require additional supplementary feed if SR is not reduced. Conversely, it follows that pasture grown during late lactation in autumn-calving systems can be greater compared to the same stage of lactation for

spring-calving systems. This can require greater conservation of surplus pasture in autumn-calving systems if SR is not increased.

2.4.1.3 Supplementary feed supply and timing

In many cases, autumn-calving systems may require supplementary feed during early lactation to fill feed deficits as a result of declining PGR. In contrast, spring-calving systems may require supplementary feed in late lactation to fill feed deficits [Figure 2.13; Spaans et al. (2019)]. Furthermore, relative differences in time and stage of lactation can require different quantities of supplementary feed between the two calving systems.

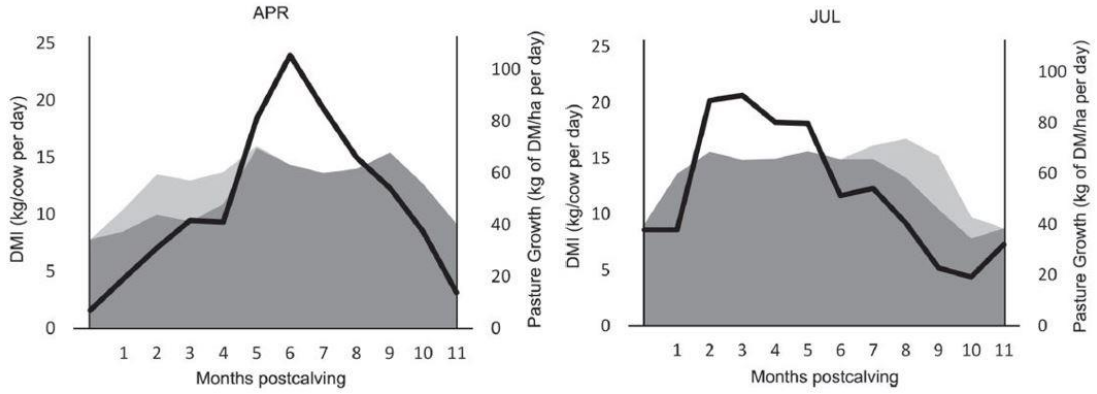

Figure 2.13. Dry matter intake [DMI; kg dry matter (DM)/cow/day] of pasture (dark grey area) and supplementary feed (light grey area) of autumn-calving (APR; month of calving was April) and spring-calving (JUL; month of calving was July) cows relative to pasture growth (black line; kg DM/ha/day) for each month post calving. From Spaans et al. (2019; pg 11530).

In a range of studies comparing autumn- and spring-calving systems, autumn-calving cows were fed 69% (478 kg DM/cow), 7% (23 kg DM/cow), 213% (810 kg DM/cow), 157% (844 kg DM/cow), 102% (624 kg DM/cow) and 42% (500 kg DM/cow) greater supplementary feed than spring-calving cows, reported by Garcia et al. (2000), Spaans et al. (2019) Manjala (2000), Patton & Lawless (2019), Ryan et al. (1998) and Fulkerson et al. (1987), respectively (Table 2.5). Although the literature suggests that autumn-calving systems offer greater quantities of supplementary feed compared with spring-calving systems, differences in the total DMI (e.g., pasture DMI + supplementary feed DMI), the ratio of pasture DMI to supplement DMI, and the quality of the supplementary feed, make any comparisons between experiments difficult. For example, supplementary feed was only sourced from home-grown conserved pasture in the experiments of Fulkerson et al. (1987) and Spaans et al. (2019), whereas maize silage was imported in the experiment of Garcia et al. (2000) and Patton & Lawless (2019), and meal was imported in the experiment by Ryan et al. (1998). In addition, wastage and substitution rates of supplementary feed can vary at different times of the season, dependent on when it is offered (see section 2.2.1.2). Therefore, it is not clear whether the tendency for autumn-calving systems

Table 2.5. Supplementary feed offered [kg dry matter (DM)/cow/year], area of the farm conserved for silage and/or hay, and total amount of pasture conserved [tons (t) DM/ha] in autumn-calving (A) and spring-calving (S) systems. "-" = data not reported; SR = stocking rate (cows/ha); NZ = New Zealand; IRE = Ireland; AUS = Australia.

	Calving system	SR	Supplements fed per year	Pasture conservation per year	
Source, location & date	(month of calving)	cows/ha	kg DM/cow	% of the farm	t DM/ha
Garcia et al. (2000)	S (July)	2.4	692	37%	0.99
Manawatu, NZ	A (March)	2.0	1,170	79%	2.43
1996/97–1998/99					
Spaans et al. (2019)	S (July)	3.0	348	-	1.25
Waikato, NZ	A (April)	3.0	371	-	1.16
1998/99–2000/01					
Manjala (2000)	S (-)	3.0	380	-	-
Northland, NZ	A (-)	2.4	1,190	-	-
1997/98–2000/01					
Patton & Lawless (2019)	S (-)	2.9	536	-	-
Co. Wexford, IRE	A (-)	2.9	1,380	-	-
-					
Ryan et al. (1998)	S (February)	2.5	613	-	-
Co. Tipperary, IRE	A (August)	2.5	1,237	-	-
1995–1998					
Fulkerson et al. (1987)	S (August)	1.6	1,180	51%	2.6
Tasmania, AUS	A (April)	1.5	1,680	62%	3.0
1983/84–1986/87					

to offer greater supplementary feed than spring-calving systems is due to the change in calving season or other systems-level changes.

2.4.1.4 Conservation of surplus pasture

There is a tendency for autumn-calving systems to conserve greater quantities of pasture than spring-calving systems (Table 2.5). During late lactation in autumn-calving systems (i.e., November–January), pasture growth increases, which can require greater conservation of surplus pasture as feed demand decreases, opposite to what occurs during late lactation in spring-calving systems (i.e., March–May). In their review of literature, Garcia & Holmes (1999) concluded that total pasture conservation is greater in autumn-calving systems, however more recently, Spaans et al. (2019) reported no significant difference in pasture conservation between systems. The conflicting results may be due to confounding SR and grazing decision rules employed in these experiments. Regardless, conserving pasture increases the cost of production, because the utilisation of pasture can decrease when fed as supplementary feed, the quality of pasture decreases when stored (Macdonald et al., 2000), and there are farm operating expenses required to harvest and then feed it back out (Ramsbottom et al., 2015; Neal & Roche, 2020).

2.4.1.5 Reproductive performance

The relative reproductive performance between autumn and spring-calving systems is presented in Table 2.6. Limited literature exists comparing reproductive performance, and often farm systems experiments have too few cows for statistically significant results to be reported, so two survey studies of commercial farms have also been presented (Fulkerson & Dickens, 1985; Chang'endo, 1996). Submission rates varied between autumn- and spring-calving systems. However, only two studies (Chang'endo, 1996; Ryan et al., 1998) reported significant differences ($P < 0.001$ and $P < 0.05$, respectively), and both authors reported greater submission rates for spring-calving cows. Similarly, conception rate also varied between systems and neither Pacheco-Navarro (2000) or Fulkerson et al. (1987) reported statistically-significant results. Non-return rate to first service was greater for spring-calving cows when reported, however only Chang'endo (1996) reported a significant difference ($P < 0.05$). Autumn-calving cows had significantly greater ($P < 0.05$) empty rates than spring-calving cows as reported by Ryan et al. (1998) and Chang'endo (1996). In contrast, no difference was reported by Pacheco-Navarro (2000).

Overall, no consistent evidence supports that reproductive performance differs significantly between autumn- and spring-calving systems. Although differences in day length, ambient temperature, climate and feeding regime have been proposed as drivers of differences in reproductive performance (Fulkerson & Dickens, 1985), results from the literature are conflicting and not always supported by statistical analysis. Variations in mating management

Table 2.6. Reproductive performance of autumn-calving (A) and spring-calving (S) herds. "-" = data not reported; NZ = New Zealand; IRE = Ireland; AUS = Australia.

Source, location & date	Calving system (month of calving)	Submission rate[2]		Conception rate[3]		Non-return rate[4]		Not-in-calf rate[5]	
Pacheco-Navarro (2000)	S (July)	84%[6]	NS	47%	NS	-		16%	NS
Manawatu, NZ	A (March)	87%[6]		54%		-		14%	
1996/97–1998/99									
Fulkerson et al. (1987)	S (August)	87%[7]	NR	64%	NR	68%	NR	-	
Tasmania, AUS	A (April)	90%[7]		53%		62%		-	
1983/84–1986/87									
Fulkerson & Dickens (1985)[1]	S (-)	87%[7]	***	-		72%	***	-	
Tasmania, AUS	A (-)	75%[7]		-		55%		-	
1983/84									
Ryan et al. (1998)	S (February)	87%[6]	***	-		-		10%	*
Co,Tipperary, IRE	A (August)	59%[6]		-		-		23%	
1995–1998									
Chang'endo (1996)[1]	S (-)	81%[8]	*	-		64%[9]	*	10%	*
Manawatu, NZ	A (-)	71%[8]		-		55%[9]		12%	
1993/94–1994/95									

NR = significance not reported; NS = not significant; * = P < 0.05; ** P < 0.01; *** = P < 0.001

[1] Survey of commercial farms

[2] Percentage of the herd submitted to mating

[3] Percentage of the herd confirmed pregnant to their first service

[4] Percentage of the herd that were not submitted to a subsequent mating after their first service

[5] Percentage of the herd not pregnant at the end of the mating period

[6] 21-day submission rate

[7] 24-day submission rate

[8] 28-day submission rate

[9] Cows that did not return for mating that were mated in the first 42 days of mating

between experiments, for example, the use of inductions and progesterone treatment of anoestrus, mean that reproductive results are confounded by management practices. In addition, reproductive performance can also be confounded by grazing management decision rules, particularly in late lactation, that determine DMI and the management of BCS prior to calving. The importance of BCS at calving to reproductive performance is well known (Roche et al., 2009a), therefore feeding levels and management decisions may have a greater effect than calving season.

2.4.1.6 Financial performance

Gross revenue, operating expenses and profit differ between autumn-calving and spring-calving systems. Differences in the amount and timing of milk production, amount of supplementary feed, SR, pasture conservation, and other associated factors cause differences in revenue and expenses, creating differences in profit. As land area is the most costly input in pasture-based dairy systems, profit per ha (i.e., gross revenue/ha − operating expenses/ha) is considered an important criterion when comparing systems (Ramsbottom et al., 2015). However, due to variations in SR, the winter milk premium, and grazing management decision rules, direct comparisons between experiments in this review are difficult, therefore the following sections discuss trends instead of direct differences.

2.4.1.6.1 Gross revenue

Gross revenue per ha tends to be greater in autumn-calving systems compared to spring-calving systems (Table 2.7). Autumn-calving gross revenue was $986/ha and $331/ha greater than the spring-calving system (Garcia et al., 1998; Manjala, 2000; respectively). However, Spaans et al. (2019) reported gross revenue to be $267/ha less for the autumn-calving system. These differences occur because gross revenue is predominantly a function of the milk price and the quantity of milk sold, with some difference in revenue from differences in stock sales. In the two former studies, the autumn-calving system produced greater quantities of milk, while in the latter study, the autumn-calving system produced less milk than the spring-calving system, hence the difference in gross revenue.

Autumn-calving systems can earn a winter milk premium on milk sold during the winter months, which increases the milk price and subsequently the gross revenue. Compared to the spring-calving system, the average annual milk price was 11% ($0.63/kg MS) greater for the autumn-calving system in the experiment reported by Spaans et al. (2019), based on the

Fonterra winter milk price structure (Fonterra, 2018). However, the greater milk price did not compensate for the lower milk production, meaning that the autumn-calving system earnt less gross revenue per ha than the spring-calving system (Spaans et al., 2019). Average annual milk price was modelled as 12% ($0.72/kg MS) greater for the autumn-calving system compared

Table 2.7. Gross revenue, operating expenses and profit per ha (NZ$/ha) of autumn-calving (A) and spring-calving (S) systems, and the relevant winter milk premium received by the A system. "-" = data not reported; NZ = New Zealand.

Source, location & date	Calving system (month of calving)	Gross revenue (NZ$/ha)	Operating expenses (NZ$/ha)	Profit (NZ$/ha)	Winter milk premium
Garcia et al. (1998)[1]	S (July)	2,657	1,894	763	$0.32/L May–July (inclusive)
Manawatu, NZ	A (March)	3,643	2,184	1,459	
1996/1997–1998/99					
Spaans et al. (2019)	S (July)	7,090	3,953	3,137	Fonterra scheme[2]
Waikato, NZ	A (April)	6,823	3,973	2,850	
1998/99–2000/01					
Manjala (2000)	S (-)	3,460	1,744	1,097	-
Northland, NZ	A (-)	3,791	1,808	1,324	
1997/98–2000/01					
Chikazhe et al. (2017)[3]	S (July)	-	4,223	1,559	Fonterra scheme[2]
Waikato and Northland, NZ	A (March)	-	4,446	1,840	
2014/15[4]					

[1] Results are summary of the first season of the experiment described by Garcia et al. (2000), as economic performance was not reported in the latter publication.

[2] Fonterra scheme = North Island winter milk premium pricing structure of $2.85/kg MS for 16–31 May, $3.50 for 1–30 June, and $2.85 for 1–15 July (Fonterra, 2018).

[3] Modelling study; averages of the four locations presented (Ruakura, Pukekohe, Te Hana, Maungaturoto).

[4] Modelling used Waikato (Ruakura, Pukekohe) and Northland (Te Hana and Maungaturoto) 2014/15 Dairy Statistics (DairyNZ, 2015) and Economic Survey (DairyNZ, 2016a) data.

with the spring-calving system by Chikazhe et al. (2017), but unfortunately gross revenue was not reported. Average annual milk price could not be calculated for the remaining two experiments.

2.4.1.6.2 Operating expenses

Operating expenses per ha also tend to be greater for autumn-calving systems than spring-calving systems (Table 2.7). Autumn-calving operating expenses were $290, $64, $223 and $20/ha greater than spring-calving operating expenses (Garcia et al., 1998; Manjala, 2000; Chikazhe et al., 2017; Spaans et al., 2019; respectively). The same trend was observed in modelling studies reported by Myers et al. (2012) and Figueredo (2003). The costs associated with feeding greater amounts of supplementary feed is one major driver of the greater operating expenses per ha. Increased effluent storage facilities, and repairs and maintenance for autumn-calving farms have also been identified as differences in expenses between the two systems (Chikazhe et al., 2017; Spaans et al., 2019). The cost of production increases as operating expenses increase, therefore autumn-calving systems may be more vulnerable to fluctuating milk price (Ramsbottom et al., 2015).

2.4.1.6.3 Profitability

Although operating expenses have been reported as greater in autumn- rather than spring-calving systems, greater gross revenue in autumn-calving systems mean these systems can be more profitable (Table 2.7). Profit was $696/ha, $227 and $281 greater, as reported by Garcia et al. (1998), Manjala (2000) and Chikazhe et al. (2017), respectively. In contrast, Spaans et al. (2019) reported a $287/ha decrease in profit. As the SR, milk price, input prices and other factors confound the results from these experiments, no conclusive statements can be made that autumn-calving is more profitable, and therefore a means to maximise profit from a fixed area of land. Empirical evidence indicates that the profitability of autumn-calving systems is equal to or less than comparative spring-calving systems on commercial NZ dairy farms (in the 2014/15 season in the Waikato region; Chikazhe et al., 2017)

Additionally, relative profitability risks of autumn- and spring-calving systems can be compared using average prices for inputs and outputs. Unfortunately, there is minimal literature reporting this approach. When modelling profitability risk through Monte Carlo simulations, cumulative density functions indicated that autumn calving was more risky than spring calving, regardless of inclusivity of a winter milk premium (Spaans et al., 2019). Comparisons utilising similar methodology could not be found in the literature. However, when modelling profitability risk and nominal rates of return over a 10-year investment period for a Victorian dairy farm, Myers et al. (2012) reported that an autumn-calving system generated greater annual operating profit over the 10-year period (AUS$488,000 vs. $363,000), with a 1.8% greater (8.9% vs. 7.1%)

nominal rate of return than a spring-calving system. Both systems were reported to have very similar standard deviations. It must be noted that in the latter study, 10% of the herd in the autumn-calving system calved during spring, and the autumn-calving system earnt a year-round premium (AUS$0.55/kg MS) for milk production, instead of a premium for just milk produced during the winter months. Hence, the limited literature indicates that over a single season, returns can be more variable for an autumn-calving system, but over a longer investment horizon, the variation in returns decreases. Future modelling of the risk is required to generate more robust conclusions.

2.4.2 Environmental impact

Any change to the farming system by way of changing season of calving must consider the environmental impact of that change. In NZ, and globally, dairy farms are consistently recognised as major contributors to environmental degradation (Parliamentary Commissioner for the Environment, 2004; Steinfeld et al., 2006; Moller et al., 2008). In particular, they impact groundwater quality through N leaching, phosphorus (P) and sediment loss, and contributing to climate change due to their greenhouse gas (GHG) emissions, namely methane and nitrous oxide (McLaren & Cameron, 1996; Sonesson et al., 2010). With NZ's recent introduction of the Climate Change Response (Zero Carbon) Amendment Act 2019, along with the Essential Freshwater programme, it is important to understand any differences in the environmental impact posed by autumn-calving systems compared with spring-calving systems.

Although N leaching predominantly occurs during winter and early spring in dairy systems (i.e., May–October; Christensen et al., 2019), the majority of the N that is leached results from earlier N deposition during late summer and autumn (i.e., March–June; Shepherd et al., 2010). The amount of N in the soil increases during this period (late summer–autumn) because cows are excreting urine containing a high N concentration, while relatively lower PGR rates mean that pasture uptake of N from the soil is low (Roche et al., 2016). Consequently, as evapotranspiration decreases and rainfall increases during winter, soil drainage increases, leaching the N that has accumulated during the late summer–autumn period. Therefore, reducing the build-up of soil N during the sensitive period between late summer and autumn minimises the N leaching risk from the system.

In spring-calving systems, reducing the lactation length, and so the number of cows lactating during the sensitive period, and utilising restricted grazing intervals and infrastructure to capture urine, have been reported to decrease N leaching (Roche et al., 2016; Romera et al., 2017; Selbie et al., 2017; Christensen et al., 2019). When lactation length is reduced, DMI decreases as more of the herd are non-lactating during the sensitive period, so overall the herd excretes less urinary N (Roche et al., 2016). Considering that cows start calving at the beginning of the

sensitive period in an autumn-calving system, the relatively greater DMI of these cows in their early lactation, compared with spring-calving cows in their late lactation, may result in them depositing greater N onto the soil. Therefore, an autumn-calving system may leach greater amounts of N than a spring-calving system with a similar SR. Modelling of winter-milking systems in Waikato and Northland reported that N leaching was greater (~ 6%) in Northland but lower (~ −3%) in Waikato, indicating that there is also a climate and soil factor irrespective of calving season that requires further research (Chikazhe et al., 2017).

There is potential for differences in pugging damage between spring- and autumn-calving systems, however there is currently no literature that has quantified this. The greatest period of risk for pugging is in winter and spring when the soil is wet (Drewry, 2006). This is exacerbated in spring-calving systems that feed their non-lactating cows on the milking platform during the winter months at high stocking densities in small grazing areas (Drewry, 2006). In contrast, stocking densities in autumn-calving systems during the winter months are relatively lower as these cows are lactating and are allocated a relatively greater daily DMI, hence, it is hypothesized that the risk of pugging damage would be lower. However, there is no current literature to support this hypothesis.

Removing cows from wet soil and housing them temporarily, or permanently, in infrastructure (e.g., stand-off pad, barn, feed pad) can minimise pugging and soil loss while also capturing effluent. Current literature reports on the impact of using this infrastructure on commercial farm winter management practices (Luo et al., 2006), soil physical properties and pasture growth (Drewry, 2003; Laurenson et al., 2016), and farm system profitability (Beukes et al., 2013), yet all of these are within the context of a spring-calving system. There is currently no literature reporting on the use of infrastructure to minimise pugging damage and soil loss in autumn-calving pasture-based dairy systems.

Greenhouse gas emissions may be greater in autumn-calving systems compared with spring-calving systems because of unique factors within each system. Although there are many confounding feed, animal and seasonal variables acting on methane production from dairy systems (Waghorn & Woodward, 2005), put simply, there is a positive relationship between DMI and methane production in dairy cattle (Moe & Tyrrell, 1979; Ellis et al., 2007). As described in section 2.4.1.3, autumn-calving systems tend to require greater supplementary feed than spring-calving systems because of the greater feed deficit at certain times of the year, therefore, it follows that, *ceteris paribus*, autumn-calving systems may produce more methane compared with spring-calving systems. However, Garcia et al. (2000) and Spaans et al. (2019) both reported no difference in total DMI between spring- and autumn-calving systems, suggesting that any increase in supplementary DMI is offset by a decrease in pasture DMI, and

hence methane emissions would be similar between calving systems with similar SR and feeding intensities.

Overall, because early and mid-lactation occur during March–June in an autumn-calving system, and this requires supplementary feed to fill a feed deficit, these systems may leach more N and emit more methane than spring-calving systems with the same SR. To date, no literature tests these hypotheses, and because environmental policy will continue to affect dairy system decisions and management, further research is required to understand environmental differences between spring- and autumn-calving systems in pasture-based dairying.

2.5 Recent drivers for changing from spring to autumn calving

Historically, in a NZ context, autumn calving was mainly utilised by year-round liquid milk suppliers to meet their daily winter milk production quota. These suppliers were situated close to urban centres and produced a year-round supply of milk for fresh consumption, for which they received a premium. Deregulation of the town milk industry in 1988 removed the NZ Milk Board's control of the milk price setting, and shifted it to individual processors, causing a change in payment structures from a year-round quota-based system to specific winter milk contracts (Moffitt & Sheppard, 1988).

More recently, climatic factors along with further structural changes to the winter milk premium has increased discussion about changing from spring- to autumn-calving systems (Brown, 2015; Woodford, 2016; Deeks, 2017; Taunton, 2017; Tennant, 2018). In addition, there is anecdotal evidence that some farmers perceive a social benefit to changing calving season and are indicating that this benefit is driving their decision to change. Therefore, farmers and processing companies are responding to different drivers, which is causing changes in milk supply.

2.5.1 Winter milk premium

Recent changes to the winter milk premium payment structure has increased farmer interest in changing to an autumn-calving system. Increasing local and international demand for fresh dairy products, like ultra-heat-treated milk and cream in China for example, has led to processors requiring greater quantities of fresh milk during the traditionally minimal winter supply period (Fonterra, 2018). These fresh products have a limited shelf life, so the period between milk collection and consumption by the customer must be short. These shorter shelf-life products require different manufacturing facilities compared with the longer shelf-life concentrate products (e.g., milk powders, butter, cheese) that form the majority of NZ's dairy export product mix (NZIER, 2017). Consequently, different skills and infrastructure are required relative to the main focus of the NZ dairy processing industry to process winter milk,

and the processing capital (i.e., tankers, plant, labour) needs to be available during the winter period when typically infrastructure is being cleaned and repaired, and seasonal labour is furloughed. To compensate for the perceived additional costs required to produce winter milk, and to incentivise suppliers, processing companies have responded by increasing their winter milk premium and changing their payment structure.

Prior to the merger that formed Fonterra in 2001, winter milk contracts varied in price and structure across NZ and between processing companies. These existing arrangements were continued post-merger until the majority expired between 2004 to 2008 (Burtt, 2006). An example of the range of these contract prices is displayed in Table 2.8. Further consolidation occurred, reducing the number of different premiums to 10 by 2006 and then four by 2012 (Askin & Askin, 2012). In 2017 this was reduced to two; a North Island premium and a South Island premium (Askin & Askin, 2018; Fonterra, 2018). This most recent change altered the winter milk premium payment structure from a 122-day flat premium to a 60-day stepped payment arrangement, that pays the greatest premium when milk supply is historically the lowest, presented in Figure 2.14. The winter milk premium increased from an average of \$1.68/kg MS, which varied from \$0.65–\$3.85/kg MS, dependent on region, to \$2.85–\$3.50/kg MS for North Island suppliers and \$3.60 –\$4.25/kg MS for South Island suppliers. This has led to farmers assessing whether they can increase profitability by producing milk during winter (Chikazhe et al., 2017).

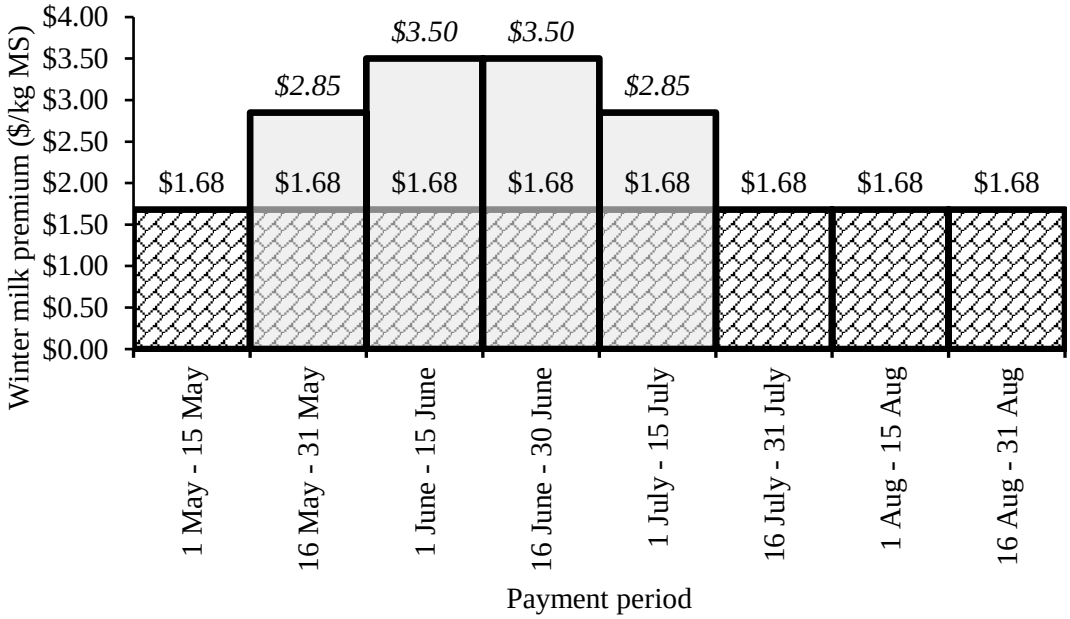

Figure 2.14. Fonterra Cooperative Group Ltd winter milk premium payment [\$/kg milksolids (MS)] and structure for 2006 (hatched) and *2017 (no hatch)*. 2006 is the average of the 10 different regional premiums offered in 2005 and 2006. 2017 is the payment and structure for North Island suppliers. Adapted from Burtt (2006) and Fonterra (2018), respectively.

Table 2.8. Fonterra regional winter milk premiums [$/kg milksolids (MS)] for the 2005/06 and 2006/07 seasons. From Burtt (2006).

Region	$/kg MS
Far North	0.65
Kauri	0.80
Auckland/North Waikato/Huntly	1.15
South Waikato/Western Bay of Plenty	0.80
Central North Island/Eastern Bay of Plenty	0.65
Taranaki/Manawatu	1.80
Hawkes Bay/Wairarapa	1.40
Central and Upper South Island	3.85
Otago	3.06
Southland	2.66

2.5.2 Climate change adaptation

Autumn-calving may also be an adaptation strategy to expected climate variability in the medium term for some farmers. Globally-increasing concentrations of GHG in the atmosphere may cause climate change within NZ during the next century (Ministry for the Environment, 2018). Across NZ, modelling predicts that daily mean air temperature will increase between 0.7 to 1.0°C by 2040, and between 0.7 to 3.0°C by 2090, relative to 1986–2005, with this increase being more pronounced in summer and autumn (Ministry for the Environment, 2018). The mean number of hot days (>25°C), as well as mean number of dry days (<1 mm rainfall) will increase in all regions. Consequently, there may be an increase in drought intensity, experienced most strongly in the northern and eastern areas of the North Island (Ministry for the Environment, 2018). Of note, modelling predicts that drought intensity in Taranaki and Manawatu will not increase (Ministry for the Environment, 2018). Because climate is the main driver of pasture growth and variability, climate change will impact on pasture growth.

Future climate-change impacts on pasture-based dairy systems and potential adaptation options have been recently reviewed (Lee et al., 2013). The authors' main conclusions were that annual pasture growth, as well as within-year growth variation, has the potential to either increase or decrease dependent on region. Specifically, winter and spring PGR are expected to increase in response to reduced temperature limitations (Clark et al., 2012; Lee et al., 2013). Changing pasture species, investing in irrigation, decreasing SR, extending lactation and, relevant to this literature review, changing the timing of calving, have been suggested as potential adaptation options (Kalaugher et al., 2012; Phelan et al., 2015). By changing from spring to autumn calving, a farmer can adapt their system so that feed demand and pasture supply may be more aligned if winter and spring PGR increase, and summer PGR decrease.

2.6 Approaches to changing from a spring- to an autumn-calving system

Climate change and the winter milk premium, as well as potentially other factors, may cause a farmer to decide to change their herd's calving season from spring to autumn. Once the decision is made, the farmer can achieve the change through a number of different approaches and across various timeframes. However, regardless of approach and time interval, changing from spring to autumn calving requires at least one, or more often, a combination, of three key on-farm management decisions:

- Sell all or a portion of the current spring-calving herd, and replace with autumn-calving cows;
- For spring-born young stock, either mate earlier than normal, or delay mating so that they enter the herd as autumn-calving cows; or,
- For lactating spring-calving cows, either mate earlier than normal, or delay mating so that they next calve closer to autumn.

Implementation of one or more of the three management decisions leads to broadly three separate approaches to changing from spring to autumn calving. These are:

1. Sale of the spring-calving herd;
2. A gradual change to the spring-calving herd by first moving to a split-calving system; or
3. A relatively abrupt change to the spring-calving herd by undertaking an extended lactation.

Minimal literature exists on these three approaches and the implications of each, therefore farmers and industry professionals have limited information to base their decisions on. Recently, Chikazhe et al. (2017) identified that changing to autumn calving could be both costly and risky, and that any financial cost could erode potential first season profits. Although these authors proposed selling the spring-calving herd and purchasing an autumn-calving herd as an approach, they did not incorporate any implications into their Farmax™ modelling or discuss the on-farm management required to instigate the change. Similarly, both Figueredo (2003) and Fulkerson et al. (1987) described that changing the calving season would incur substantial costs during the period of change, but did not include those costs in their linear programming model exploring seasonal milk-price schemes in the South Island or in calculating gross margin per ha, respectively. On-farm management requirements for the three approaches were described by Chestnut & Robinson (2001), while Taylor (1996) described the gradual change approach for one case study farm, but neither study detailed financial or system implications. There is

increasing farmer interest in using the extended lactation approach to change calving season, hence, it is described in more detail in the following section.

2.7 Implications of undertaking an extended lactation to change from a spring- to an autumn-calving system

A visual representation of the extended lactation approach to changing from a spring- to an autumn-calving system is provided in Figure 2.15. In brief, this approach requires mating to be delayed after the final calving in spring until the next winter, so that the herd then calves in autumn, creating an approximately 20-month CI. As a consequence of extending the CI, the herd undergoes an extended lactation, before returning to a 12-month CI and 'normal' lactation length. Mating of young stock that were born in spring must also be delayed so that they will calve in autumn. The deviation from, and return to, the steady state arrangement (12-month CI) of seasonal calving has implications on the farm system that must be incorporated into the decision on changing the season of calving.

The extended lactation required to change from a spring- to an autumn-calving system has many implications on the farm system because it is a deviation from the 12-month CI that underpins seasonal calving pasture-based dairy systems. In this context, an extended lactation refers to a lactation greater than 305 days that occurs as a result of the CI being greater than 12 months (Kolver, 2001; Borman et al., 2004).

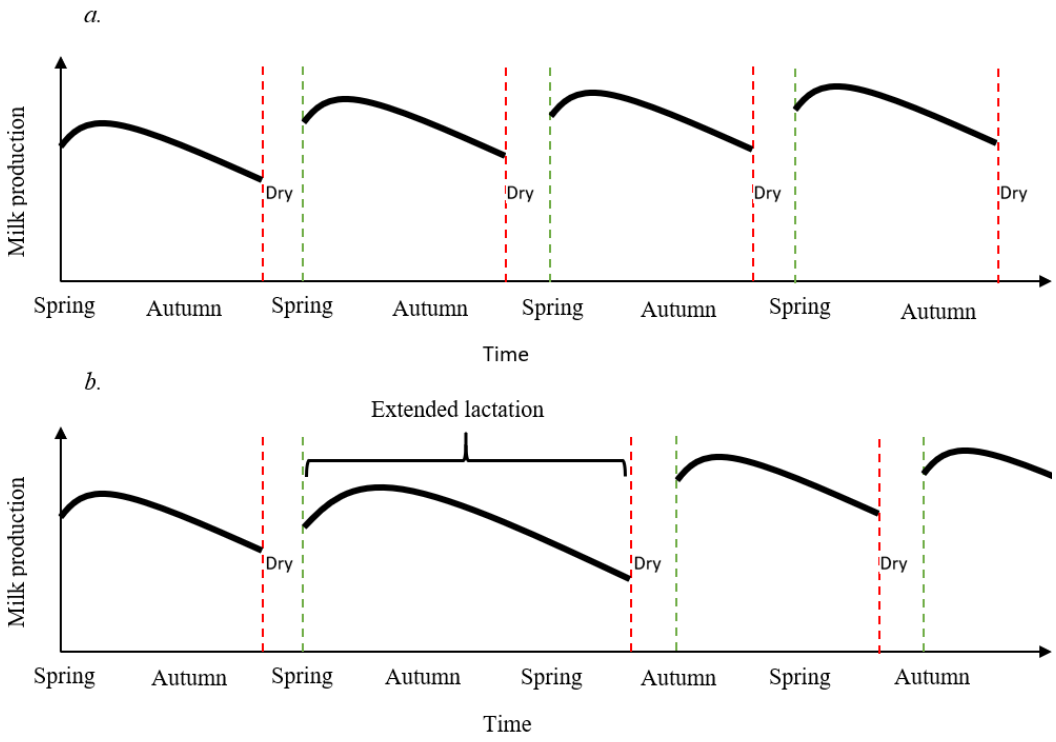

Figure 2.15. Simplistic diagram displaying lactation curves over time of a steady-state spring-calving herd *(a.)* and a herd undergoing an extended lactation to change from a spring- to an autumn-calving system *(b.)*. Adapted from Lehmann (2018).

2.7.1 Extended lactation performance

A summary of lactation performance from extended lactation experiments is presented in Table 2.9. Total lactation MS production varied between 762 to 1,180 kg MS/cow across 24-month CI treatments, increasing with increasing level of feeding (Kolver et al., 2007; Grainger et al., 2009; Butler et al., 2010). Milksolids production also increased with increasing CI (Auldist et al., 2007). North American HF produced greater kg MS/cow than NZ HF, leading to a significant ($P < 0.001$) interaction between breed and MS production over the extended lactation (Kolver et al., 2007).

Extended lactation experiments have annualised the total lactation or split the total lactation into two periods to allow comparisons with 'normal' lactations from 12-month CI herds. Kolver et al. (2007) reported annualised MS production as the MS produced during a calendar year, calculated by dividing the extended lactation MS production by two. Butler et al. (2010) also divided the extended lactation into two periods. The first period referred to milk produced from calving until the end of a 'normal' 12-month CI (~10 months), and the second period referred to the milk produced after this point until drying off. Grainger et al. (2009) also reported two periods. The first from 1–300 days in milk (DIM) and the second from 301–607 DIM. Due to different CI lengths, Auldist et al. (2007) reported annualised lactation production as the total lactation production multiplied by 12/CI.

Annualised or periodised milk production data are detailed in Table 2.10. Annualised production numerically decreased as CI increased, however this trend was not significant (Auldist et al., 2007). North American HF cows produced greater ($P < 0.01$) annualised MS and had a greater ($P < 0.01$) ratio of annualised to normal lactation yield compared with NZ HF, regardless of feeding level (Kolver et al., 2007). Milksolids production was greater in the first period compared with the second period of the extended lactation in the studies of both Butler et al. (2010) and Grainger et al. (2009). The relative production level has implications for the revenue generated over the extended lactation period compared to a 'normal' 12-month CI lactation. Based on these results, the second year of an extended lactation (assuming a 24-month CI) may generate less revenue relative to a 12-month seasonal-calving system if lactation yield is lower.

The ability of the cow to continue lactating past a normal dry-off time (~305 DIM) determines the MS production of the extended lactation. For the 24-month CI treatments in Table 2.9, the herds were managed for 670-day lactations, however the average DIM was less than 670 days because some cows were dried off early, based on a minimum daily milk yield threshold, resulting in the average DIM varying between 567 to 643 days across the 24-month CI treatments. There was no significant genotype or diet interaction affecting average DIM (Kolver

et al., 2007), or diet interaction affecting the proportion of cows still lactating at final dry off (Grainger et al., 2009). However, a greater (48% vs. 14%, significance not reported) proportion of the NA HF herd was still lactating at final dry off compared to NZ HF, indicating that NA HF cows may be better suited to extended lactations than NZ HF cows (Kolver et al., 2007). When CI was progressively increased in 3-month increments from 15- to 24-months, the proportion of HF cows, of unreported ancestry, reaching target DIM decreased from 100% to 96%, 83% and 42%, respectively (Auldist et al., 2007). This indicates that the majority of cows are able to lactate for at least 16 months (i.e., an 18-month CI).

Table 2.9. Days in milk (DIM), percentage of cows reaching targeted dry-off date and extended lactation production [kg milksolids(MS)/cow] during extended lactations. "-" = data not reported; CI = calving interval; NZ = New Zealand; IRE = Ireland; AUS = Australia.

	Experimental treatments		Planned CI			
Source, location & date	Factor one	Factor two[1]	(months)	DIM[2]	Cows reaching target[7]	Milksolid production (kg MS/cow)
Kolver et al. (2007)[3]		0 kg DM	24	595	20%	762
Waikato, NZ	NZ HF[8]	3 kg DM	24	608	22%	919
2003–2005		6 kg DM	24	567	0%	789
		0 kg DM	24	623	38%	881
	NA HF[9]	3 kg DM	24	604	56%	1,109
		6 kg DM	24	630	50%	1,180
Butler et al. (2010)	-	3 kg DM[4]	24	593	-	854
Co. Tipperary, IRE	-	6 kg DM[4]	24	593	-	892
2004–2005						
Grainger et al. (2009)	-	160 MJ ME[5]	24	-	58%	817
Victoria, AUS	-	180 MJ ME[5]	24	-	50%	921
2004–2005	-	Ad-lib TMR[6]	24	-	42%	1,088
Auldist et al. (2007)	15-month CI	-	15	393	100%	623
Victoria, AUS	18-month CI	-	18	485	96%	743
2003–2006	21-month CI	-	21	561	83%	830
	24-month CI	-	24	643	42%	925

[1] Supplementary feeding regime used [kg dry matter (DM)/cow/day or megajoules metabolisable energy (MJ ME)/cow/day]
[2] Herd average DIM
[3] Supplementary feed offered during the whole lactation
[4] Supplementary feed offered during the 13-week winter period
[5] Supplementary feed offered varied across the season to achieve steady energy intake
[6] Total mixed ration (TMR) consisted of wheat/barley/triticale (17%), canola meal (14%), alfalfa hay (34%), maize silage (16%), grass silage (13%), minerals (1%), and cereal straw (5%). Offered ad lib until 440 DIM, then restricted by 2 kg DM/day thereafter
[7] Percentage of cows within the treatment herd still lactating at the planned dry-off date
[8] NZ Holstein Friesian genotype
[9] North American Holstein Friesian genotype

Table 2.10. Annualised or periodized extended lactation production [kg milksolids (MS)/cow], and the ratio of either, annualised production to 12-CI production, or second period production to first period production. "-" = data not reported; CI = calving interval; HF = Holstein Friesian; NZ = New Zealand; IRE = Ireland; AUS = Australia; NA = North American.

	Experimental treatment		Planned CI	Milksolid production (kg MS/cow)			
Source, location & date	Factor one	Factor two	(months)	Annualised	First period	Second period	Ratio
Kolver et al. (2007)[1]		0 kg DM	24	381[5]			0.78
Waikato, NZ	NZ HF	3 kg DM	24	460[5]			0.83
2003–2005		6 kg DM	24	395[5]			0.75
		0 kg DM	24	441[5]			0.89
	NA HF	3 kg DM	24	555[5]			1.00
		6 kg DM	24	590[5]			0.94
Butler et al. (2010)		3 kg DM[2]	24		473[7]	381[7]	0.80
Co. Tipperary, IRE		6 kg DM[2]	24		461[7]	431[7]	0.94
2004–2005							
Grainger et al. (2009)		160 MJ ME[3]	24		439[8]	373[8]	0.93
Victoria, AUS		180 MJ ME[3]	24		444[8]	407[8]	0.90
2004–2005		Ad-lib TMR[4]	24		514[8]	401[8]	0.79
Auldist et al. (2007)	15-month CI		15	498[6]			-
Victoria, AUS	18-month CI		18	495[6]			-
2003–2006	21-month CI		21	474[6]			-
	24-month CI		24	463[6]			-

[1] Supplementary feed offered during the whole lactation
[2] Supplementary feed offered during the 13-week winter period
[3] Supplementary feed offered varied across the season to achieve steady energy intake
[4] Total mixed ration (TMR) consisted of wheat/barley/triticale (17%), canola meal (14%), alfalfa hay (34%), maize silage (16%), grass silage (13%), minerals (1%), and cereal straw (5%). Offered ad lib until 440 DIM, then restricted by 2 kg DM/day thereafter
[5] Total extended lactation yield divided by two
[6] Total extended lactation yield multiplied by 12/CI, where CI is the calving interval of the treatment in months
[7] First period = calving until end of 12-CI lactation. Second period = end of first period until drying off
[8] First period = 1–300 DIM. Second period = 301–607 DIM

2.7.2 Liveweight and body condition score changes during an extended lactation

The change in cow LWT and BCS between calving and drying off during extended lactation experiments is displayed in Table 2.11. In all experiments, cows undergoing an extended lactation increased LWT and BCS between calving and drying off. There was also a significant ($P < 0.01$) linear interaction between diet and LWT and BCS increase in one experiment (Kolver et al., 2007). In support, Grainger et al. (2009) reported a significant ($P < 0.05$) difference in LWT and BCS increase between the TMR diet treatment and two other diet treatments. Liveweight numerically increased as the CI increased, however only the 15-month CI treatment significantly ($P < 0.05$) differed from the other treatments (Auldist et al., 2007). No numeric trend was reported for BCS, however the 15- and 18-month CI treatments did significantly ($P < 0.05$) differ from the 21- and 24-month CI treatments, indicating that BCS increased as CI increased (Auldist et al., 2007). The BCS at drying off tended to be closer to the obese end of the scale, and greater relative to the optimum of 5.0–5.5 (1–10 scale; Roche et al., 2009a) at calving (Macdonald et al., 2010). Thus, cows undergoing extended lactation may be at risk of increased periparturient metabolic diseases and reduced DMI in their subsequent lactation, if their suboptimal BCS at drying off remains the same until their next calving (Roche et al., 2009a).

Table 2.11. Comparison of the change in liveweight (LWT) and body condition score (BCS) from calving until dry off during extended lactations. "-" = data not reported; CI = calving interval; HF = Holstein Friesian; NZ = New Zealand; IRE = Ireland; AUS = Australia; NA = North American.

	Experimental treatments							
Source, location & date	Factor one	Factor two[1]	Planned CI (months)	LWT at calving	LWT increase at drying off	BCS at calving	BCS increase at calving	BCS scale[6]
Kolver et al. (2007)[2]		0 kg DM	24	512	126	5.78	1.96	
Waikato, NZ	NZ HF	3 kg DM	24	508	203	5.99	2.54	
2003–2005		6 kg DM	24	512	181	5.81	3.22	10-point NZ
		0 kg DM	24	623	92	5.78	0.52	scale
	NA HF	3 kg DM	24	591	118	5.45	0.65	
		6 kg DM	24	605	175	5.89	1.37	
Butler et al. (2010)	-	3 kg DM[3]	24	-	-	-	0.46	5-point IRE
Co. Tipperary, IRE	-	6 kg DM[3]	24	-	-	-	0.39	scale
2004–2005								
Grainger et al. (2009)	-	160 MJ ME[4]	24	582	143	4.9	0.22	8-point AUS
Victoria, AUS	-	180 MJ ME[4]	24	569	173	4.7	0.59	scale
2004–2005	-	Ad-lib TMR[5]	24	605	245	5.2	3.64	
Auldist et al. (2007)	15-month CI	-	15	490	89	4.53	0.41	
Victoria, AUS	18-month CI	-	18	474	160	4.44	0.37	8-point AUS
2003–2006	21-month CI	-	21	473	179	4.41	1.25	scale
	24-month CI	-	24	481	188	4.52	0.88	

[1] Supplementary feeding regime used [kg dry matter (DM)/cow/day or megajoules metabolisable energy (MJ ME)/cow/day]
[2] Supplementary feed offered during the whole lactation
[3] Supplementary feed offered during the 13-week winter period
[4] Supplementary feed offered varied across the season to achieve steady energy intake
[5] Total mixed ration (TMR) consisted of wheat/barley/triticale (17%), canola meal (14%), alfalfa hay (34%), maize silage (16%), grass silage (13%), minerals (1%), and cereal straw (5%). Offered ad lib until 440 DIM, then restricted by 2 kg DM/day
[6] Roche et al. (2004)

2.7.3 Reproductive performance

Extending the CI has been suggested as a management response to mitigate declining fertility in pasture-based dairy herds, particularly herds with large proportions of NA HF cows (Borman et al., 2004; Butler et al., 2010; Abdelsayed et al., 2015). In a 12-month CI system, attempting to rebreed whilst the cow is at peak milk production and in a state of negative energy balance, results in poor reproductive performance (Walsh et al., 2011). Therefore, by extending the CI, mating occurs when the cow is in a potential positive energy balance state, and the hypothesis is that this can improve reproductive performance.

The reproductive performance of cows during an extended lactation from two experiments is displayed in Table 2.12. The 21-day submission rate during the extended lactation was similar (85.5% vs. 87%) across both experiments, although in the experiment reported by Butler et al. (2010), mating began 46 days earlier than the experiment by Kolver et al. (2007). Within the experiment reported by Kolver et al. (2007), the empty rate in the extended lactation mating was significantly ($P < 0.01$) greater for NA HF cows compared with NZ HF cows (30% vs. 3%),indicating that the fertility of NA HF cows is suboptimal even when the period between calving and mating is extended. For context, the NZ dairy industry advises 21-day submission rates to be greater than 82% and final nonpregnancy rates to be less than 14% (assuming a 12-week mating period; Blackwell et al., 2017), hence the results presented here do not indicate poor reproductive performance, except for the NA HF cows in the first experiment.

Unfortunately, due to small experimental herd size (Grainger et al., 2009), and a focus on milk production (Auldist et al., 2007), there is limited literature to support the reproductive performance of cows undergoing an extended lactation in this research. Furthermore, experimental methodology confounds reproductive performance results. In the experiment reported by Kolver et al. (2007), cows were first mated at 82 DIM to provide data for a normal lactation (e.g., a 12-month CI). Pregnancy was then terminated between 74 to 112 DIM and cows were mated again at 451 DIM to establish a 24-month CI. Therefore, the extended lactation reproductive performance of these cows may have been impacted by the mating and pregnancy termination they were subject to in early lactation. Similarly, cows recruited into the experiment reported by Butler et al. (2010) were selected from 12-month CI herds because they had failed to conceive during the normal mating period. Therefore, selection bias confounds the impact of the extended lactation on reproductive performance.

2.7.4 Delay in replacement heifers entering the herd

When the CI of the herd is extended to facilitate the herd changing from a spring- to an autumn-calving system, replacement heifers that were born during the two prior seasons enter the herd later than if the CI was consistently 12 months. The age at first mating, and subsequently the

Table 2.12. Reproductive performance of herds undergoing an extended lactation. "-" = data not reported; CI = calving interval; HF = Holstein Friesian; NZ = New Zealand; IRE = Ireland; NA = North American; submission rate is the percentage of cows in the herd submitted for mating within the first 21 days of the mating period; final empty rate is the percentage of cows not-in-calf at the end of the mating period.

					21-day submission rate		Final empty rate	
Source, location & date	Treatment	n	Planned CI (months)	Days between calving and mating during extended lactation	Extended lactation	Normal lactation[1]	Extended lactation	Normal lactation[1]
Kolver et al. (2007)	NZ HF	30	24	451 (84 for normal lactation)	86%	93%	3%	14%
Waikato, NZ	NA HF	30	24		85%	59%	30%	48%
2003–2005								
Butler et al. (2010)								
Co. Tipperary, IRE		46	24	405	87%	-	15%	-
2004–2005								

[1] Normal lactation is reproductive performance recorded when cows were mated ~3 months after calving, to replicate a 12-month CI

age at first calving, of these heifers is older relative to heifers in a 12-month CI system. This approach to changing calving season impacts on two cohorts of heifers: the calves born in the final spring-calving season and the calves born in the second to last spring-calving season.

Delaying the age of mating, and age at first calving of heifers, can cause changes to lifetime milk production and reproductive performance, but limited literature exists comparing the age of first calving in pasture-based dairy systems. In the most relevant experiment, Dobos et al. (2004) reared 135 heifers from birth until first calving to achieve three different ages at first calving (25, 30 and 34 months), with three different LWT at first calving (498, 549 and 595 kg, respectively). They reported that heifers calving at the two oldest ages, and heifers calving at the two heaviest LWT, produced greater quantities ($P < 0.05$) of milk fat and protein than the youngest and lightest heifers. However, this difference did not persist at the end of the third lactation. Infertility was the major driver of voluntary culling, therefore in this experiment the mean number of lactations was reported as a proxy for reproductive performance. No significant

difference in mean number of lactations between age at first calving or LWT at first calving was reported. In support, Lin et al. (1988) and Lin et al. (1986) reported that compared with heifers first mated at 350 days old, heifers first mated at 462 days old produced greater ($P < 0.05$) quantities of milk fat and protein during their first lactation, but they reported no significant difference in reproductive performance. Furthermore, they reported that as the number of lactations increased, the impact of age at first calving on milk production decreased. Chuck et al. (2018) also reported that first lactation milk production was positively associated with age of first calving, when greater than 24 months old, but not with age at first calving when less than 24 months old, and hypothesised that older (i.e., later calving) heifers may be more skeletally mature, so require less partitioning of energy to growth during their first lactation. However, they did not report effects on second and subsequent lactations.

More recently Macdonald et al. (2005) reported that replacement heifer calves fed a reduced ration achieved puberty at a later age, indicating a relationship between pre-pubertal feeding level and the age when mating is successful. Although the authors did not directly compare age at first calving, they reported that pre-pubertal feeding levels, and as a consequence, the age of first mating, had no impact on milk production in lactations subsequent to the first, consistent with Lin et al. (1986, 1988). Therefore, literature identifies that delaying the age of first mating and calving can impact on the future milk production and reproductive performance of heifers, but this advantage does not persist in future lactations.

Delaying the age of first calving can also increase the costs associated with rearing replacement heifers. These costs include heifer grazing costs, if replacement heifers are grazed away from the milking platform, or the cost of forgone pasture and supplementary feed plus associated

farm costs (labour, administration etc), if replacement heifers are reared on the milking platform. Modelling, in a UK context, reported that the mean cost of rearing a replacement heifer increased by £2.87/day (NZ$5.65/day[1]) for each extra day of age at first calving, with feed and labour costs accounting for 59% of total farm inputs required for rearing (Boulton et al., 2017). Similarly, modelling in a USA context concluded that reducing the age at first calving reduced the cost of rearing (Tozer & Heinrichs, 2001). However, this model was based on a TMR system, so results may not transfer to pasture-based systems.

2.7.5 Economic factors

Implementing extended lactations within pasture-based systems is perceived to lead to positive economic performance, however there is limited literature to support this. Based on a survey of 250 Victorian dairy farmers, the majority (>51%) agreed that extended lactations would positively affect per cow profitability (O'Brien & Cole, 2004). It is hypothesised that extending the CI reduces the exposure of cows to the post-parturition period, where 60% of all health-related expenses occur (Knight, 2001). In support, spreadsheet modelling predicted that increasing the CI reduced the fixed costs associated with lactation (e.g., breeding costs, health costs, replacement costs) by diluting them across greater milk production (Lormore & Galligan, 2001). It is also predicted that greater reproductive performance from cows undergoing extended lactations may lead to a reduction in involuntary culling, and a consequent decrease in the cost of rearing replacement animals (Borman et al., 2004).

From a whole farm perspective, incorporating an extended lactation for a portion of the herd was modelled to increase financial performance compared to a strict 12-month CI on two case study farms in Victoria, Australia (Malcolm, 2005). Instead of culling non-pregnant animals when their pregnant herd mates were dried off, these cows were modelled to be milked for a further five or eight months, for case study farm 1 and 2, respectively. Annual operating profit was modelled to increase by $48,000 and $23,000, and annual return on capital (ROC) by 1.6% and 0.6% for each farm when non-pregnant cows underwent an extended lactation before being culled (Table 2.13). Malcolm (2005) estimated that implementing an extended lactation caused no increase in labour costs compared to the status quo. However, because both case study farms were implementing a 12-month CI within a split-calving system, this result may not transfer when comparing seasonal extended lactation systems with seasonal 12-month CI systems. This is because daily milking may be required for a whole calendar year during an extended lactation, whereas a 12-month CI system has a dry period. The author concluded that lactation persistency during the extended lactation was a key determinant of profitability in extended

[1] £1.00 = NZ$1.97, 9 January 2020

lactations, but that the economic success of extended lactations is a product of the complex farm and management interactions unique to each situation. Interestingly, the author also outlined that both case study farm owners identified substantial non-financial benefits to utilising an extended lactation that could not be accurately accounted for. Unfortunately, no literature based on experimental trials or large dataset analysis was found that corroborated these results.

Table 2.13. Modelled annual operating profit and annual return on capital comparison for two case study farms in Victoria, Australia. From Malcolm (2005).

	Case study farm 1		Case study farm 2	
	Extended lactation[1]	12-month CI	Extended lactation[1]	12-month CI
Annual operating profit[2]	$223,000	$175,000	$172,000	$149,000
Return on capital	7.4%	5.8%	4.3%	3.7%

[1] Non-pregnant cows were milked past a 12-month calving interval (CI), then culled and replaced at either a 17- or 20-month CI
[2] AUS$

2.8 Economics of farm system change

As discussed in section 2.4.1.6, there are differences in economic performance between spring- and autumn-calving systems, and extended-lactation systems, respectively. In those sections, means-based metrics, including gross revenue, operating expenses and profit, allowed comparisons to be made between systems. However, those metrics assumed the systems to be in a steady state. Changing calving season requires manipulation of the mating dates of the herd, or turnover of the herd completely, which means that for a period of time the farm is not operating under steady-state conditions (see section 2.6). Therefore, while those metrics adequately describe the relative differences between systems, they do not describe the economic performance of a farm business during the period of change when changing from a spring- to an autumn-calving system. There is no literature to date that reports the economic performance during which the herd changes calving season. This section briefly discusses the change of calving season from an investment-decision context.

Changing from a spring-calving system to an autumn-calving system, by undertaking an extended lactation, is an investment decision because:

- Changing the season of calving changes the production system of the capital resource (i.e., the milking herd; Gardner et al., 2005);
- Changing the season of calving sacrifices likely immediate returns for uncertain future benefits (i.e., milk revenue may be greater in the future due to a winter milk premium; Gardner et al., 2005); and

- Changing season of calving incurs sunk costs that are not recoverable if the decision to change is reversed (e.g., a reduction in MS production).

Net present value (NPV) is a general investment approach (Brealey et al., 2018), appropriate for agricultural investment evaluation (Tauer, 2000). However, NPV does not account for uncertainty in the performance of the investment in the future, so sensitivity analysis via simulation of a distribution of NPV is also recommended in investment evaluation (Tauer, 2000).

2.8.1 Net present value of farm system change

An investment can be evaluated based on its NPV, calculated as the sum of discounted future cash flows over a number of periods at a chosen discount rate, minus the initial investment outlay (Tauer, 2000). The NPV of an investment of *t* periods is described in Equation 1, where the summation occurs from $t = 1$ to t, cash flow is the net cash flow for the period t, r is the chosen discount rate, and I is the initial cost of the investment in $t = 0$ (Tauer, 2000).

$$Net\ present\ value = \sum \frac{Cash\ flow_t}{(1+r)^t} - I \qquad 1$$

Depending on the investment context, a salvage value can also be included in the final cash flow period, which assumes the investment is terminated and depreciable assets are sold (Gardner et al., 2005). An investment is considered worthwhile when the NPV is positive (Tauer, 2000). Net present value is most often used to evaluate potential returns from on-farm investments in technology and infrastructure, and has been used as a decision criterion in a number of different contexts, including investing in conventional or precision agriculture grain harvesting machinery (Tozer, 2009), investing in automatic or conventional milk harvesting technologies (Shortall et al., 2016), investing in different oestrus detection technology (Thomas et al., 2019), and investing in centre pivot instead of border-check irrigation (Wood et al., 2007). However, limited literature reports NPV for biological investments on dairy farms. Furthermore, infrastructure and technology investment analyses commonly assume that investment occurs in year zero (i.e., $t = 0$) and that there is no 'transition' period (i.e., benefits from the investment occur immediately). Because it has been identified that the benefits of changing calving season may not occur immediately, and there may instead be immediate net costs before a new steady state is realised (Fulkerson et al., 1987; Figueredo, 2003; Chikazhe et al., 2017), it is important that this period is adequately accounted for in NPV analysis. For example, when changing from conventional to organic crop production in the midwestern USA, Delbridge & King (2016) incorporated a two-year transitional period in their NPV analysis, defined as land producing crops at an organic production volume (i.e., reduced yields) but receiving conventional unit returns, before receiving organic premium returns (i.e., greater unit returns) from year three

onwards. Therefore, the decision to invest in organic production accounted for the transitional period required to implement that investment.

2.8.2 Sensitivity analysis of farm system change

An identified weakness of NPV as an investment criterion, is that future cash flows are assumed, when in reality they are uncertain (Tauer, 2000). Uncertainty refers to the imperfect knowledge the farmer has about future cash flows because they do not know, for example, the future market situation, the actual output of the investment or the actual life of the investment (Hardaker et al., 2015). Furthermore, farm businesses are constantly exposed to risk (Komarek et al., 2020), defined as exposure to unfavourable consequences (Hardaker et al., 2015). Therefore, evaluation of investments in dairy farming must account for both the imperfect knowledge that is used to calculate the criterion, and the inherent risk that all farming business are exposed to.

Sensitivity analysis is one method used to account for uncertainty in investment analysis. Sensitivity analysis is a procedure that analyses changes to output data when input data is changed (Jovanović, 1999). It has been used to assess outcomes of different future dairy farm intensity options under different milk price scenarios (Ho et al., 2005), the profitably of different stand-off strategies to avoid pugging damage on dairy farms under different pasture recovery scenarios (Beukes et al., 2013), and the profitability of supplementary feeding on Waikato dairy farms under different milk, PKE and fertiliser prices (Doole, 2014). Sensitivity analysis allows for the uncertainty of future cash flows, dependent on changing inputs, however, it is limited to the decisions and assumptions on which the range of input values are changed.

2.9 Conclusions

Calving every 12 months during winter and early spring so that feed demand matches pasture supply allows the NZ dairy industry to compete as a low-cost producer in international markets. However, due to a range of drivers, some farmers have adopted alternatives systems to spring calving. Calving in autumn is one such alternative, and this system is reported to have both advantages and disadvantages in comparison to spring calving.

Many approaches exist for farmers wanting to change from spring to autumn calving. In particular, farmers have expressed interest in extending the CI of their herd and undertaking an extended lactation across two seasons to achieve the change in calving season. Previous research has detailed impacts on the farm system when adopting an extended lactation in pasture-based systems. However, no literature exists that describes the farm system as it changes from a spring-calving system to an autumn-calving system by undertaking an extended lactation, and what, if any, impact this has on the steady-state autumn-calving system.

Moreover, no literature has adequately defined the period over which a herd changes from a steady-state spring-calving system to a steady-state autumn-calving system, and no literature has appraised the change of calving season from an investment perspective when including the period of change.

2.10 Thesis objectives

Changing calving season is a strategic decision a farmer makes that has long-term impacts on their business. Although farmers have access to information regarding the relative differences of autumn-calving compared with spring-calving systems, there is less relevant information concerning how to change the calving season, and what, if any, implications there are when doing so. Therefore, the objectives of this thesis are:

1. To quantify the biophysical and economic effects on a farm system that undertakes an extended lactation to change from a spring-calving system to an autumn-calving system, compared with a steady-state spring-calving system; and
2. To evaluate the change of calving season from an investment context, and quantify the impact of the period of change on future system performance.

2.11 Hypothesis

I hypothesise that using an extended lactation to change calving season to autumn will negatively impact the whole farm system (biophysical and economic), due to reduced performance during and following the extended lactation, and that future cash flows would need to be greater than a spring-calving system to recover the initial cost of the investment.

Chapter 3 Materials and Methods

This chapter details the two interconnected methodologies used to achieve the dual objectives. The first objective required analysis of a farmlet experiment where a farmlet that changed from spring calving to autumn calving was compared with a farmlet that maintained spring calving. Biophysical and economic results from this farmlet experiment were then used to assess the change in calving season from an investment context. This chapter first details the farmlet experiment, and then describes the economic and investment analyses.

The farmlet experiment analysed is part of a long-term farm-system research project with the objective of comparing spring- and autumn-calving systems in South Taranaki, NZ. Therefore, the experimental design was decided prior to myself undertaking this thesis and the data were analysed retrospectively. The farmlet systems experiment approach was chosen instead of a modelling study as it allowed the testing and comparison of the two contrasting calving systems at a scale comparable to commercial farms, and allowed potentially unknown system interactions to occur in a controlled and measured environment. Data analysed for the current experiment were collected from June 2017 until January 2020, as part of the longer-term research project that is due to end in May 2023.

The experiment was undertaken at the Dairy Trust Taranaki 'Kavanagh' farm (formally the Whareroa Research Centre); 39°36'S, 174°17'E, approximately 100 m above sea level, 1.2 km from the South Taranaki coastline, in the North Island of NZ. Kavanagh farm is approximately 209 effective ha of flat to undulating terrain, representative of coastal Taranaki dairy land.

The experimental farm area contains Egmont black loam (orthic allophanic soil in the NZ classification; Hewitt, 2013; Manaaki Whenua, 2018), and pastures were predominantly ryegrass and white clover. Some crops (maize: *Zea mays* and turnips: *Brassica rapa*) were grown on a portion of the farm. Details of the experimental design and management decisions are provided in subsequent sections.

All experimental procedures were approved by the Ruakura Animal Ethics committee (Application 14787) in accordance with the NZ Animal Welfare Act (1999).

3.1 Weather conditions

Monthly rainfall during the experimental period was recorded at a weather station situated on Kavanagh farm. The long-term average was calculated from ~100 years of data from three sites, accessed from the CliFlo (2020) data base (Table 3.1). The 'Hawera AWS' weather station is located on Kavanagh Farm.

Table 3.1. Details of the weather stations that recorded rainfall data at Kavanagh farm that was accessed from CliFlo (2020).

Name	Agent number	Latitude and longitude	Observation years	Distance from Kavanagh farm
Hawera AWS	25222	39°36'S, 174°17'E	2004–2020	0 km
Hawera Green Lane	3561	39°59’S, 174°26’E	1977–2004	2.9 km
Hawera 2	3566	39°60’S, 174°28’E	1920–1970	1.1 km

Calendar year rainfall at Kavanagh farm for 2017–2019 and the long-term average (1920–2016) are presented in Table 3.2. Calendar year rainfall exceeded the long-term average in all three calendar years. The percentage difference in monthly rainfall during the experimental period compared with the long-term average (1920–2016) is presented in Figure 3.1. During the experimental period, below-average rainfall during October, November and December 2017 across Taranaki and the lower North Island resulted in the NZ Government declaring a medium-scale drought event in this region on 23 December 2017. Monthly rainfall was also well below average during January 2020.

Table 3.2. Calendar year rainfall (mm) during the experimental period and long-term average (1920–2016) at Kavanagh farm, South Taranaki, New Zealand.

	2017	2018	2019	Long-term average (1920–2016)
Rainfall (mm)	1,314	1,174	1,187	1,151

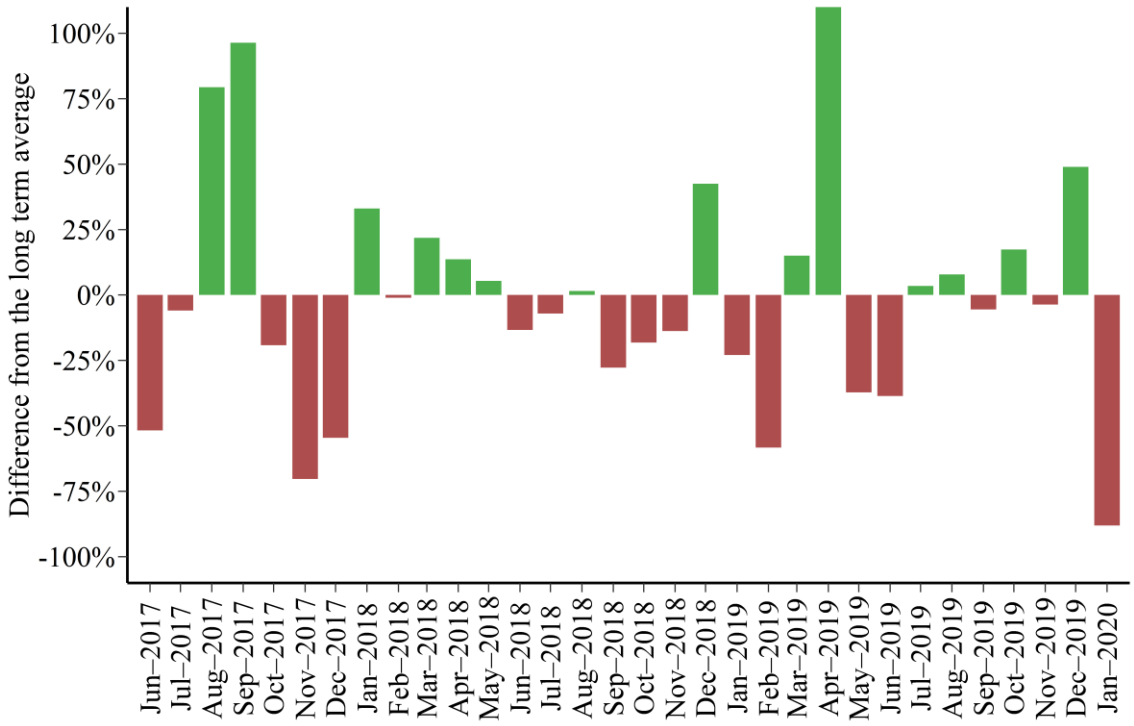

Figure 3.1. Difference (%) in monthly rainfall during the experimental period compared with the long-term average (1920–2016) at Kavanagh farm, South Taranaki, New Zealand.

Other weather-related variables, including evapotranspiration, minimum and maximum air temperature, and solar radiation were accessed from the Virtual Climate Station Network (VCSN) operated by NIWA (2020), for the years 1980–2020. Data were selected from the closest 5-km grid point of the VCSN to the milking parlour of Kavanagh farm. Although the VCSN data do not extend back further than 1980, they were used because there were no long-term weather station measurements of evapotranspiration, air temperature or solar radiation near Kavanagh farm.

3.1.1 Weather data analysis

Weather data were analysed in R (R Core Team, 2020). Heat accumulation, which is associated with PGR (Hutchinson et al., 2000), was calculated over time as growing degree days (GDD). Growing degree days were defined as the sum of the average daily temperature minus the minimum threshold. A minimum threshold identifies the temperature below which growth ceases in perennial ryegrass and white clover, with 4°C chosen as the minimum threshold, as outlined by Hutchinson et al. (2000). Daily minimum and maximum air temperature, GDD, and solar radiation were converted to time series data. The time series was seasonally decomposed into seasonal, trend and irregular components using locally-weighted scatterplot smoothing to account for the seasonality of weather-related variables. A linear regression of the extracted trend component was calculated, providing an equation for change over time. Daily rainfall and daily evapotranspiration were summed to a seasonal total (summer, December–February; autumn, March–May; winter, June–August; spring, September–November; inclusive) for each year, and then trends identified for each season through linear regression over time. Daily rainfall was also summed to monthly and yearly totals to test for change in variance over time. Heteroskedasticity of linear regressions from monthly and yearly rainfall was detected using the Goldfeld-Quandt test and Breusch-Pagan test in the lmtest package in R (Zeileis & Hothorn, 2002).

3.2 Farmlet experimental design

3.2.1 Animal allocation

Cows for the current experiment were sourced from the existing Kavanagh farm herd. This consisted of HF x Jersey crossbred multiparous and primiparous cows (n = 602), which had been mated previously to begin calving on 3 July 2017 (median calving date = 31 July 2017). Following calving, all animals were managed as one herd according to best management practice for NZ pasture-based dairy systems (Roche et al., 2017b) until 1 October 2017 when cows were allocated into two farmlets.

On 1 October 2017, 602 lactating cows [48 ±18 days in milk (DIM); 561 multiparous and 41 primiparous] were allocated to one of two farmlets: autumn-calving, AUT (n = 301); or spring-calving, SPR (n = 301). Multiparous cows (n = 279 for AUT; n = 282 for SPR) were balanced for age, breeding worth (BW) and production worth (DairyNZ, 2020a), current daily MS production, cumulative-to-date MS production, DIM, LWT, BCS and somatic cell count (SCC), based upon individual herd test data collected on 7 September 2017 (Table 3.3). On the same day, heifers and yearlings, currently grazing off the milking platform, were randomly allocated to each farmlet, balanced for LWT (n = 22 for AUT; n = 19 for SPR). Subsequent mating dates were altered so heifers in the AUT farmlet returned to the milking platform in February 2019 (~30 months old) to calve in March, while in the SPR farmlet they returned in June 2018 and June 2019 (~23 months old) to calve in July.

Table 3.3. Total number of cows, age, breeding worth, production worth, daily milksolids (MS) production, cumulative-to-date MS production, days in milk (DIM), liveweight (LWT), body condition score (BCS) and somatic cell count (SCC) of the autumn-calving (AUT) and spring-calving (SPR) farmlets established on 1 October 2017. SD = standard deviation, NZ$ = New Zealand dollars.

	AUT		SPR	
	Mean	SD	Mean	SD
Total number of cows	301		301	
Multiparous	279		282	
Primiparous	22		19	
Age (years)	5.4	2.4	5.2	2.3
Breeding worth (NZ$)	81	39	81	40
Production worth (NZ$)	89	88	86	88
Daily MS production (kg MS/day)	1.83	0.4	1.82	0.4
Cumulative MS production (kg MS)	80	33	79	30
DIM	48	19	48	18
LWT (kg)	465	56	456	54
BCS	4.1	0.5	4.1	0.5
SCC[1]	140,000		122,000	

[1] 75th percentile presented due to skewed nature of the data

3.2.2 Paddock allocation

A farm map (Figure 3.2) identifies paddocks in each farmlet and indicates the location of the milking parlour, where all cows were milked. On 1 October 2017, paddocks were randomly allocated to each farmlet, balanced for area, distance from the milking parlour, pasture species and age, previous cropping history and effluent application, and Olsen P and Quick Test potassium (K) levels. Thirty paddocks (total area = 104.8 ha) were assigned to the AUT farmlet and twenty-nine paddocks (total area = 104.0 ha) to the SPR farmlet. Stocking rate at the commencement of the experiment was approximately 2.9 cows/ha for both farmlets.

3.2.3 Timeline and experimental definitions

To retain a spring-calving system, cows allocated to the SPR farmlet were mated from 1 October to 26 December 2017 in accordance with normal farm practice for the Kavanagh farm, described further in section 3.3.1.3. To create an autumn-calving system, cows in the AUT farmlet were withheld from mating in October–December 2017, and instead, were mated at approximately 311 ±30 DIM, from June to August 2018. Although the two separate farmlets were not established until October 2017, all data analysed, results presented, and discussion points in this thesis include the four months prior (June 2017–October 2017) when all cows were managed as one herd.

Figure 3.2. Farm map of paddocks allocated to the autumn-calving (AUT; orange shade) and spring-calving (SPR; green shade) farmlets, and the location of the milking parlour. From Google (n.d; image retrieved 24 February 2020).

A diagram outlining the timeline of the experiment is presented in Figure 3.3. Different time periods have been created (i.e., year and lactation) to ensure clarity and enable comparisons between different variables. Briefly, 'year' refers to the 12-month financial year beginning 1 June and ending 31 May, which is standard for most NZ dairy farm businesses. Hence, year one (Y1), year two (Y2) and year three (Y3) refer to the 2017/2018, 2018/2019 and 2019/2020 financial years, respectively.

'Lactation' refers to the period when the herd was approximately one month prior to PSC, until drying off. This period was chosen as it broadly represents the period when the herds were

lactating, as well as allows comparisons between farmlets and previous literature. For accuracy of analyses these periods are rounded to month end. Therefore, for the AUT farmlet, lactation one (L1) includes the period from 1 June 2017 until 31 January 2019 (an extended lactation). Lactation two (L2) includes the period from 1 February 2019 until the end of the experiment on 31 January 2020.

In contrast, for the SPR farmlet, L1 includes the period from 1 June 2017 until 31 May 2018, L2 from 1 June 2018 until 31 May 2019, and lactation three (L3) from 1 June 2019 until the end of the experiment on 31 January 2020 (only eight months).

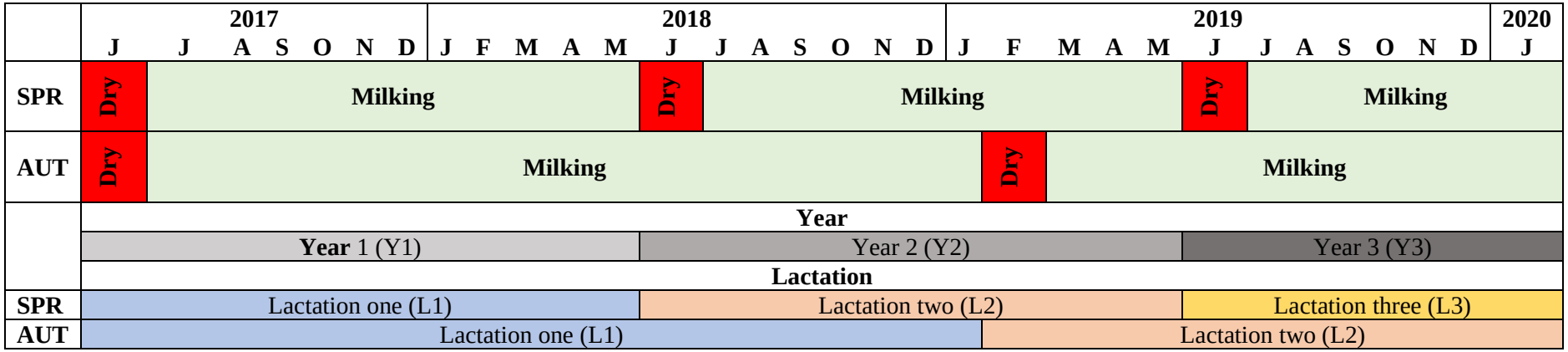

Figure 3.3. Diagrammatic definitions of year and lactation for the autumn-calving (AUT) and spring-calving (SPR) farmlets during the experimental period

3.3 Management of farmlets

Each farmlet in the current experiment was managed as a closed system and daily operational decisions for each farmlet were made independently based on a pre-determined set of decision rules, referred to herein as decision rules. Farmlets (i.e., cows, paddocks, and supplementary feed) were not reset at the beginning of each lactation. Therefore, any supplementary feed not used in one lactation was carried forward into the next.

3.3.1 Animal management

Cows were managed in their respective farmlets under a rotational grazing system with milking, mating and feeding regimes detailed below.

3.3.1.1 Milking

All cows were milked in their respective farmlets through the same milking parlour twice a day (TAD) at approximately 06:00 and 14:00 for the majority of each lactation. Cows were milked once a day (OAD) for the final three days of lactation.

3.3.1.2 Drying off

The drying-off protocol was the same for the SPR farmlet in L1 and for both farmlets in L2. After 1 March for the SPR farmlet during L1 and L2, and 1 December for the AUT farmlet during L2, cows identified as not in calf, with a high SCC, or possessing other unfavourable attributes (e.g., three teats, lame, etc.) were identified for culling. When available DMI was estimated to be less than 14 kg DM per cow for 14 consecutive days, these cows were removed from the farmlet and culled. Concurrently, cows producing less than 0.5 kg MS/cow/day were dried off and entered a non-lactating herd within each farmlet. In addition, cows identified with low BCS (<3 BCS units; 1–10 point scale, Roche et al., 2009a), as assessed weekly by the same trained BCS assessor, were dried off so that they had sufficient time to achieve a 4.5 BCS on 31 January for the AUT herd and 31 May for the SPR herd (DairyNZ, 2010). Remaining cows were dried off as one herd, either at 40 days prior to PSC or if calculated APC targets would not likely be met at PSC, whatever occurred first. Details on APC measurements, calculations and targets are contained in section 3.4.2.

Throughout L1 for the AUT herd (extended lactation), individual cows were dried off when milk yield decreased below 10 L/cow/day at the monthly herd test. Any remaining cows were dried off in January 2018 to achieve target APC at calving (details are in section 3.3.2) and to ensure a minimum of 30 days between drying off and PSC.

The drying-off process for all lactating cows followed the SmartSAMM guidelines (DairyNZ, 2012). Briefly, all multiparous and primiparous cows that recorded a herd test SCC of >150,000

and >120,000, respectively, were administered long-acting antibiotic and a teat sealant. Remaining primiparous and multiparous cows, and all nulliparous heifers, were administered teat sealant when the total herd ceased milking.

3.3.1.3 Mating

Mating decision rules were the same for both farmlets. Four weeks prior to planned start of mating (PSM), cows with previous calving difficulty (e.g., dystocia, stillborn, required intervention, retained foetal membranes, etc.) were Metri-checked™ for endometritis by a veterinarian and treated accordingly. There was no pre-mating oestrus detection. For six weeks from PSM, cows visually detected in oestrus via twice-daily tail-paint observations, in the paddock and in the milking parlour, were artificially inseminated (AI) after the morning milking with fresh semen by a trained technician. Cows in oestrus, but considered low BW, were AI with short-gestation length Hereford semen. After six weeks of AI, cows underwent five weeks of natural mating by a team of Hereford bulls. Six weeks after the end of mating, all cows were pregnancy tested. No controlled internal drug release intervention techniques were used.

Commencement of mating and the subsequent PSC dates for both farmlets are displayed in Table 3.4. To maintain a 12-CI the SPR herd began mating on 1 October every year, while mating was delayed for AUT cows in L1 until 6 June 2018. The AUT herd then maintained a 12-CI by beginning mating in L2 on 5 June 2019.

Table 3.4. Dates for the planned start of calving (PSC) and planned start of mating (PSM) for the autumn-calving (AUT) and spring-calving (SPR) farmlet herds prior to the experiment and during each lactation.

	AUT		SPR	
	PSC	PSM	PSC	PSM
Prior to the experiment		*1 October 2016*		*1 October 2016*
Lactation one	3 July 2017	6 June 2018	3 July 2017	1 October 2017
Lactation two	15 March 2019	5 June 2019	10 July 2018	1 October 2018
Lactation three	14 March 2020		10 July 2019	1 October 2019

3.3.1.4 Calves and replacement animals

Details of replacement heifers reared are presented in Table 3.5. As calving began, calves were collected twice daily and reared on farm. Calves were fed three L of milk twice daily, in the morning and afternoon, until they were weaned at 100 kg LWT (~60–80 days old; recorded on electronic walk-over scales). Calves also received ad-lib calf meal during this period. Post-weaning, all calves were grazed together off the milking platform.

Table 3.5. Number of replacement heifer calves reared from the autumn-calving (AUT) and spring-calving (SPR) farmlet herds during each lactation. "-" = data not applicable.

	AUT	SPR
Lactation one	73	73
Lactation two	74	64
Lactation three	-	85

When both the AUT and SPR farmlet cows calved during spring 2017, replacement heifer calves from both farmlets were reared together in the same calf shed. In subsequent lactations, calves were born in autumn or spring, so were reared in the calf shed with other calves from their farmlet. Because replacement heifer calves were born either in spring 2016 or spring 2017, heifers allocated to the AUT farmlet for L2 were mated at ~22 months old, compared with heifer calves allocated to the SPR farmlet which were mated at ~15 months old. As a consequence, heifer calves from the AUT farmlet calved at 31 months old, while heifer calves from the SPR farmlet calved at 24 months old.

Both farmlets aimed for an equal number of multiparous and primiparous cows at the start of the experiment and for a 22% replacement rate throughout the experiment. However, as a result of the imposed treatments, herd numbers and age structure varied throughout the experiment (Table 3.6). Actual replacement rates were 25% for the AUT herd and 26% for the SPR herd in L2, and 21% for the SPR herd in L3.

Table 3.6. Number of mixed-aged cows (i.e., multiparous) and heifers (i.e., primiparous) in the autumn-calving (AUT) and spring-calving (SPR) farmlet herds at the start of each lactation.

	AUT		SPR	
	Mixed age cows	Heifers	Mixed age cows	Heifers
Lactation one (L1)	279	22	282	19
Lactation two (L2)	250	76	227	78
Lactation three (L3)	-	-	243	63

3.3.1.5 Animal health

Any cow with an acute illness or injury was treated according to veterinary advice, as part of best management practice. Cows from either farmlet identified as unwell (e.g., lame, mastitis, facial eczema) were grazed together in a 'sick' cow mob that rotated grazing between paddocks allocated to each farmlet to reduce any bias. Specific preventative animal health management included the following:

To aid in the prevention of hypocalcaemia (i.e., milk fever), three to four weeks pre-calving, dry cows were supplemented with 100 g/cow/day of magnesium oxide dusted onto pasture, and 40 g/cow/day of magnesium chloride dissolved into water troughs (Roche et al., 2013a). Post-

calving, lactating cows were supplemented for four months with 35 g/cow/day of magnesium oxide and 50 g/cow/day of limeflour (calcium carbonate) mixed into their supplementary feed, which was fed via an in-shed feeding facility during milking. Newly-calved cows were supplemented with 200 g/cow/day of limeflour dusted onto pasture during their colostrum period, which was the first four days after calving.

To prevent facial eczema, zinc sulphate was administered via an in-line mineral water dispenser (Dosatron; Bell-Booth Ltd, Palmerston North, NZ) between February and April each year. From February until April in 2018 and 2019, a local veterinary practice completed a weekly facial eczema spore count. When spore counts exceeded 30,000/g of pasture, paddocks due to be grazed in the next 14 days were sprayed with 300 ml/ha of carbendazim (166 g active ingredient).

Decision rules based on best management practice, specified that bloat oil was to be used to both treat and prevent bloat in each farmlet herd if required. In response to an increased risk of bloat during August to December 2019, bloat oil was administered via water troughs to the SPR herd only.

3.3.2 Pasture grazing, supplementary feeding and fertiliser management

Grazing management on both farmlets targeted a 1,500–1,600 kg DM/ha post-grazing residual for lactating cows, and a 1,100 kg DM/ha post-grazing residual for non-lactating cows. Both farmlets also targeted an APC of 2,200–2,400 kg DM/ha at PSC.

Weekly or fortnightly individual paddock pasture masses (kg DM/ha) were calculated from either a visual pasture assessment, tow-behind C-Dax Pasture Meter©, or rising plate meter (Lile et al., 2001). Measurements were stored electronically in a farm management software database by farm staff. These were used in conjunction with forecasted PGR (from historic data) to complete a feed budget and implement a grazing plan for each farmlet.

The feed budget was updated after each farmlet pasture mass assessment, beginning in March for the SPR farmlet and December for the AUT farmlet. The feed budget estimated future feed supply from APC, estimated future pasture growth and supplementary feed available, and estimated future feed demand using cow performance data to determine cow energy requirements, and herd size, to predict daily DMI requirements.

The grazing plan specified, for each farmlet, how much area would be allocated from which paddocks for the next seven or 14 days. Pasture management decisions were also guided by predetermined grazing rotation targets, except from about July–September in L1 for both farmlets, and from about July–September in L2 and L3 for the SPR farmlet. During these

periods (~July–September; from the start of calving until PGR exceeded herd feed demand), a spring rotation planner (Macdonald et al., 2010) was followed.

Predetermined grazing rotation targets defined the area of the farmlet to be grazed daily by the respective farmlet herd. The grazing rotation is reported as the fraction of the effective milking area that is being grazed at that point in time. This excluded paddocks currently in crop. For example, if the grazing rotation was set at 1/20th of the farmlet, and 7.5 ha was currently cropped in maize, the grazing area for that day would be 1/20th multiplied by 96.5 ha (104 ha effective area − 7.5 ha cropping area) = 4.83 ha per day.

If the feed budget indicated that PGR exceeded herd pasture demand, a 1/24th grazing rotation was implemented until the end of December, then decreased to 1/30th until the 25th March. Grazing rotation then followed:

- 25 March–1 April = 1/35th;
- 1 April–22 April = 1/42nd;
- 22 April–drying off (~31 May) = 1/52nd; and
- A 1/80th–1/100th rotation was implemented for the dry cows, with a larger area provided when wet weather was forecast.

3.3.2.1 Grazing management in the AUT farmlet during the extended lactation

When undertaking the extended lactation in L1, the grazing rotation for the AUT farmlet was the same as for the SPR farmlet up until cows in the SPR farmlet were dried off. The AUT farmlet then followed the grazing rotation outlined in Table 3.7 from this point onwards (~31 May). During L2 the AUT farmlet also followed the grazing rotation outlined in Table 3.7.

Table 3.7. Diagram of the grazing rotation for the autumn-calving farmlet during the later stages of their extended lactation and for their lactation two.

March to July	August	Sep to Dec	January	February
1/115th → 1/40th	1/35th → 1/30th	1/24th	1/30th	1/80th → 1/100th

3.3.3 Supplementary feed inputs

Prior to the commencement of the experiment, pasture silage and maize silage conserved in the previous year were allocated equally to all cows before 1 October 2017, such that the supplementary feed inventory was nil (except for concentrate meal in the silo) when cows and paddocks were allocated to the farmlets.

3.3.4 Homegrown feed

3.3.4.1 Conservation of pasture

During the experiment, if there was a surplus of feed (i.e., pasture supply was ~10% greater than pasture demand as determined from the feed budget and grazing plan), individual paddocks were identified for conservation. Paddocks were removed from the grazing plan in October and harvested into pasture silage prior to December, or hay post-December.

Pasture silage and hay made from a farmlet were stored and subsequently fed back to cows in that farmlet. Farmlets purchased additional pasture silage, maize silage and hay when the feed budget indicated a feed deficit unable to be filled with available feeds. Decision rules also dictated that if adequate pasture silage and hay had been harvested, paddocks were to be 'deferred grazed' (McCallum et al., 1991). This occurred in 4 ha in the AUT farmlet from January–March 2019 at the end of L1 and beginning of L2.

3.3.4.2 Nitrogen fertiliser

Nitrogen fertiliser was used tactically according to best management practice to increase pasture growth throughout the experiment. Decision rules targeted 150–175 kg N/ha/year for both farmlets. Application was timed to coincide with pastures being at between six to eight cm tall. Nitrogen fertiliser was not applied when soils were saturated or when soil moisture was limiting.

3.3.4.3 Gibberellic acid

Gibberellic acid was applied at 20 g/ha (8 g/ha of active ingredient) to increase pasture growth during June–August, with the aim of grazing this pasture later in the season. Gibberellic acid was applied one to five days post-grazing via foliar spray. The AUT farmlet received between one and two applications per year. Paddocks grazed twice within the June–August period received two applications; paddocks grazed once received one application. The cost of gibberellic acid has been included in the economic analysis, however, data from individual paddocks, applied area and the total amount of gibberellic acid used were not recorded by farm staff, and so no further analysis of its biophysical impact could be completed.

3.3.4.4 Fertiliser management

Both farmlets received similar maintenance fertiliser applications for pasture paddocks based on individual paddock soil samples taken to 7.5 cm depth every two years. Nitrogen was applied as either urea [Ravensdown®, Christchurch, NZ; N, P, K, sulphur (S): 46, 0, 0, 0] or N-Protect™ (Ravensdown®, Christchurch, NZ; N, P, K, S: 46, 0, 0, 0) or granular ammonium sulphate (Ravensdown®, Christchurch, NZ; N, P, K, S: 20, 0, 0, 23) or di-ammonium phosphate (Ravensdown®, Christchurch, NZ; N, P, K, S: 18, 20, 0, 1). Potassium was applied as

potassium chloride (Ravensdown®, Christchurch, NZ; N, P, K, S: 0, 0, 50, 0) or 20% potash super (Ravensdown®, Christchurch, NZ; N, P, K, S: 0, 7, 10, 9) or 30% potash super (Ravensdown®, Christchurch, NZ; N, P, K, S: 0, 6, 15, 8). Selenium was applied as Selprill Double™ (as sodium selenate; Ravensdown®, Christchurch, NZ; N, P, K, S: 0, 0, 0, 0). Nitrogen was applied throughout the year to tactically increase pasture growth (further detailed in section 3.3.4.2). Potassium chloride and ammonium sulphate were applied in the spring; potash super was applied in both spring and autumn. Fertiliser was not applied on paddocks where effluent was spread.

Table 3.8. Fertiliser type and quantity (kg) applied to the autumn-calving (AUT) and spring-calving (SPR) farmlets in each year during the experimental period.

	2017/2018	
Year one	AUT	SPR
Urea	10,682	10,752
Di-ammonium phosphate	6,958	6,258
30% potash super	3,600	3,600
20% potash super	8,488	8,488
	2018/2019	
Year two	AUT	SPR
Urea	35,270	28,129
Granular ammonium sulphate	8,586	7,210
Potassium chloride	2,257	237
20% potash super	1,883	1,883
Sodium selenate	631	388
	2019/2020	
Year three	AUT	SPR
Urea	37,812	31,910
Granular ammonium sulphate	9,853	9,564
Potassium chloride	3,596	1,143
Sodium selenate	0	28

3.3.4.5 Effluent management

A travelling irrigator evenly spread effluent captured from the milking parlour over ~28 ha (~7 paddocks) for each farmlet. As both herds were milked through the same milking parlour, effluent was pooled together, and as such, management aimed to evenly distribute the effluent across both farmlets to reduce bias.

3.3.4.6 Crops

Crops were incorporated into each farmlet to provide a source of homegrown feed when pasture growth did not meet feed demand. Information on the cropping regime is provided in Table 3.9. Maize and turnips were selected due to their yield potential, timing of feed availability, ease of feeding management, and established use in the Taranaki region.

On each farmlet, 4.1–7.3 ha of maize was sown in October and harvested in March each year. In addition, approximately 4 ha of turnips were grown as a summer forage crop for both farmlets in Y1 (2017/18), and for the SPR farmlet in Y2 and Y3. Maize and turnip cultivars were P8500™ (Pioneer®, Gisborne, NZ) and Barkant™ (PGG Wrightson®, Christchurch, NZ), respectively. Paddocks with suitable contour and that had not been regrassed recently (i.e., within the last ~10 years) were selected as cropping paddocks. Paddocks chosen for maize were ploughed prior to precision planting, whereas paddocks chosen for turnips were sprayed with glyphosate and then direct drilled. Maize was planted as early as possible in October, based on suitable ground conditions for cultivation. Turnips were planted 70 days prior to planned harvest date. Prior to planting in Y2 and Y3, maize paddocks received 2 t/ha of limestone (calcium carbonate). Limestone was not applied in Y1. At planting, maize paddocks received 260 kg/ha of Nitrophoska™ Perfect (Ravensdown®, Christchurch, NZ; N, P, K, S: 15, 2, 17, 8). Post-planting, maize paddocks received 140 kg/ha of N-Protect™ (Ravensdown, Christchurch, NZ; N, P, K, S: 46, 0, 0, 0). Turnips received 210 kg/ha of Cropmaster DAP Boron Plus™ (Ravensdown, Christchurch, NZ; N, P, K, S: 16, 19, 0, 1) at planting. A contractor harvested the maize when DM was estimated to be 35% and it was stored in a bunker. Details on measurements of supplementary feed yield are provided in section 3.4.2.2.

Table 3.9. Crop area (ha), planting date, harvest or feeding date, and yield [t dry matter (DM)/ha] for the autumn-calving (AUT) and spring-calving (SPR) farmlets in each year during the experimental period.

Year one	2017/2018			
Crop	AUT Maize	AUT Turnips	SPR Maize	SPR Turnips
Area (ha)	4.3	4.2	4.1	4.1
Planting date	Not recorded	18 October	Not recorded	18 October
Harvest or feeding date	5 March	23 January	5 March	23 January
Yield (t DM/ha)	17.5	13	17.5	13
Year two	2018/2019			
Crop	AUT Maize		SPR Maize	SPR Turnips
Area (ha)	4.6		5.0	4.4
Planting date	10 October		10 October	Not recorded
Harvest date or feeding date	23 March		23 March	15 January
Yield (t DM/ha)	20		20	13.2
Year three	2019/2020			
Crop	AUT Maize		SPR Maize	SPR Turnips
Area (ha)	7.5		6.3	4.1
Planting date	10 October		10 October	10 October
Harvest date or feeding date				6 January
Yield (t DM/ha)				12.8

3.3.4.7 Imported supplementary feed

A custom blend of concentrate meal, purchased through a stock feed company, was stored in one silo and offered to both herds for periods of each lactation via an in-shed feeding facility with individual bins during milkings on a kg DM/cow basis. Individual bins were not cleaned out between farmlet herds during milking. Due to changes in price and seasonal requirements, the type and composition of the meal changed over the course of the experiment. In general, meal components included pelletised dried distillers' grains (DDG), palm kernel expeller (PKE), tapioca, soya hulls, high-starch wheat pellets and barley starch pellets. The meal was also fortified with magnesium oxide when fed during early lactation. Palm kernel expeller was also purchased and fed through the in-shed feeding facility.

3.3.4.8 Crop and supplementary feed allocation

Grazing of turnips began in January, 70 days after planting. Turnips were allocated on a kg DM/cow basis, and break fed according to best management practice behind a temporary electric fence (DairyNZ, 2006). Immediately following morning milking, cows were offered a fresh break of turnips. The herd was removed from the turnip paddock and returned to pasture when visually judged by staff to have consumed their daily allocation.

The decision to offer supplementary feed was made independently for each farmlet based on the same decision rules. Maize silage, pasture silage and concentrate meal were offered to farmlet herds when the feed budget indicated that farmlet herd feed demand exceeded farmlet feed supply from pasture. Both maize and pasture silage were allocated on a kg DM/cow basis and were fed out in the paddock prior to the cows entering a new paddock in the evening. Dry matter was determined by drying a subsample of the feed when the respective bunker was first opened for use. Wet weight allocations for each farmlet were then calculated and electronic scales on the feed-out wagon were used to measure the required amount. In wet conditions, this allowance was increased to account for poor utilisation and increased wastage in the paddock. In addition, to increase utilisation and minimise wastage from trampling and fouling by excrement, maize and pasture silage were fed alongside fence lines.

3.4 Measurements

Data were collected in a consistent manner to ensure reliability and quality; however, as this experiment was undertaken at a commercial farm scale, some standard operating procedures varied as the experiment progressed, and farm management staff and systems changed.

3.4.1 Animal data

3.4.1.1 Bulk milk production

Following the establishment of the farmlets on 1 October 2017 until 31 May 2018, bulk milk from both farmlets was collected into one milk vat for collection. Therefore, bulk milk production was not separately measured between farmlets for Y1. A second milk vat was installed on 1 June 2018 allowing separation of farmlet milk for Y2 and Y3. Bulk milk volume (litres) and composition (percentage of fat and protein, and SCC) were subsequently available either daily or every second day. These data were aggregated for year and lactation for each farmlet and used to validate individual milk production data as described in section 3.4.1.2.

3.4.1.2 Individual cow milk production

Monthly individual herd testing was undertaken from August 2017 until the end of the experiment. Herd testing was completed by a qualified technician based on the standard procedure developed by Livestock Improvement Corporation (LIC; Hamilton, NZ). Individual cow milk volume was measured, and milk composition was determined based on LIC standard herd test protocol.

As farmlet bulk milk data were not available for Y1, an approximation of individual cow milk production variables (MS, fat, protein) was calculated for all lactations instead. The rectangular sum approach was used to approximate the area under the curve for each cow for each relevant milk production variable using individual cow calving date, drying-off date and their respective monthly herd test result. Herd test data were used before and after the herd test date, either from the date halfway between the current test date and the previous test date, or between the current test date and the subsequent test date. Exceptions were for the first and last herd test data, which were used from the start of lactation and end of lactation, respectively. Rectangles were formed based on the height of the herd test record and the width of the base between the two dates, such that individual cow performance was calculated as per the rectangular sum approach (Johnson, 1996). Cow production data were accumulated within year and lactation to calculate farmlet-level production. The rectangular sum approach was chosen over simple lactation functions, for example those described by Wood (1976) or Wilmink (1987), as visual inspection of the AUT farmlet herd test data displayed a second peak of lactation which these functions are unable to accurately model (Garcia & Holmes, 2001).

3.4.1.3 Liveweight and body condition score

Individual cow LWT was recorded monthly by electronic walk-over scales at the milking parlour following the morning milking (during the lactation period) or prior to shifting to a new break (during the dry period). At the same time, individual cow BCS was visually assessed by

the same trained assessor, based upon a 10-point scale with 0.5 increments (Roche et al., 2009a). No measurements for LWT or BCS were undertaken in April 2018 or in January and March 2019.

3.4.1.4 Reproduction

Farm staff and qualified technicians (i.e., veterinarians) uploaded mating dates, calving dates and pregnancy scanning results for individual cows to the LIC database during the experimental period. Similar to the method described by Hemming et al. (2018), farmlet measures of reproductive performance were calculated from the LIC database according to the rules described in the InCalf Fertility Focus User Guide (DairyNZ, 2019a). Reproductive performance measures were analysed and are defined as follows: 3-week submission rate was the percentage of cows in the farmlet that received at least one AI or natural mating in the first three weeks of the mating period, 6-week in-calf rate was the percentage of cows in the farmlet that became pregnant in the first six weeks of the mating period, conception rate was the percentage of inseminations that resulted in a pregnancy as determined by pregnancy testing, and not-in-calf rate was the percentage of cows in each farmlet that failed to become pregnant by the end of the mating period (Blackwell et al., 2017). Reported values were extracted from Fertility Focus reports (version 3.01) for each farmlet for each lactation.

3.4.1.5 Animal health

Staff recorded incidence of common diseases or disorders in cows into an animal recording software system (MINDA®, LIC). Date and reason for culling of cows was also recorded into MINDA.

3.4.2 Feed data

3.4.2.1 Pasture

The method for measuring pasture herbage mass has been previously described in section 3.3.2. Pasture data analyses were completed similar to that described by McCahon (2019). Briefly, net herbage accumulation for each measurement period was calculated for ungrazed paddocks as the increase in herbage mass during the accumulation period. Where a grazing had occurred, defined as growth rate of less than −20 kg DM/ha/day for the period, herbage accumulation was calculated from the average PGR of the farmlet during the period multiplied by the length of the period. Pasture growth rate during the experiment was presented as the average of paddocks within each farmlet at each recording, after accounting for grazing events. Similarly, APC during the experiment was presented as the APC of paddocks within each farmlet at each recording date after removing observations <1,000 kg DM/ha that represented paddocks in crop. To calculate seasonal (i.e., winter, spring, summer, autumn) and annual pasture growth,

individual paddock growth rates greater than −20 kg DM/ha/day were firstly grouped based on date within season (winter, June to August; spring, September to November; summer, December to February; autumn, March to May; inclusive) and the average calculated for each farmlet. The average season PGR was then multiplied by the number of days in each season to calculate pasture growth for each season. Total pasture growth was calculated from the sum of the four seasons for that year, starting in winter (1 June).

Pasture measurements were also used to approximate the average weekly pasture DMI of the herds. Intakes were estimated as the difference between the average pre-grazing and post-grazing pasture herbage mass, reported by farm staff, multiplied by the area grazed (in ha) divided by the number of cows grazing. For example,

1. 2,700 kg DM/ha – 1,500 kg DM/ha = 1,200 kg DM/ha;
2. 1,200 kg DM/ha × 4 hectares = 4,800 kg DM available;
3. 4,800 kg DM ÷ 301 cows = 16 kg DM/cow/day.

3.4.2.2 Supplementary feed offered

Daily supplementary feed offered (kg DM/cow) and the number of cows fed were recorded by farm staff in farm management software (FarmIQ®, Wellington, NZ) for all supplementary feed except turnips. Supplementary feed offered prior to the beginning of this experiment but during Y1 and L1 was not recorded and is unable to be presented. Therefore, the amount of supplementary feed offered in Y1 and L1 only includes what was fed after the farmlets were established (October 2017), instead of the whole lactation.

Turnips were offered as kg DM/cow based on the calculated crop yield. Therefore, the amount of turnips offered (kg DM) were calculated as 90% of the turnip crop yield, representing a 90% utilisation rate when feeding turnips using best management practices (Harris et al., 1998). Turnips were still being offered at the end of the experimental period (Y3) on the SPR farmlet. Therefore, total turnip crop yield grown is presented for Y3 but the total turnip crop offered for Y3 has been calculated by multiplying the number of cows grazing turnips by the number of days grazing by the kg DM offered per cow, as reported by farm staff in the weekly farm walk report.

Turnip yield was visually estimated by farm staff. Maize yield was calculated by measuring the dimensions of the maize bunker, based on best management practice (DairyNZ, 2016b). When the bunker was opened to begin feeding, a subsample of maize was measured for DM percentage via oven drying for 24 hours. Bunker volume was multiplied by the DM percentage to calculate total maize yield. In Y1 (2017/18) and Y2 (2018/19), grass silage yield was calculated by measuring the dimensions of the silage bunker and subsampling as for maize

silage. In 2019/20, grass silage was weighed when harvested by net weighing the silage trailers on electronic scales.

3.5 Statistical analysis

Data were analysed in R (R Core Team, 2020). Due to the nature of the farm systems experiment and experimental design not having replicates, statistical analysis of results is restricted to variables attributed to the individual cow or individual paddock within each farmlet within each lactation or year. Therefore, statistical results can only be presented for these variables.

Where appropriate, a Student's t-test was used to determine the significance of differences between farmlet means for individual cow and individual paddock data, with least-squares means and standard error of the difference (SED) reported accordingly. Significance was declared if $P \leq 0.05$. A trend was declared if $0.05 \leq P \leq 0.1$.

For variables unable to be statistically analysed due to the structure of the raw data, means or absolute totals are presented instead as they are relevant to the objective of this thesis. To distinguish between the former statistically-significant results and latter numerically-different results, a P value is provided in text for statistically-significant results.

3.6 Economic analysis

Biophysical data along with economic data from each farmlet were used to determine the economic performance of the farmlets for each year of the experiment. A spreadsheet-based economic model was constructed in Excel® (Microsoft, Washington, USA). Results are presented for financial years (i.e., 1 June–31 May). The following sections describe the methodologies and assumptions used to calculate farmlet gross revenue, dairy operating expenses and capital costs for each year, as well as the assumptions used to provide biophysical data for the first four months of Y1 and the final four months of Y3, that were not recorded as part of the biophysical experiment. Farmlet profit for each year was calculated as the gross revenue minus dairy operating expenses and capital costs specific to that year (i.e., effluent infrastructure and additional processing company shares).

3.6.1 Methodology for calculating gross farmlet revenue

Income from milk sales, cull cow sales, bobby calf sales, and dividends were able to be calculated based on the biophysical performance of each farmlet for Y1 and Y2. Gross revenue was the sum of these four income sources. As the biophysical performance during the last four months of Y3 (February–May) was not recorded in this experiment because of the timeline, income received in these four months was estimated, and is detailed further in section 3.6.1.2.

3.6.1.1 Calculations of farmlet revenue during the experimental period

Farmlet milk revenue was calculated according to the farmgate milk pricing structure employed by the Fonterra Cooperative Group, NZ, on the 'A + B − C' basis, where A and B are the monetary values per kilogram of fat and protein, and C is the penalty per litre of milk volume (Sneddon et al., 2013). Fonterra processes 84% of the raw milk in NZ (MBIE, 2017), and has been the dominant company in the NZ dairy industry (Woodford, 2008), hence, Fonterra pricing was used in this analysis. Other NZ processing companies employ their own variation of the 'A + B − C' pricing structure (Sneddon et al., 2013), and most offer a winter milk premium, therefore, the milk pricing presented in this analysis is also relevant to farmers supplying milk to processing companies other than Fonterra.

Total farmlet fat and protein production, and the fat and protein percentage of milk, were allocated to each month of lactation based on herd test data. A milk price of $6.42/kg MS was assumed, based on the 14-year, average farmgate milk price (Interest, 2020), adjusted for inflation. Monetary values of fat ($/kg fat) and protein ($/kg protein) were calculated from the farmgate milk price and the Valued Component Ratio (VCR), a ratio comparing the value of fat with the value of protein within the milk price. A VCR of 1.3 was chosen, which was the actual VCR in the 2018/19 season (Fonterra, personal communication, January 15, 2020).

The penalty per litre of milk volume included both a 'seasonal' charge and a 'peak' charge, incurred in every month of supply and during September–December (inclusive), respectively. The seasonal charge was calculated monthly in Equation 2, where MS% was the sum of the fat% and protein%, the Fonterra MS% was 8.92%, the litre charge was $0.0275/L, and $litres_m$ was the total litres produced in each month.

$$Seasonal\ charge_m = \frac{Farmlet\ MS\% - Fonterra\ MS\%}{Fonterra\ MS\%} \times litre\ charge\ \times litres_m \qquad 2$$

The peak charge was calculated monthly in Equation 3 for the peak months of supply (September–December, inclusive), where the Fonterra MS% was 8.55%, and the litre $charge_{peak}$ was $0.0127/L.

$$Peak\ charge_{m(Sep-Dec)} = \left(\frac{Farmlet\ MS\%_{peak} - Fonterra\ MS\%_{peak}}{Fonterra\ MS\%_{peak}}\right) \times litre\ charge_{peak}\ \times litres_{m(Sep-Dec)} \qquad 3$$

To recognise the cost of transporting and processing milk from farms with a relatively higher peak milk supply, Fonterra pays a 'capacity adjustment' during months of non-peak milk supply (i.e., June-August, and January-May), which aims to provide an equitable distribution of costs across all of their farmer suppliers (P. Johnson, Fonterra, personal communication February 13, 2020). A capacity adjustment of $0.61/kg MS was included for MS produced during June–August and January–May. All preceding Fonterra MS%, litre charges and capacity adjustment values were from the 2018/19 season (Fonterra, personal communication, January 15, 2020).

The AUT farmlet received a premium for milk produced during winter but the SPR farmlet did not. For farmers with a contract, Fonterra pays a winter milk premium for MS produced during 16–31 May ($2.85/kg MS), 1–30 June ($3.50/kg MS), and 1–15 July ($2.85/kg MS), in the North Island. Due to the nature of the data, MS production in the current experiment could not be calculated for parts of months, hence a winter milk premium was calculated at a rate of $2.85/kg MS for 50% of the MS produced during May, $3.50/kg MS for 100% of the MS produced during June, and $2.85/kg MS for 50% of the MS produced during July. A transport charge of $0.025/kg MS per 10 km band in straight-line distance to the processing factory (139 km; Longburn, Manawatu, NZ) was included, and totalled $0.35/kg MS. Final monthly milk income was calculated as the income from fat and protein, capacity adjustment, and winter milk premium, minus the seasonal and peak volume charges, and transport charge.

Certain NZ milk-processing companies, including Fonterra, require farmers to be supplier shareholders in the company, based on the quantity of milk they supply. Although this requires capital investment if milk production increases, company dividends can contribute to gross revenue. It was assumed that both farmlets owned 130,000 shares that received a $0.30/share dividend each year, based on the 14-year inflation-adjusted average Fonterra dividend (Interest, 2020). Due to an increase in milk production in Y3 and Y4, it was assumed that the AUT farmlet required 30,000 additional shares. Purchase of the additional shares was assumed to occur in Y3 (described further in section 3.6.2.1), and additional dividend income from those shares was first realised in Y4. The source of funding for the purchase of additional shares, and other capital expenses described in the following sections, are not specified as it does not affect the NPV analysis.

Actual cull cow information (e.g., kill sheets or invoices) was not available for each farmlet, so the number and month of cull cow sales was approximated from when individual cows were removed from the animal recording software system (MINDA®, LIC). Although this approximation meant that natural on-farm deaths were included as cull cow sales, temporal data on deaths were not available so could not be netted from the cull cow number, and farmlet deaths only differed by two cows during the experimental period, so this did not materially

affect relative cull cow sale income. Cull cows were assumed to have been sold in the month they were removed from MINDA. The average between cow LWT at calving and LWT at drying off in each farmlet for each lactation was assumed as the cow LWT at sale. Carcass weight was assumed as 50% of LWT (i.e., a 50% dressing out percentage; Muir et al., 2008). Carcass weight payments ($/kg) varied by month of sale and were based on industry information (Beef + Lamb NZ) previously published by Spaans et al. (2019): June = $3.14, July = $3.25, August = $3.34, September = $3.35, October = $3.19, November = $3.08, and December = $3.03, January = $2.92, February = $2.96, March = $2.98, April = $2.94, May = $2.96.

Farm staff recorded calf fate into MINDA, and the total number of bobby calves sold from each farmlet in each lactation was extracted from this database. The proportion of bobby calves sold each month was then assumed as 5%, 30%, 40% and 25% for each month beginning from the month of PSC. Bobby calf LWT was assumed as 32 kg (Hickson et al., 2015), their dressing out percentage as 50% (Muir et al., 2008), and the carcass weight payment as $2.00/kg (Askin & Askin, 2018). No premium or discount was applied to autumn-calving cull cows or autumn-born calves relative to spring-calving cull cows and spring-born calves, which is the same approach as used by Chikazhe et al. (2017).

3.6.1.2 Assumptions for revenue received during the last four months of year three

Fat and protein quantities, and milk fat and protein percentages, calculated from daily bulk milk collection, from both farmlets after the period analysed in the biophysical section were provided by farm staff (D. McCallum, personal communication, April 29, 2020). This guided estimates for production in February–April for both farmlets (SPR farmlet herd dried off at the end of April). Milksolids production in May Y3 for the AUT farmlet was assumed as 90% of the AUT farmlet May Y2 production. This percentage was chosen because the biophysical results indicated that undertaking the extended lactation meant that AUT farmlet cows had greater BCS prior to May Y2 than if they had been in a steady-state autumn-calving pattern. Thus, MS production in May Y3 would be reduced relative to May Y2 because less BCS would be available to convert to MS production in early lactation.

The number of cull cows sold during February–May in the SPR farmlet was assumed as the average of the same months in Y1 and Y2. In the AUT farmlet it was assumed that two cows were sold in March and April, and four cows were sold in May, similar to Y2. Cull cow LWT in Y3 was calculated by the same method used in Y1 and Y2 (see section 3.6.1.1). No assumption for bobby calves was required for the SPR farmlet because no bobby calves were sold during

February–May in the spring-calving system. Bobby calves sold in the AUT farmlet in each month were assumed to be the same as the number sold in Y2.

3.6.2 Methodology for calculating expense items

Wherever itemised expenses could be separated between farmlets, based on biophysical results, these data were directly allocated to that farmlet, and are further described in section 3.6.2.1. Where itemised expenses could not be separated, due to the commercial accounting system of the research farm, calculations based on industry data were used instead, and are further described in section 3.6.2.2. Expenses were split into two categories. Dairy operating expenses were defined as those expenses used in the day-to-day management of the farm, and capital expenses were defined as the one-off expenses for the farm. Depreciation, although not a cash expense, was included in the analysis, as it served as a proxy for capital replacement of assets. As supplementary feed offered to the farmlets between 1 June and 1 October 2017 was not recorded by farm staff, the cost of this supplementary feed was estimated, and is detailed further in section 3.6.2.1.

3.6.2.1 Dairy operating expenses calculated from biophysical results

Unit costs of itemised expenses that were able to be calculated from biophysical results are described in Table 3.10. Further description of some of these expenses are detailed in Appendix A and Appendix C. The cost of fertiliser was assumed to apply to the year it was spread on the farmlet. The 23-month to 29-month (post-heifer) grazing cost refers to the extended time that replacement heifers in the AUT farmlet were required to stay on agistment, because their grazing period occurred during the extended lactation. As described in section 3.4.2.2, supplementary feed offered prior to the establishment of the farmlet herds on 1 October 2017 (i.e., between 1 June 2017 to 30 September 2017) was not recorded by farm staff and was unable to be presented in the biophysical results. However, for this economic analysis, an assumption was made as to the quantity of this supplementary feed so that expenses were able to be compared between years. It was assumed that any pasture silage, hay, and maize silage that was fed during this period was harvested in the prior year, so their expenses were not included in Y1. It was assumed that the average of the PKE and meal offered to the SPR farmlet during June–September of Y2 and Y3 was offered equally to both the AUT and SPR farmlets during Y1, and this totalled 9,821 kg DM and 23,956 kg DM of PKE and meal, respectively. The additional cost of the PKE and meal was assumed to have occurred during Y1.

Table 3.10. Assumed unit cost for itemised expenses that were able to be calculated from the biophysical results and their source.

Item	Cost	Unit	Source
Urea	580	$/ton	Ravensdown (2020)
Di-ammonium sulphate	800	$/ton	
Ammonium sulphate	460	$/ton	
Potassium chloride	720	$/ton	
20% potash super	410	$/ton	
30% potash super	450	$/ton	
Sodium selenate	5000	$/ton	J. Sabine (personal communication, April 14, 2020)
Gibberellic acid	42	$/ha applied	DairyNZ (2011)
Homemade silage	0.18	$/kg DM	See Appendix A
Homemade hay	0.07	$/kg DM	
Imported silage	0.56	$/kg DM	
Imported hay	0.40	$/kg DM	
Imported maize silage	0.35	$/kg DM	Fausett et al. (2015)
Establishment of turnips	438	$/ha cropped	See Appendix A
Establishment of maize	2,713	$/ha cropped	
PKE	280	$/ton DM	McCahon (2019)
Meal	600	$/ton DM	Macdonald et al. (2017)
4-months to 10-months old (yearling) grazing	12.50	$/animal/week	J. Gunivin (personal communication, April 14, 2020)
11-month to 22-months old (heifer) grazing	12.50	$/animal/week	
23-month to 29-months old (post-heifer) grazing	12.50	$/animal/week	
Additional depreciation cost for effluent	43	$/ha	Journeaux & Newman (2015); MacDonald et al. (2015)

3.6.2.2 Dairy operating expenses estimated from industry data

The research farm operated as a single commercial entity, without complete separation of costs by farmlet. Therefore, the expense items that were unable to be separated (listed in Table 3.11) were based on the apportioning of costs based on values extracted from DairyBase, a voluntary database of individual farm physical and financial accounts (Shadbolt, 2009). A group of physical and financial accounts from owner-operator South Taranaki dairy farms during the three most recent seasons (2016/17–2018/19) was extracted from DairyBase. The data contained farms that produced milk during winter, although season of calving was unknown. Outlier farms, based on SR, were removed, providing a group of 113 farms. Average per ha and per cow costs for each itemised expense were calculated and are provided in Appendix C.

Previous research methodology has allocated per cow and per ha proportions to each expense item to calculate a total per ha cost when SR and supplementary feed use have differed between farmlets (Macdonald et al., 2011; Macdonald et al., 2017; McCahon, 2019; Spaans et al., 2019). As this current experiment investigated a change to calving season that required an extended lactation, the approach of the previous authors was expanded to include ‘per days milking’, ‘per

cow days milking', and 'per ton of imported supplementary feed' as additional proportion categories, to account for differences in the length of lactations and supplementary feed use between farmlets. Briefly, per days milking is the number of days between PSC and drying off within the financial year and was assumed to be 300 days in the extracted data. Per cow days milking is the SR multiplied by per days milking. Per ton of imported supplementary feed is the quantity of supplementary feed per cow (t DM/cow) imported onto the milking platform and averaged 0.92 t DM/cow in the extracted data. Individual expense proportions are detailed in Appendix C.

Economic values for per days milking, per cow days milking, and per ton of imported supplementary feed were calculated for each expense by dividing the per ha value by the respective unit. Farmlet and lactation-specific SR, days milking, and net imported supplements per cow units were then multiplied by the economic value for each proportion category. This was then multiplied by the proportion to calculate total per ha cost for each expense.

Table 3.11. List of expense items that were calculated from values extracted from a commercial database (DairyBase; Shadbolt, 2009).

Category	Expense item
Labour expenses	Labour
Stock expenses	Animal health
	Breeding and herd improvement
	Farm dairy
	Electricity
Supplement expenses	Calf rearing, excluding labour
Other farm working expenses	Regrassing
	Weed and pests
	Vehicles
	Fuel and oil
	Repairs and maintenance — plant
	Repairs and maintenance — land
	Freight
Administration	Administration
	Insurance
	ACC
	Rates
	Depreciation

An alternative approach was considered, that served to validate the approach and data described previously. Eight multiple regression models, with different combinations of SR, t DM of supplementary feed imported per cow, and cost of supplementary feed per cow as predictors, were applied to a group of physical and financial accounts from 191 owner-operator dairy farms for the 2015/16–2017/18 seasons from a similar region, extracted from DairyBase. Itemised

expenses ($/ha) were then calculated using farmlet-specific predictor values substituted into the models.

3.6.2.3 Expense assumptions for the final four months of year three

To account for supplementary feed offered during the final four months of Y3, it was assumed that the AUT farmlet fed an additional 60,000 kg DM of maize silage and 30,000 kg DM of PKE, while the SPR fed an additional 10,000 kg DM of meal, which was extrapolated from previous years' data. Both farmlets were also assumed to have applied an additional 4,000 kg of 20% potash super fertiliser, again, extrapolated from previous years' data.

3.6.2.4 Capital expenses

Autumn-calving dairy systems have been identified as requiring greater effluent storage and spreading infrastructure compared with spring-calving systems, due to the winter peak rainfall coinciding with peak effluent volume (Chikazhe et al., 2017; Spaans et al., 2019). In addition, the Fonterra winter milk premium contract stipulates that suppliers must have "adequate effluent storage capacity so that effluent irrigation to pasture can be deferred during rainfall and when soils are saturated" (Fonterra, 2018, p. 5). Hence, it was assumed that the AUT farmlet required capital expenditure on effluent infrastructure to reflect this implication of changing calving season, and it was assumed that the SPR farmlet did not require any change to their effluent system. A capital cost of $718/ha was assumed, based on the survey results from 35 Waikato dairy farmers reported by MacDonald et al. (2015). This capital cost was apportioned to Y1 for the AUT farmlet.

It was also assumed that the capital investment incurred greater depreciation costs, similar to that reported by Spaans et al. (2019). An additional depreciation cost of $43/ha was included for the AUT farmlet in every year (Table 3.10), based on the IRD "Shed & yard" diminishing value rate of 6% (Journeaux & Newman, 2015).

To account for the AUT farmlet requiring additional processing company shares due to an increase in MS production, a capital investment was made in Y3 for 30,000 additional shares in the AUT farmlet. A share price of $6.13/share was assumed, based on the monthly-average Fonterra share price from December 2012–April 2020, adjusted for inflation (Interest, 2020). This one-off $1,755/ha cost was assumed to occur during Y3.

3.6.3 Assumptions used to model year four performance

Farmlet biophysical and economic data during a fourth year (Y4) were required for the NPV analysis (see section 3.6.4). As Y4 corresponded to the 2020/21 dairy season, without any actual results available, total farmlet performance was modelled on historic farmlet performance, assuming both farmlets were maintained in a steady-state 12-month CI pattern.

In the SPR farmlet, prior performance during Y1–Y3 guided estimates of Y4 performance. A weighted average was used, instead of directly averaging all three years, to account for different climatic conditions, and therefore milk production performance, in each year, similar to the approach described by Neal & Cooper (2016). Pasture growth during the 2017/18 season (i.e., Y1) was below the long-term average in South Taranaki for both a sample of farms extracted from DairyBase, and the Waimate West research farm (located 15 km from Kavanagh farm; Figure 3.4). Conversely, pasture growth during the 2018/19 season (i.e., Y2) was greater than the 75th percentile of historic pasture growth in both the DairyBase and Waimate West datasets (Figure 3.5). Yearly pasture growth information was not available at the time of analysis for the 2019/20 season (i.e., Y3), however, the season was considered to be below average because of low rainfall during January–March, with some commercial spring-calving herds drying off earlier than normal (D. McCallum, personal communication, April 28, 2020). As a result, Y1 was weighted 0.2, Y2 weighted 0.6 and Y3 weighted 0.2. This weighting was applied to monthly fat and protein production, total cull cow and bobby calf sales, and expenses calculated from biophysical results (described in section 3.6.2.1). Remaining expenses were calculated as described in section 3.6.2.2.

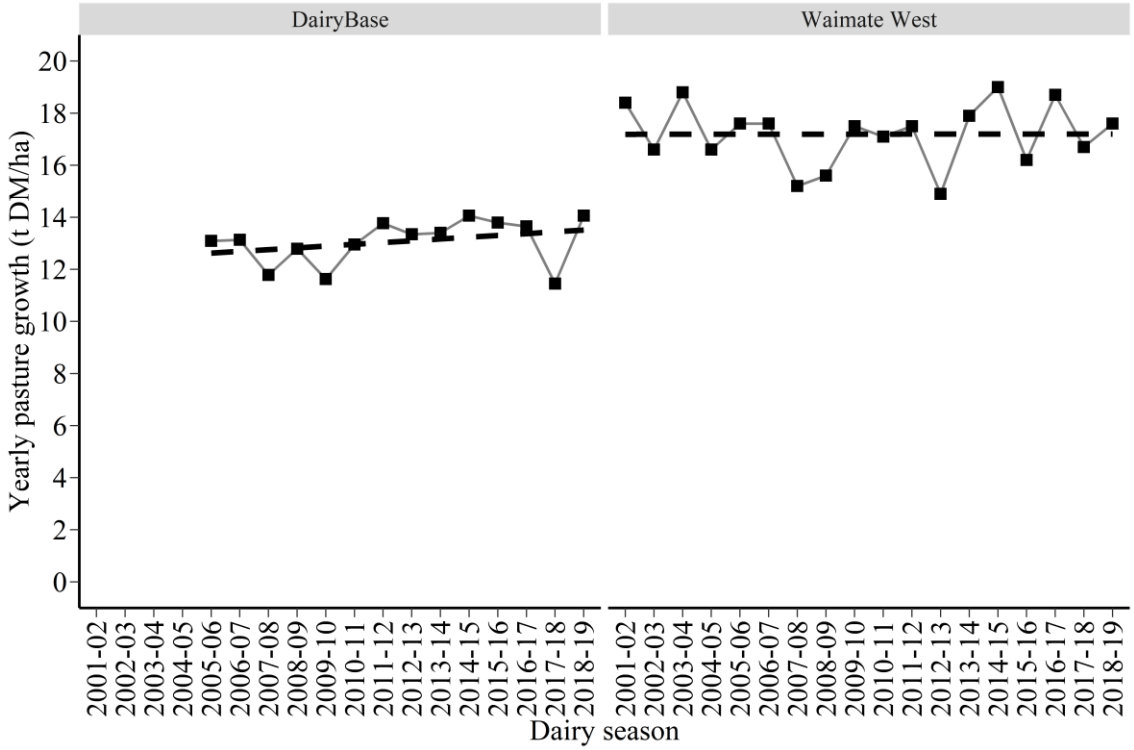

Figure 3.4. Historic yearly pasture growth [■; t dry matter (DM)/ha] extracted from DairyBase (Shadbolt, 2009) for South Taranaki farms (n = 43), and for the Waimate West research farm (located 15 km from Kavanagh farm; J. Clough, personal communication, November 6, 2019). DairyBase is the average of 43 farms present for >6 seasons in the database, and pasture growth is an energetic back calculation from farm milk production. Waimate West pasture growth is calculated from cage cuts (J. Clough, personal communication, November 6, 2019). Dashed line is the linear regression of the yearly pasture growth.

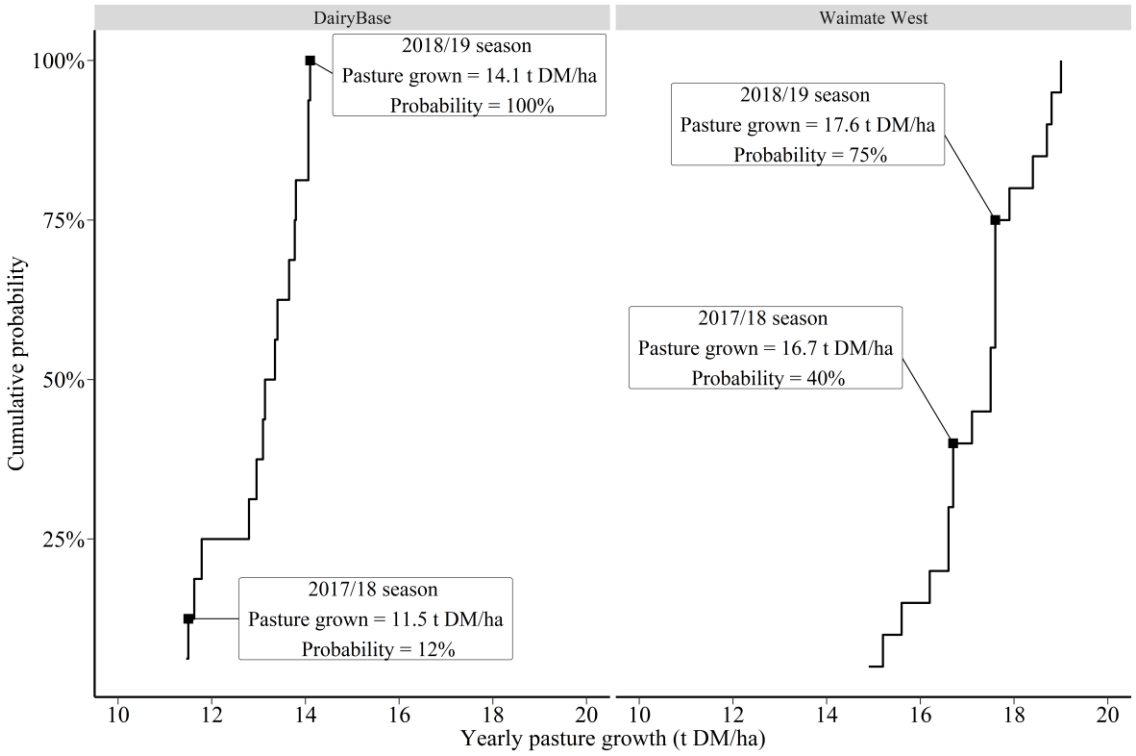

Figure 3.5. Empirical cumulative probability density functions of the average yearly pasture growth [t dry matter (DM)/ha] for the 2005/06–2018/19 seasons for 43 South Taranaki farms extracted from DairyBase (Shadbolt, 2009), and for the 2001/02–2018/19 seasons for the Waimate West research farm (located 15 km from Kavanagh farm; J. Clough, personal communication, November 6, 2019). DairyBase pasture growth is an energetic back calculation from farm milk production. Waimate West pasture growth is calculated from cage cuts (J. Clough, personal communication, November 6, 2019).

In the AUT farmlet, Y1 and Y2 could not be used to model Y4 performance, because the farmlet was undergoing an extended lactation during both these years and was therefore not representative of a steady-state autumn-calving system. Instead, AUT farmlet performance during Y4 was assumed to be the same as Y3, except that the additional shares purchased in Y3 provided additional income as dividends in Y4. Although this approach assumes that performance during one season (i.e., Y3) is representative of performance into the future, there were limited alternatives available to model Y4 performance in the AUT farmlet.[2]

3.6.4 Investment analysis

This thesis considers that a change in calving season is an investment decision as it requires changing the production system of the capital resource (Gardner et al., 2005). Hence, NPV analysis was used as a criterion for investment performance (see section 2.8.1 for a description

[2] Relative differences in yearly pasture growth between DairyBase and the Waimate West research farm presented in Figure 3.4 and Figure 3.5 can be attributed to differences in the methods used to calculate annual pasture growth, differences in management potential between the commercial farms in DairyBase and the research farm, and the pasture growth potential of the farms in DairyBase compared with the Waimate West research farm based on geographical location and soil type.

of NPV). Instead of summing all cash flows and including an initial investment cost in one equation, for this analysis the NPV of each period was calculated separately, and there was no inclusion of an initial investment cost. A series of discounted cash flows were calculated from farmlet profit ($/ha) for a 10-year investment horizon. Ten years was chosen, as previous authors have assessed production and profitability of different calving seasons over a 10-year investment horizon (Myers et al., 2012). For Y1–Y4, nominal cash flow was the farmlet profit. For Y5–Y10, each year's nominal cash flow was assumed to equal that of Y4, effectively making this an annuity. No adjustment was made for inflation as nominal values were used alongside the discount rate. It was assumed that each cash flow was received at the end of that period such that Y1 equalled period 1, etc. The NPV of each cash flow in year zero (Y0) was then calculated in Equation 3, where *i* is the period of the cash flow and *r* is the discount rate. A discount rate of 6% was used, based on the default rate outlined by Treasury NZ (2018), as recommended by Rendel et al. (2015).

$$NPV_i = \frac{Cash\ flow_i}{(1+r)^i} \quad 3$$

The NPV (i.e., discounted cash flow) for each year was cumulatively summed across the investment horizon, so that the cumulative NPV in Y10 represented the total NPV of the investment at Y0.

For a capital investment, such as changing calving season, the decision should be made separate to the finance decision, and so principle and interest repayments were not included in this analysis (Rendel et al., 2015). Furthermore, as taxation implications vary with farm entity structure, tax was also not included in this analysis (Rendel et al., 2015). Cash flow, which included the non-cash depreciation adjustment (which was a proxy for capital asset replacement), formed the basis of this analysis. It was also assumed the farmer already owned the dairy farm, and that both farmlets were worth the same at the end of investment horizon, meaning that including an assumed salvage value would not change the relative NPV difference. Although there was a difference in the value of processing company shares owned by each farmlet at the end of Y10, initial analysis concluded that this difference in value was immaterial once the shares were discounted and presented as a per ha value, thus, this difference was not included in this investment analysis.

3.6.5 Scenario analysis

Initial analysis of farmlet performance identified that both the winter milk premium and the increase in MS production in the AUT farmlet were major factors in the difference in yearly profit and NPV. Chikazhe et al. (2017) identified that winter milk premiums are not guaranteed to remain at current levels. Therefore, the performance of the AUT farmlet in the current experiment should include scenarios where there is a reduced or removed winter milk premium. Furthermore, the milk production assumptions for AUT Y4 are limited to only one season's data (see section 3.6.3), so an overestimation of production may be inflating the relative performance of the AUT farmlet. Thus, different combinations of scenarios were modelled, where the NPV of cash flows for each farmlet was subject to changes to the inputs of the winter milk premium, and for the AUT farmlet, changes in total MS production.

Results are presented where the winter milk premium (see section 3.6.1) in each month (May–July) was as outlined in the base economic model (i.e., no change), either half of the base economic model (i.e., reduced by 50%), or there was no winter milk premium, similar to the method detailed by Chikazhe et al. (2017). To assess a reduction in MS production in the AUT farmlet, two alternative scenarios were modelled.

The first scenario (Scenario 1; S1) assumed that AUT farmlet total MS production in Y4 was the average of MS production in the AUT and SPR farmlets in the base economic model in Y4. As Y5–Y10 was modelled from Y4, this reduction in MS production in Y4 carried forward from Y5 onwards. The second scenario (Scenario 2; S2) assumed that AUT farmlet total MS production in Y4, and so Y5–Y10, was reduced to equal that of the SPR farmlet in Y4. In both scenarios, monthly MS, fat and protein production was back calculated based on the base economic model Y4 monthly proportions of yearly production such that the production profile in S1 and S2 remained the same as the base economic model.

In both S1 and S2 the quantity of additional processing company shares purchased during Y3 was reduced to reflect the reduced MS production in future years. In S1, 15,000 shares were purchased during Y3, compared with 30,000 in the base economic model. In S2, no additional shares were purchased. There was a subsequent reduction in dividend income compared with the base economic model from Y4 onwards in both S1 and S2.

A pro-rata decrease in supplementary feed use in the AUT farmlet was also included, assuming that less energy was required to produce the lower MS in both scenarios[3]. To calculate an approximate decrease in supplementary feed, it was assumed that supplementary feed provided a MMPR of 80 g MS/kg DM, which is in the upper bounds of previously reported MMPR (50–90 g MS/kg DM; Bargo et al., 2003; Macdonald et al., 2017; Roche et al., 2017b). The reduction in MS was multiplied by the MMPR to calculate the total quantity of supplementary feed required to be removed from the AUT farmlet base economic model. Individual supplements were removed in the following order until the correct total quantity remained:

1. Meal
2. Imported maize silage
3. Imported pasture silage
4. Imported hay
5. PKE
6. Homegrown pasture silage
7. Homegrown hay
8. Homegrown maize silage

Individual quantities for Y4 and the two different scenarios are presented in Table 3.12. Although the quantity of homegrown maize silage reduced in S1, the area planted in maize, and so the cost of maize, was assumed to remain the same in both S1 and S2 for simplicity in the model.

Table 3.12. Supplementary feed offered [kg dry matter (DM)] to the AUT farmlet in the sensitivity analysis of the base economic model (Base) in year four. S1 = Scenario 1, AUT farmlet Y4 milksolids (MS) production is the average of the AUT and spring-calving (SPR) Y4 MS production. S2 = Scenario 2, AUT farmlet Y4 MS production is equal to SPR Y4 MS production. Supplementary feed has been pro rata reduced in S1 and S2 assuming a marginal MS response of 80 g MS/kg dry matter (Roche et al., 2017b).

Supplementary feed	Base	S1	S2
Meal	130,220	0	0
Imported maize silage	0	0	0
Imported pasture silage	38,230	0	0
Imported hay	44,400	22,200	0
Palm kernel expeller	30,000	30,000	0
Home grown pasture silage	126,200	126,200	0
Home grown hay	0	0	0
Home grown maize silage	81,667	81,667	61,250

[3] An alternative approach could have been used, in which there was a pro-rata reduction in pasture harvested which would have resulted in a decrease in MS production. This would have meant that total supplementary feed offered remained the same, which may be a more accurate representation of an autumn-calving system. However, this approach was outside the timeframe of the thesis due to the added complexity of calculation.

Chapter 4 Biophysical Results

In justifying their interest in changing to autumn calving, farmers have described observing that winter PGR are increasing and so changing the pasture supply profile on their farm. Hence, to explore this premise and provide broader context to the current farmlet experiment, this chapter begins by first describing historic climatic trends at Kavanagh farm and then describing the biophysical results from the farmlet experiment.

4.1 Climatic trends

A 100-year dataset of rainfall, and a 39-year dataset of other related climatic variables were analysed to identify trends in climatic variables that may influence pasture growth at Kavanagh farm. There were no consistent trends over time with seasonal rainfall, evapotranspiration rates or solar radiation, and there was no detected heteroskedasticity in monthly or yearly rainfall, so these data are not presented.

4.1.1 Daily minimum air temperature

The seasonally-adjusted daily minimum air temperature at Kavanagh farm is presented in Figure 4.1. Over the 39-year timeframe, average daily minimum air temperature increased 1.62°C ±0.01 (±standard error). Residual standard error was 0.39°C.

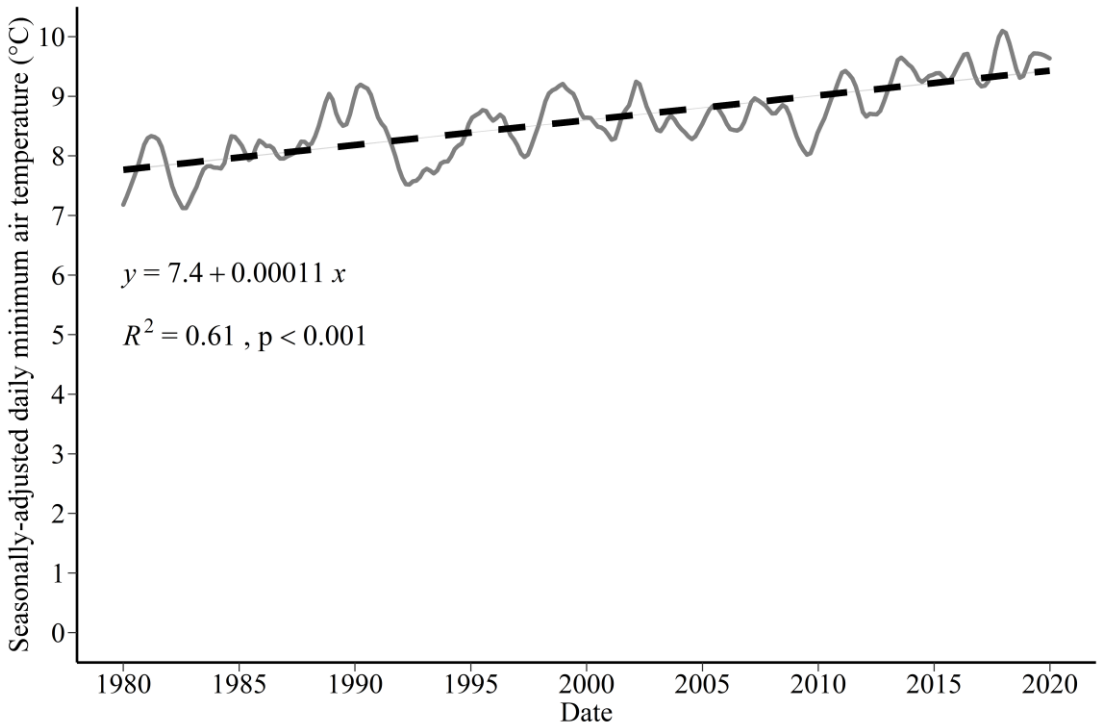

Figure 4.1. Seasonally-adjusted daily minimum air temperature (°C; grey solid line) estimated from Virtual Climate Station Network data, and linear regression line (black dashed line) for Kavanagh farm, South Taranaki, New Zealand. Presented data are the trend after seasonal values have been removed in seasonal decomposition of time series in R (R Core Team, 2020). Displayed equations describe the linear regression line.

4.1.1.1 Winter daily minimum air temperature

Seasonally-adjusted winter daily minimum air temperature at Kavanagh farm is presented in Figure 4.2. During the 39-year timeframe, daily minimum air temperature during winter (June–August, inclusive) increased 1.41°C ±0.03, with a residual standard error of 0.58°C.

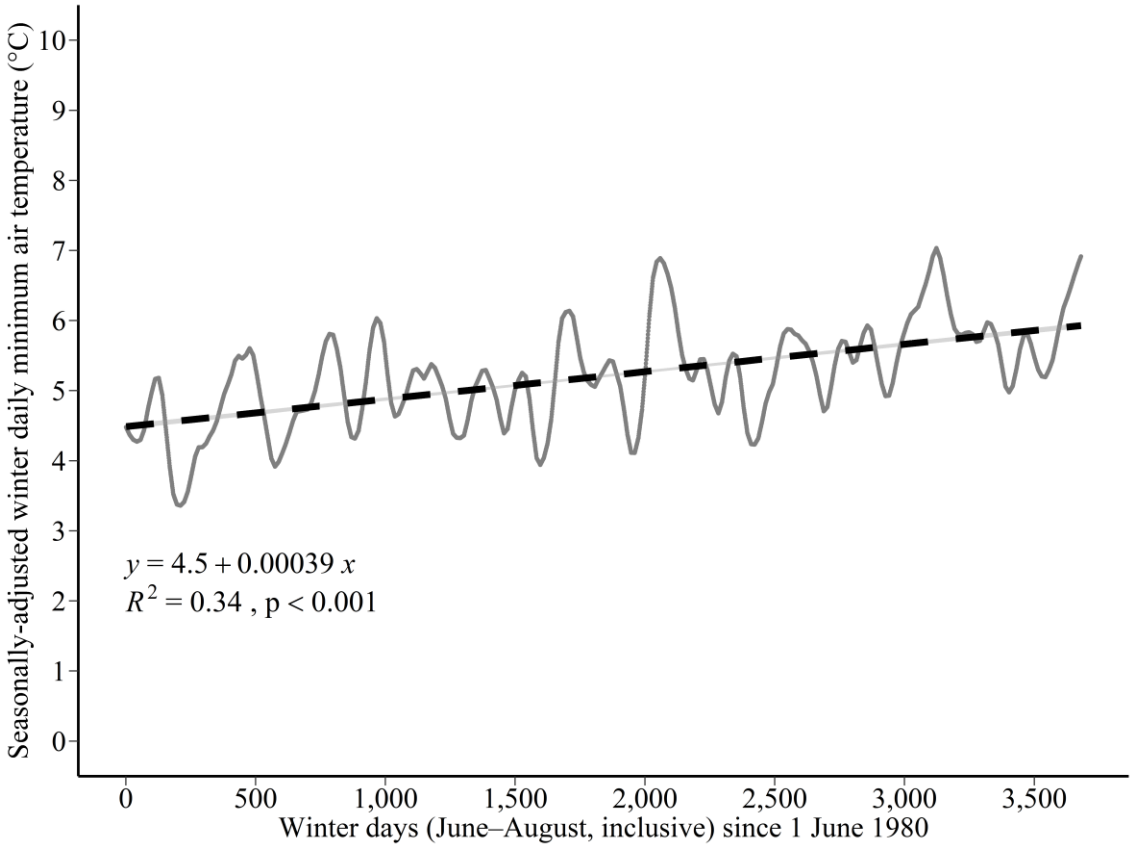

Figure 4.2. Seasonally-adjusted winter daily minimum air temperature (°C; grey solid line) estimated from Virtual Climate Station Network data, and linear regression line (black dashed line) for Kavanagh farm, South Taranaki, New Zealand. Presented data are the trend after seasonal values have been removed in seasonal decomposition of time series in R (R Core Team, 2020). Winter is 1 June–31 August. Displayed equations describe the linear regression line.

4.1.2 Daily maximum air temperature

The seasonally-adjusted daily maximum air temperature at Kavanagh farm is presented in Figure 4.3. During the 39-year time frame, average daily maximum air temperature increased 0.70°C ±0.01. The residual standard error was 0.49°C.

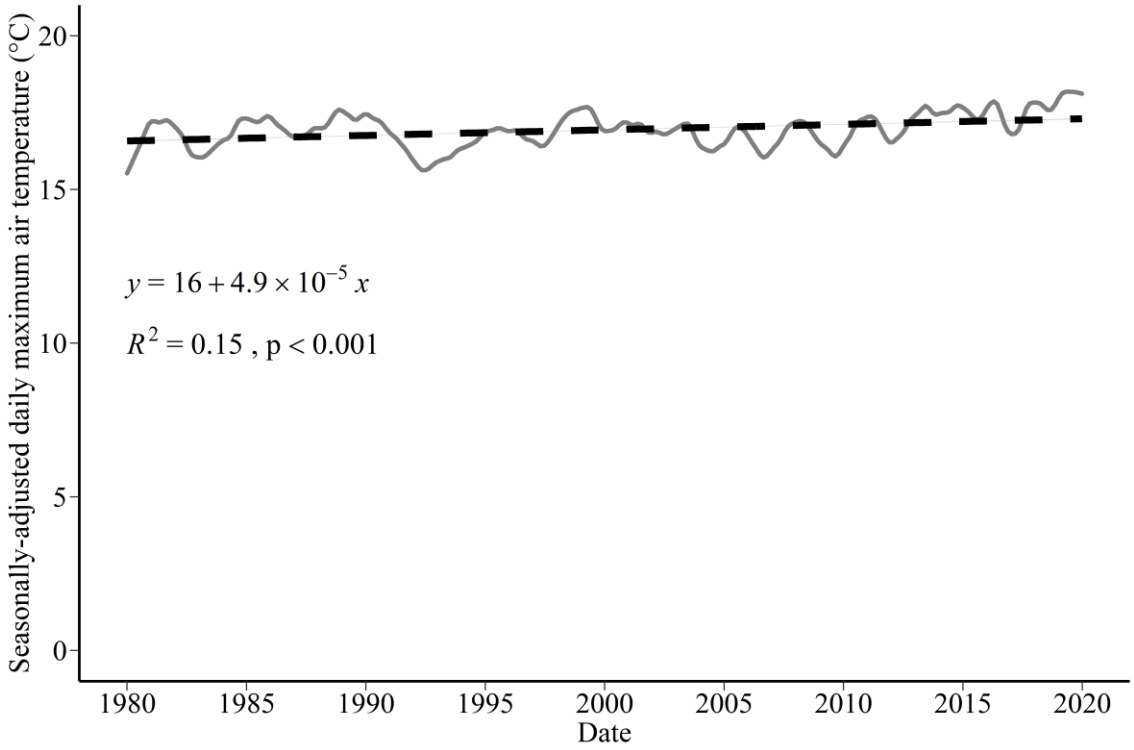

Figure 4.3. Seasonally-adjusted daily maximum air temperature (°C; grey solid line) estimated from Virtual Climate Station Network data, and linear regression line (black dashed line) for Kavanagh farm, South Taranaki, New Zealand. Presented data are the trend after seasonal values have been removed in seasonal decomposition of time series in R (R Core Team, 2020). Displayed equations describe the linear regression line.

4.1.3 Growing degree days

Annual GDD and seasonally-adjusted winter GDD at Kavanagh farm, using a 4°C base temperature, are presented in Figure 4.4 and Figure 4.5, respectively. Annual GDD increased 10.7°C ±2.2 per year between 1980 and 2019, with the linear regression explaining 38% of the variation of the data. During the winter months (1 June–31 August), daily average GDD also increased. Daily GDD in winter increased 1.233°C ±0.003, with a residual standard error of 0.495°C during the 39-year timeframe.

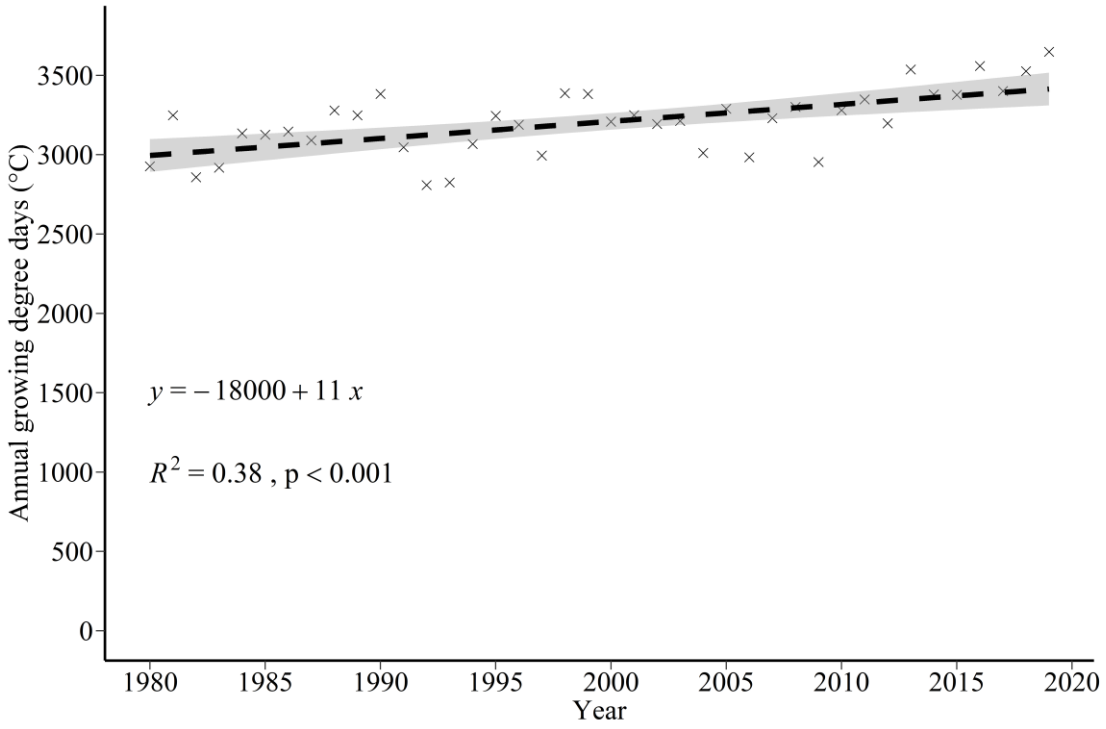

Figure 4.4. Annual growing degree days (×; °C) estimated from Virtual Climate Station Network data and linear regression line (black dashed line) for Kavanagh Farm, South Taranaki, New Zealand, based on a 4°C base temperature (Hutchinson et al., 2000). Displayed equations describe the linear regression line.

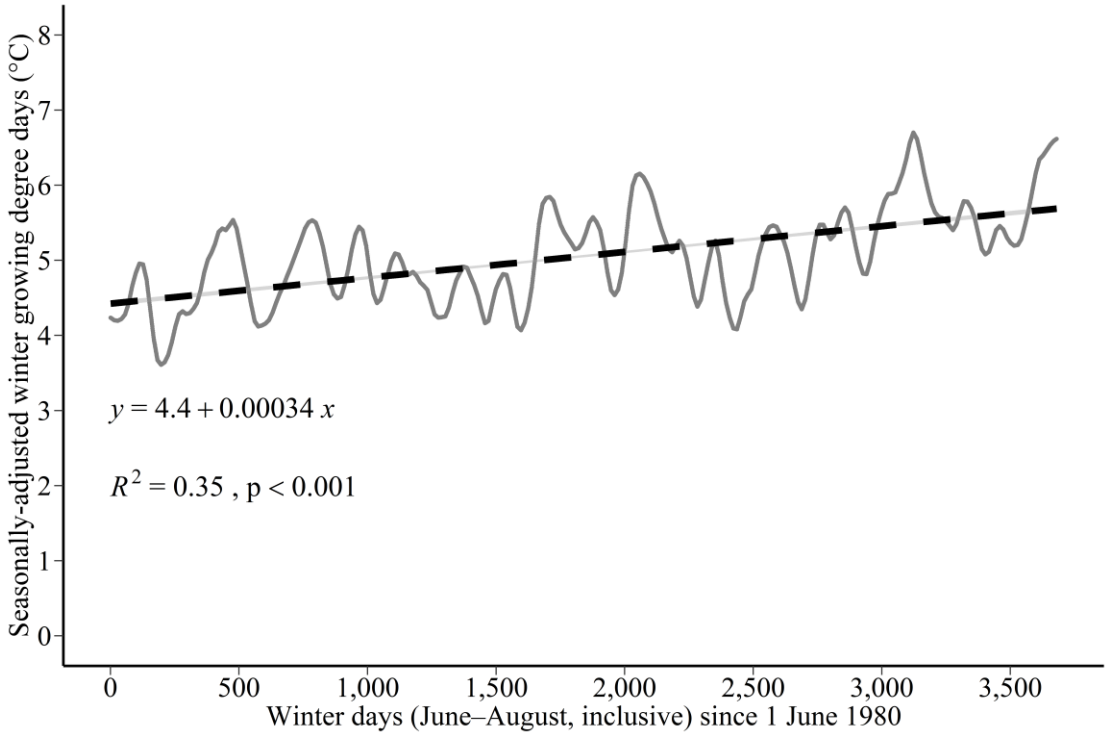

Figure 4.5. Seasonally-adjusted daily growing degree days (grey solid line) estimated from Virtual Climate Station Network data and linear regression line (black dashed line) for Kavanagh Farm, South Taranaki, New Zealand, based on a 4°C base temperature (Hutchinson et al., 2000). Presented data are the trend after seasonal values have been removed in seasonal decomposition of time series in R (R Core Team, 2020). Winter is 1 June–31 August. Displayed equations describe the linear regression line.

4.2 Animal performance

During the experimental period (1 June 2017–31 January 2020) the AUT farmlet herd completed two lactations; one extended lactation when their CI was extended to ~20 months, referred to as L1, and one normal lactation when their CI was 12 months, referred to as L2. Conversely, the SPR farmlet completed two 12-month CI lactations, L1 and L2, and cows were still lactating at the end of the experimental period, so were undergoing a third lactation, referred to as L3. Results presented in this section refer to the respective lactations for each farmlet herd.

4.2.1 Milk production

Milk production variables during the experimental period for each farmlet are presented in Table 4.1. During L1, the AUT farmlet produced greater MS, fat and protein per ha compared with the SPR farmlet (751, 401 and 350 kg/ha, respectively), as would be expected with an extended lactation. Cows in the AUT farmlet had greater DIM ($P < 0.01$) and greater MS per cow ($P < 0.01$), however these cows produced less MS on a daily basis ($P < 0.01$).

Daily MS production profiles (kg MS/cow/day) for each farmlet by DIM and by date of the experimental period are presented in Figure 4.6 and Figure 4.7, respectively. During L1, average daily MS production began to diverge at ~250 DIM between farmlets (Figure 4.6). The AUT farmlet also had a second lactation peak, lower than the first, at approximately 420 DIM. When analysed by date of the experiment, during L1 there were three distinct MS production peaks for the AUT farmlet, compared with two peaks for the SPR farmlet. The first and second MS production peaks for the AUT farmlet align with the first and second peaks of the SPR farmlet. The third production peak for the AUT farmlet, during the later stages of the extended lactation, aligns with the single peak of the SPR farmlet during L2 (Figure 4.7).

During L2, the AUT farmlet produced greater MS, fat and protein per ha (299, 179, 119 kg/ha, respectively) compared with the SPR farmlet (Table 4.1). Cows in the AUT farmlet had 25 DIM more ($P < 0.01$), produced 105 kg MS more ($P < 0.01$) and had a greater daily MS yield ($P < 0.01$), compared with cows in the SPR farmlet. During L2, the temporal profiles for MS production differed between the AUT and SPR farmlets (Figure 4.6). The AUT farmlet had two MS peaks, with the first at approximately 80 DIM and the second at approximately 210 DIM. Conversely, the SPR farmlet had a single MS peak at approximately 50 DIM. When analysed by date, the MS production peak for the AUT farmlet in L2 was less than the SPR farmlet peaks in L2 and L3 (Figure 4.7).

Table 4.1. Average days in milk (DIM; days), milksolids (MS; kg), MS per day (kg/day), fat (kg) and protein (kg) for the autumn-calving (AUT) and spring-calving (SPR) farmlets, displayed by farmlet total (kg), kg per hectare (kg/ha) and kg per cow for lactation one, lactation two, and lactation three. Combined MS, fat and protein from all lactations for each farmlet is presented as the total for the experimental period (1 June 2017 to 31 January 2020). SED = standard error of the difference; "-" = data not applicable.

		AUT	SPR	SED	P value
Lactation one					
Production, kg/farmlet	DIM per cow	488	261	6.5	<0.01
	Peak cows milked	301	301		
	MS	199,003	119,393	-	-
	Fat	108,646	66,156	-	-
	Protein	90,353	53,247	-	-
Production, kg/ha					
	MS	1,899	1,148	-	-
	Fat	1,037	636	-	-
	Protein	862	512	-	-
Production, kg/cow					
	MS	661	395	10.8	<0.01
	MS/day	1.36	1.51	0.02	<0.01
	Fat	361	219	6.1	<0.01
	Protein	300	176	4.9	<0.01
Lactation two					
Production, kg/farmlet	DIM per cow	293	268	3.0	<0.01
	Peak cows milked	306	305		
	MS	163,026	130,680	-	-
	Fat	90,563	71,227	-	-
	Protein	72,463	59,457	-	-
Production, kg/ha					
	MS	1,556	1,257	-	-
	Fat	864	685	-	-
	Protein	691	572	-	-
Production, kg/cow					
	MS	533	428	7.4	<0.01
	MS/day	1.82	1.61	0.02	<0.01
	Fat	296	234	4.2	<0.01
	Protein	237	195	3.4	<0.01
Lactation three					
Production, farmlet	DIM per cow	-	178	-	-
	Peak cows milked	-	310	-	-
	MS	-	108,796	-	-
	Fat		58,748	-	-
	Protein		50,042	-	-
Production, kg/ha					
	MS	-	1,046	-	-
	Fat	-	565	-	-
	Protein	-	481	-	-
Production, kg/cow					
	MS	-	351	-	-
	MS/day	-	1.98	-	-
	Fat	-	190	-	-
	Protein	-	161	-	-

Experimental period					
Production, farmlet	MS	362,028	358,869	-	-
	Fat	199,210	196,131	-	-
	Protein	162,816	162,746	-	-
Production, kg/ha	MS	3,454	3,451	-	-
	Fat	1,901	1,886	-	-
	Protein	1,554	1,565	-	-
Production, kg/cow	MS	1,194	1,174	-	-
	Fat	657	643	-	-
	Protein	537	532	-	-

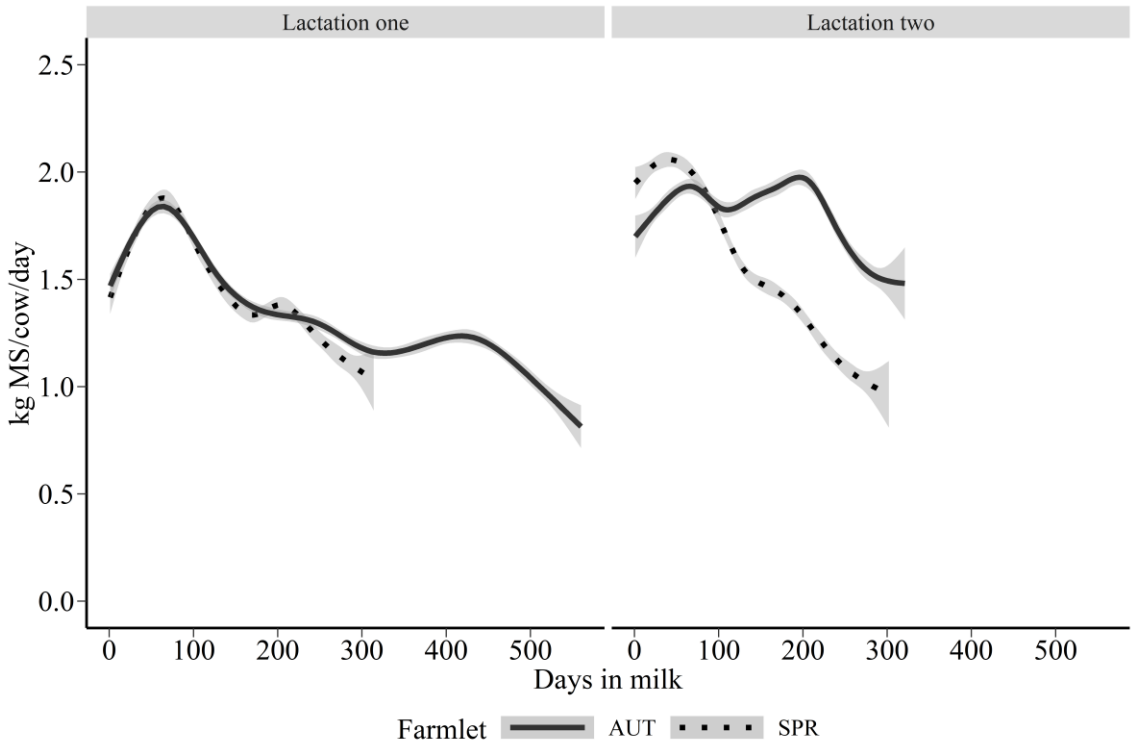

Figure 4.6. Average daily milksolids (MS) production (kg MS/cow/day) by days in milk during lactation one and lactation two for the autumn-calving (AUT) and spring-calving (SPR) farmlets. Grey ribbon indicates the 95% confidence interval.[4]

During L3, SPR farmlet cows were 178 DIM and had produced 351 kg MS to the end of the experimental period (Table 4.1). The milk production profile of the SPR farmlet in L3 was steeper and peaked higher than in L1 and L2 (Figure 4.7).

[4] The *x* axis scale in this figure, as well as the following figures that display days in milk on the *x* axis, has been purposefully set to be the same for both lactation one and lactation two, so that inferences can be made between lactations.

During the entire experimental period (1 June 2017 to 31 January 2020, inclusive) the AUT farmlet produced 1% greater MS (3,159 kg MS; 3 kg MS/ha) than the SPR farmlet, of which 97% was due to greater fat yield (3,079 kg fat; Table 4.1). On average, cows in the AUT farmlet, milked for more days, produced greater MS, fat and protein, and produced less MS per day, compared with cows in the SPR farmlet.

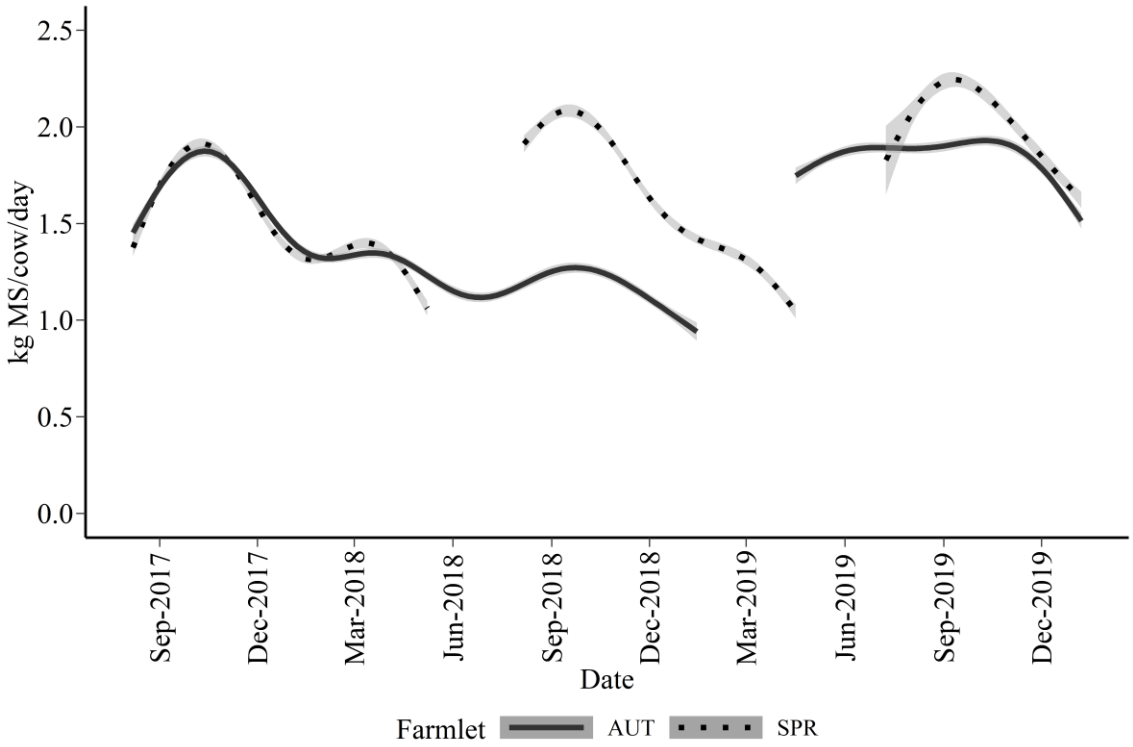

Figure 4.7. Average daily milksolids (MS) production (kg MS/cow/day) during the experimental period (June 2017–January 2020) for the autumn-calving (AUT) and spring-calving (SPR) farmlets. Grey ribbon indicates the 95% confidence interval.

4.2.1.1 Extended lactation performance

On average, AUT farmlet cows had 488 DIM during the extended lactation (L1), however the maximum was 577 DIM (Table 4.2). This meant, on average, cows had a 132-day dry period before PSC of L2, with a minimum dry period of 43 days. Of the total AUT farmlet herd, approximately half were still lactating at final dry off during the extended lactation in L1 (577 days from PSC), with greater than two-thirds of the herd lactating to at least 500 DIM. In comparison, cows in the SPR farmlet were dried off 312 days from PSC during L1 and 300 days from PSC during L2, with 75% and 84% still lactating at final dry off, respectively. Between L1 and L2, and L2 and L3, there was 52 and 64 days between final dry off and PSC in the SPR farmlet, respectively.

Table 4.2. Average days in milk (DIM) performance of the autumn-calving (AUT) farmlet herd during lactation one (L1; extended lactation).

		AUT L1
DIM	Average	488
	Maximum	577
Percentage of the herd still lactating at:	300 DIM	92%
	400 DIM	86%
	500 DIM	67%
	Final dry off	52%

Correlations between MS production, DIM, age, BW and the breed proportion that is HF of AUT farmlet cows undergoing the extended lactation are presented in Figure 4.8. There was a strong positive correlation (0.619, $P < 0.01$) between MS production and DIM during the extended lactation. Breeding worth was weakly positively correlated with MS production (0.245; $P < 0.01$), and tended to be weakly positively correlated with DIM (0.178; $P < 0.05$), while it was weakly negatively correlated with age (-0.223; $P < 0.01$). There was a moderate negative correlation between the proportion of HF and BW (-0.488; $P < 0.01$), but no correlation with MS production or DIM.

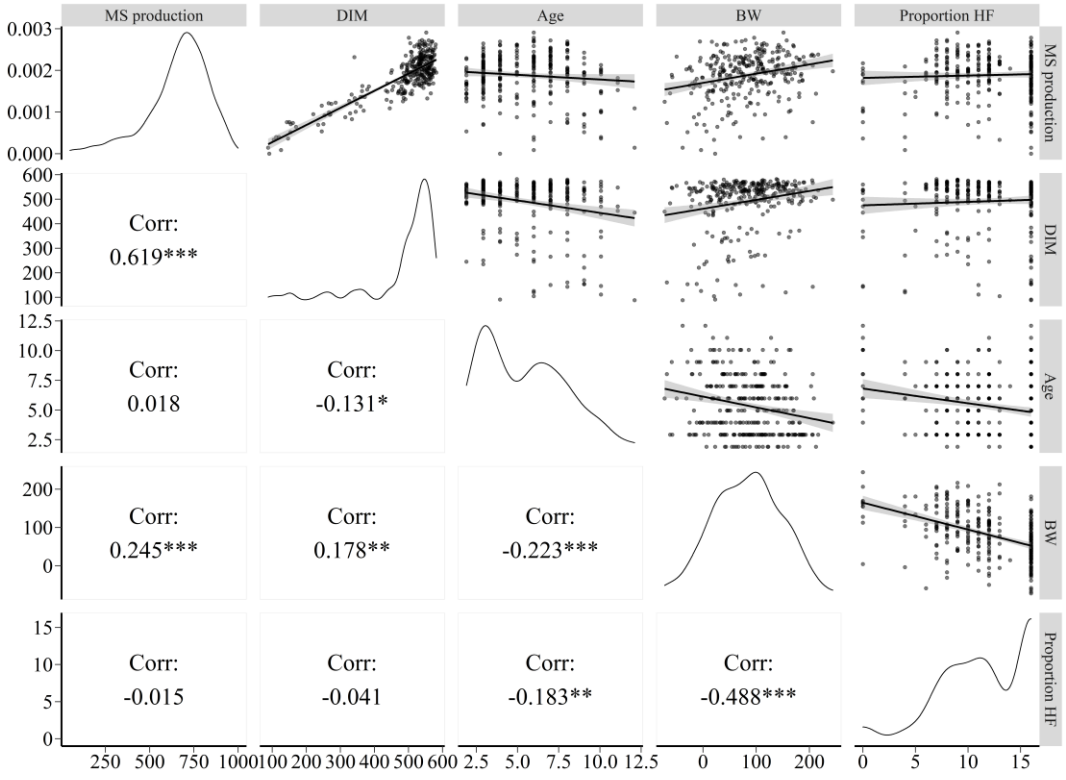

Figure 4.8. Frequency distribution (top left to bottom right diagonal plots), Spearman correlation coefficients ("Corr"; lower left plots), and scatterplots with a linear regression line (top right plots) for the relationships between milksolids (MS) production, days in milk (DIM), age, breeding worth (BW), and breed proportion as parts sixteenth Holstein Friesian (Proportion HF) of the autumn-calving farmlet cows during their extended lactation when changing calving season. * = $P < 0.1$; ** = $P < 0.05$, *** = $P < 0.01$

4.2.1.2 Heifer lactational performance

During L1, heifers in the AUT farmlet had greater DIM and produced greater MS, fat and protein, compared with heifers in the SPR farmlet (all $P < 0.01$; Table 4.3). In L2, AUT farmlet heifers produced greater MS, fat and protein (all $P < 0.01$); however, there was no difference in DIM between farmlets ($P = 0.4$).

Table 4.3. Average days in milk (DIM; days), milksolids (MS), fat and protein production per cow (kg/cow) of primiparous cows (i.e., heifers) in the autumn-calving (AUT) and spring-calving (SPR) farmlet herds during lactation one and lactation two. SED = standard error of the difference.

		AUT	SPR	SED	P value
Lactation one	DIM per cow	508	244	19	<0.01
Production, kg/cow	MS	591	300	31	<0.01
	Fat	317	162	17	<0.01
	Protein	273	137	15	<0.01
Lactation two	DIM per cow	287	280	9	0.4
Production, kg/cow	MS	467	364	12	<0.01
	Fat	256	199	7	<0.01
	Protein	212	165	6	<0.01

4.2.1.3 Fat percentage of milk

The average fat percentage of milk was greater ($P < 0.05$ in both cases) for the AUT farmlet compared with the SPR farmlet during L1 and L2, respectively (Table 4.4). A profile of the average fat percentage of milk produced from the AUT and SPR farmlet herds by DIM and by date is presented in Figure 4.9 and Figure 4.10, respectively. During L1, the fat percentage of milk increased as the lactation progressed for both farmlet herds. In the AUT farmlet, the fat percentage of milk declined between 300 and 400 DIM, and then increased until drying off (Figure 4.9).

Table 4.4. Average fat percentage of milk of autumn-calving (AUT) and spring-calving (SPR) farmlet herds during lactation one, lactation two and lactation three. SED = standard error of the difference; "-" = data not applicable.

	AUT	SPR	SED	P value
Lactation 1	5.21%	5.08%	0.06	0.03
Lactation 2	5.14%	5.04%	0.05	0.04
Lactation 3	-	4.77%	-	-

During L2, the fat percentage of milk profile differed between the two farmlets (Figure 4.9). Compared to the SPR farmlet, the average fat percentage was flatter for the AUT farmlet during L2 and displayed a shorter increase towards the end of lactation. During all three lactations for the SPR farmlet, the average fat percentage of milk declined at the beginning of the lactation and then increased at the end of the lactation (Figure 4.10).

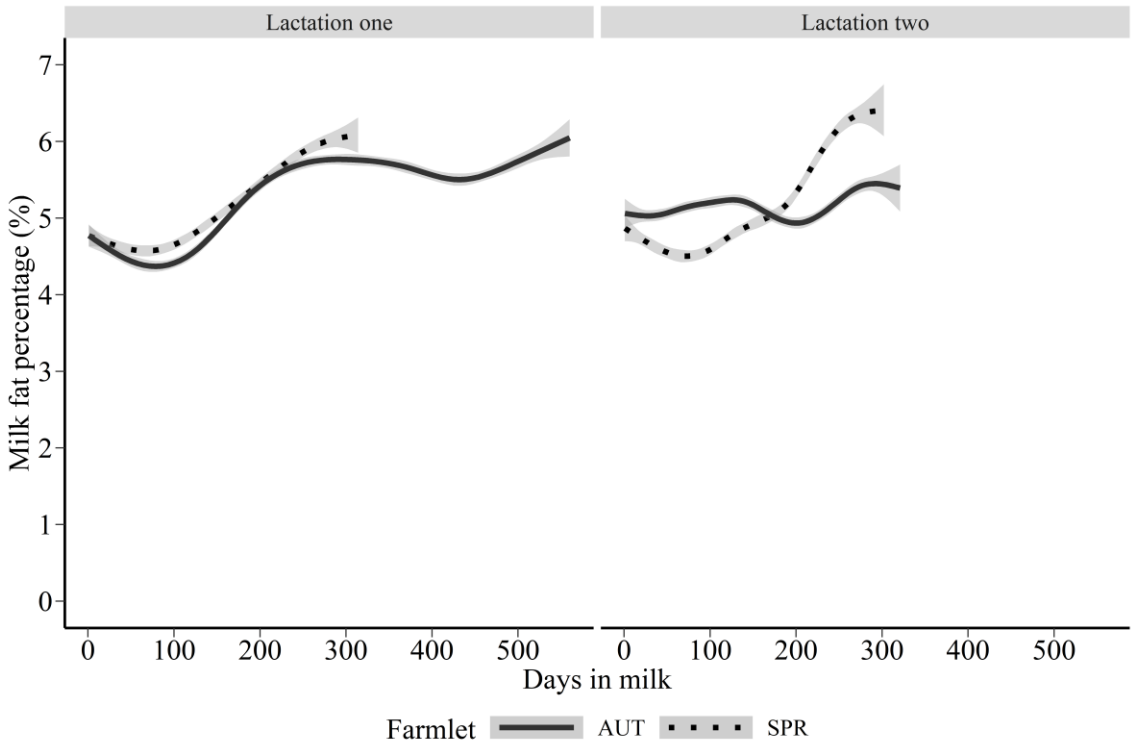

Figure 4.9. Average daily fat percentage of milk produced from the autumn-calving (AUT) and spring-calving (SPR) farmlet herds during lactation one and lactation two by days in milk. Grey ribbon indicates the 95% confidence interval.

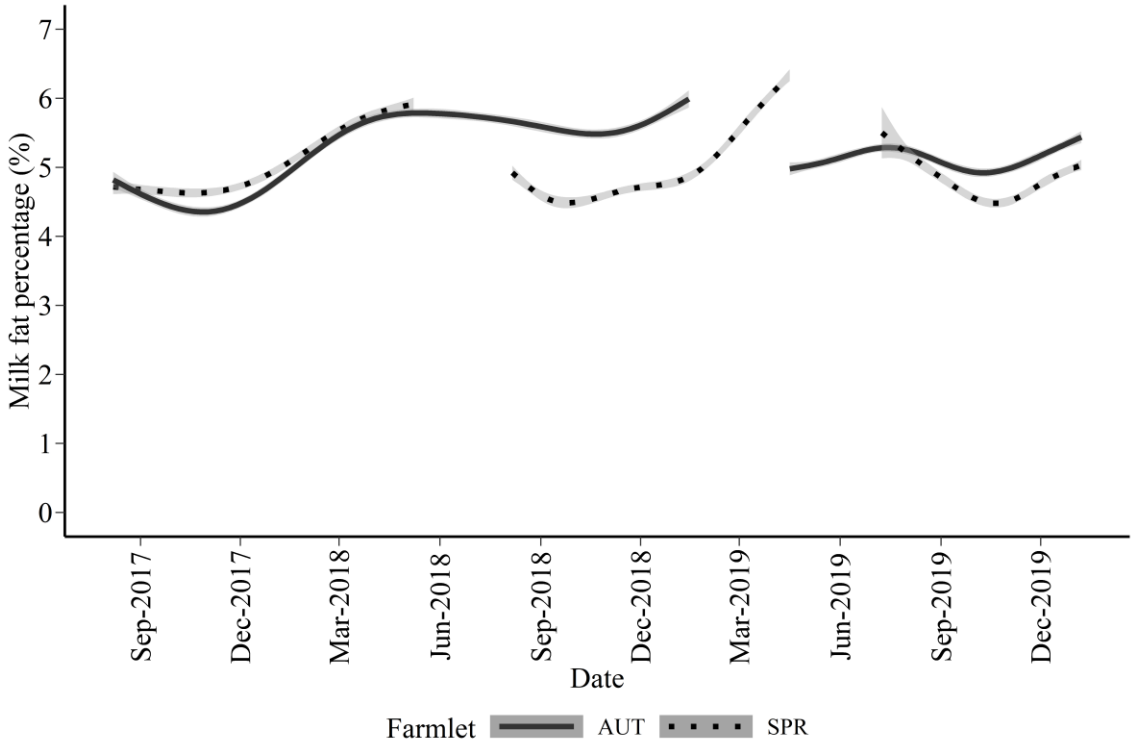

Figure 4.10. Average daily fat percentage of milk produced from the autumn-calving (AUT) and spring-calving (SPR) farmlet herds during the experimental period (June 2017–January 2020). Grey ribbon indicates the 95% confidence interval.

4.2.1.4 Protein percentage of milk

During L1, the average protein percentage of milk was greater ($P < 0.01$) for the AUT farmlet compared with the SPR farmlet, however it was less ($P < 0.05$) during L2 (Table 4.5). The average daily protein percentage of milk produced from the AUT and SPR farmlets by DIM and by date is presented in Figure 4.11 and Figure 4.12, respectively. The protein percentage of milk increased as the lactation progressed for both farmlets in L1 and L2. During L2, the protein percentage of milk diverged at approximately 220 DIM, with the SPR farmlet increasing by more than the AUT farmlet (Figure 4.11). When analysed by date, there was a constant increase in the protein percentage of milk during L2 in the AUT farmlet, whereas in the SPR farmlet the protein percentage of milk increased more rapidly in late lactation during L2 and did not increase in L3.

Table 4.5. Average protein percentage of milk of autumn-calving (AUT) and spring-calving (SPR) farmlet herds during lactation one, lactation two and lactation three. SED = standard error of the difference; "-" = data not applicable.

Protein percentage	AUT	SPR	SED	P value
Lactation 1	4.32%	4.06%	0.03	<0.01
Lactation 2	4.09%	4.15%	0.02	<0.05
Lactation 3	-	4.05%	-	-

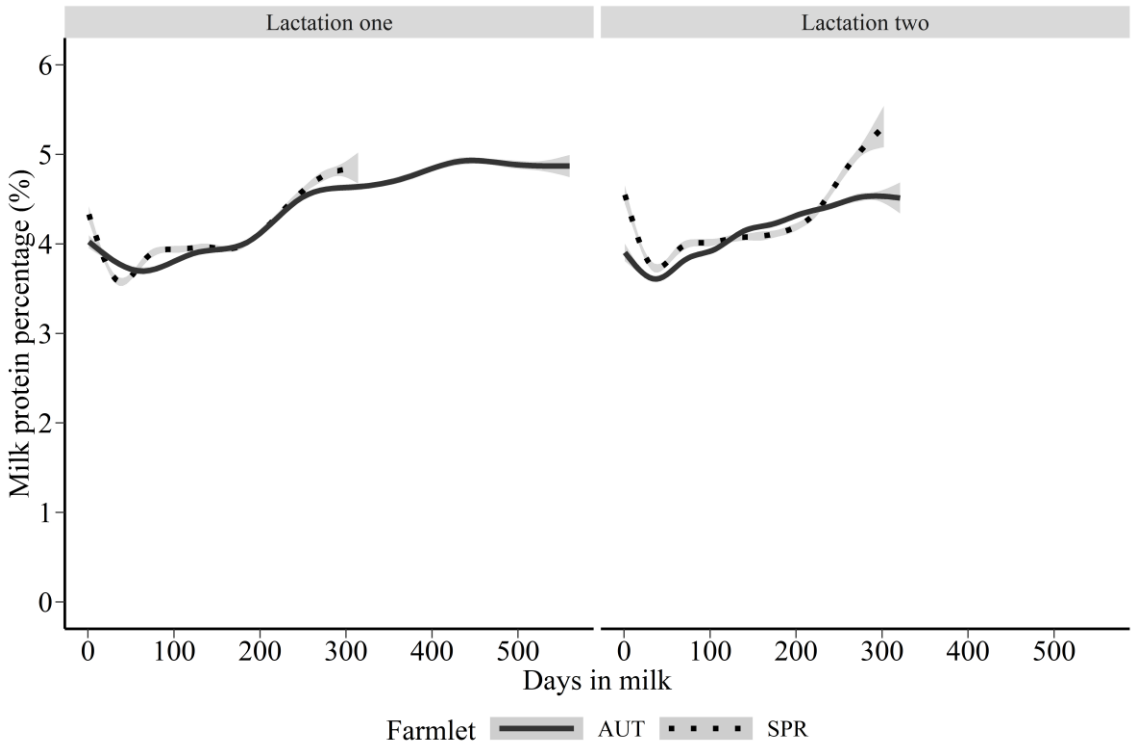

Figure 4.11. Average daily protein percentage of milk produced from the autumn-calving (AUT) and spring-calving (SPR) farmlet herds during lactation one and lactation two by days in milk. Grey ribbon indicates the 95% confidence interval.

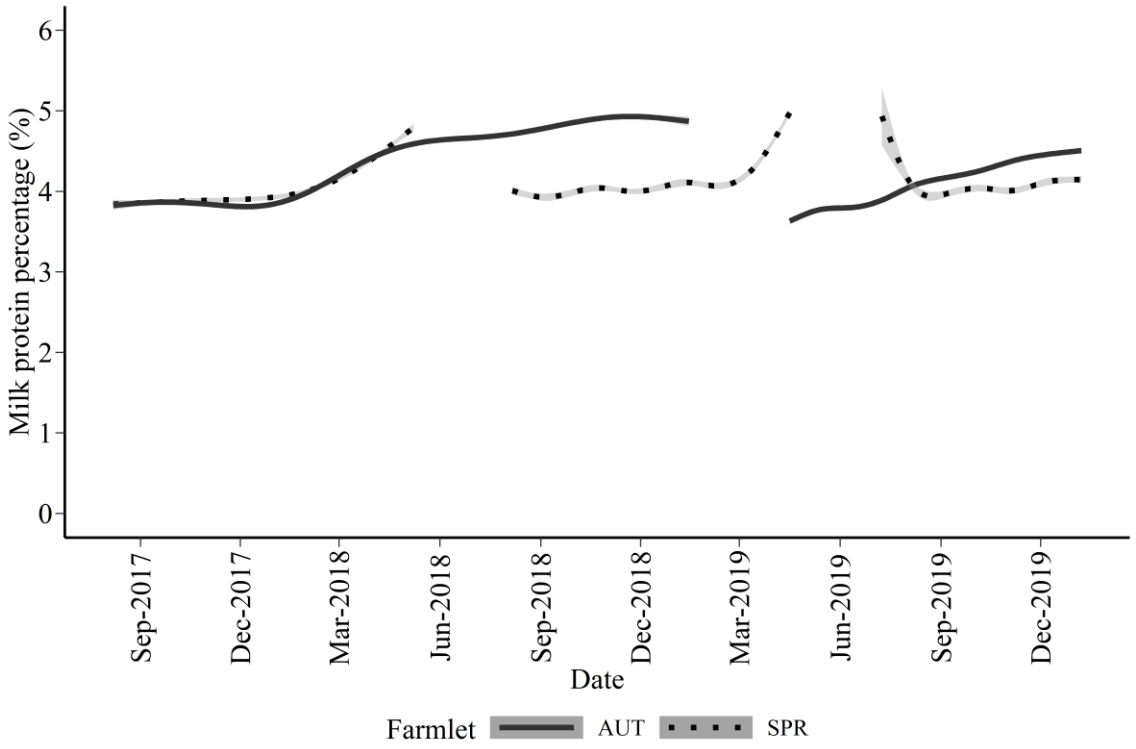

Figure 4.12. Average daily protein percentage of milk produced from the autumn-calving (AUT) and spring-calving (SPR) farmlet herds during the experimental period (June 2017–January 2020). Grey ribbon indicates the 95% confidence interval.

4.2.2 Liveweight

Liveweight and change in LWT for lactating cows in the AUT and SPR farmlets are presented in Table 4.6. Except for the start of L1, when the AUT and SPR farmlet herds were similar LWT, cows in the AUT farmlet herd were heavier at the start of L2, heavier at the time of drying off for both lactations, gained greater LWT and gained LWT at a greater rate, compared with cows in the SPR farmlet herd (all $P < 0.01$). Visual representation of the change in herd LWT by DIM and by date is presented in Figure 4.13 and Figure 4.14, respectively. During L1, the AUT farmlet herd had a greater rate of LWT gain after ~300 DIM (Figure 4.13). At the end of the experiment (31 January 2020), cows in the AUT farmlet herd were heavier than those in the SPR farmlet herd (Figure 4.14).

Table 4.6. Liveweight (LWT, kg) at the start of the lactation[1], drying off[2], change in LWT and daily gain[3] in LWT (kg/day) for autumn-calving (AUT) and spring-calving (SPR) farmlet herds during lactation one and lactation two. Lactation three is presented for the SPR farmlet, with LWT at the end of the experimental period (January 2020) presented instead of at the time of drying off. SED = standard error of the difference; "-" = data not applicable.

		AUT	SPR	SED	P value
Lactation one	Start of lactation	469	461	4.6	0.09
	Drying off	578	497	4.9	<0.01
	Change	109	36	3.4	<0.01
	Daily gain	0.25	0.16	0.01	<0.01
Lactation two	Start of lactation	518	476	5.1	<0.01
	Drying off	573	503	5.1	<0.01
	Change	54	27	2.8	<0.01
	Daily gain	0.20	0.11	0.01	<0.01
Lactation three	Start of lactation	-	485	-	-
	End of experiment	-	495	-	-
	Change	-	9	-	-
	Daily gain	-	0.05	-	-

[1] First recorded LWT post-calving
[2] Last recorded LWT before drying off
[3] Change in LWT divided by the number of days between the first and last recorded LWT

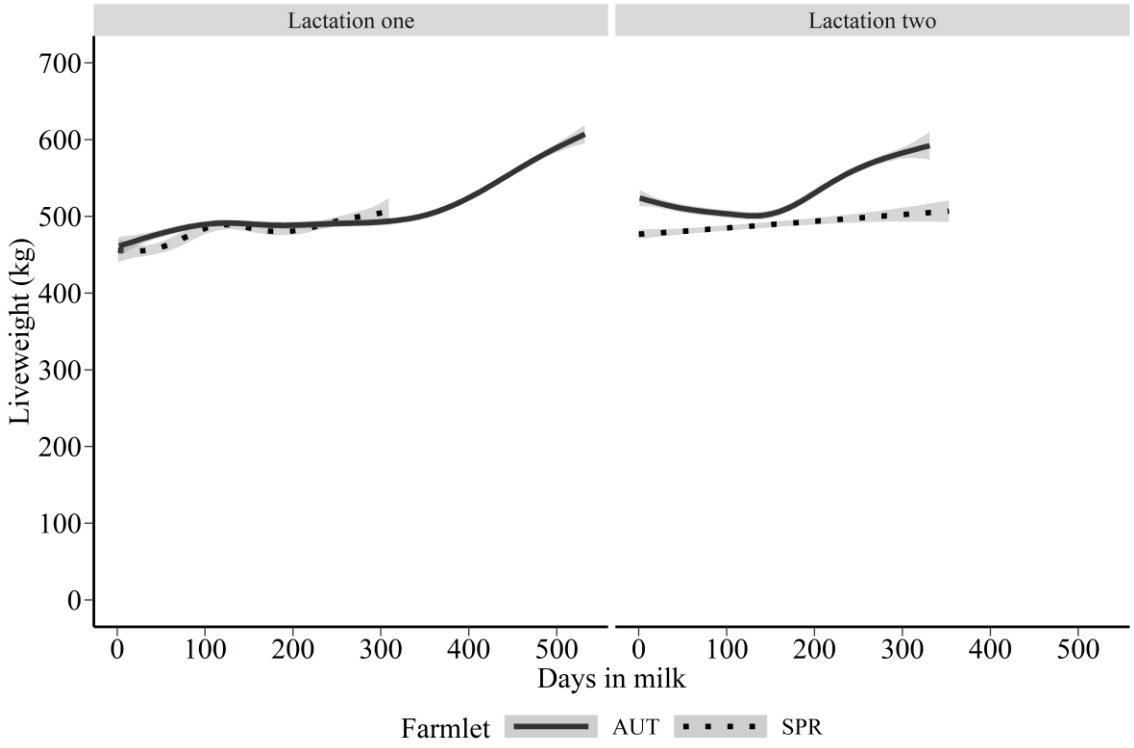

Figure 4.13. Average liveweight (kg) of the lactating autumn-calving (AUT) and spring-calving (SPR) farmlet cows by days in milk during lactation one and lactation two. Grey ribbon indicates the 95% confidence interval.

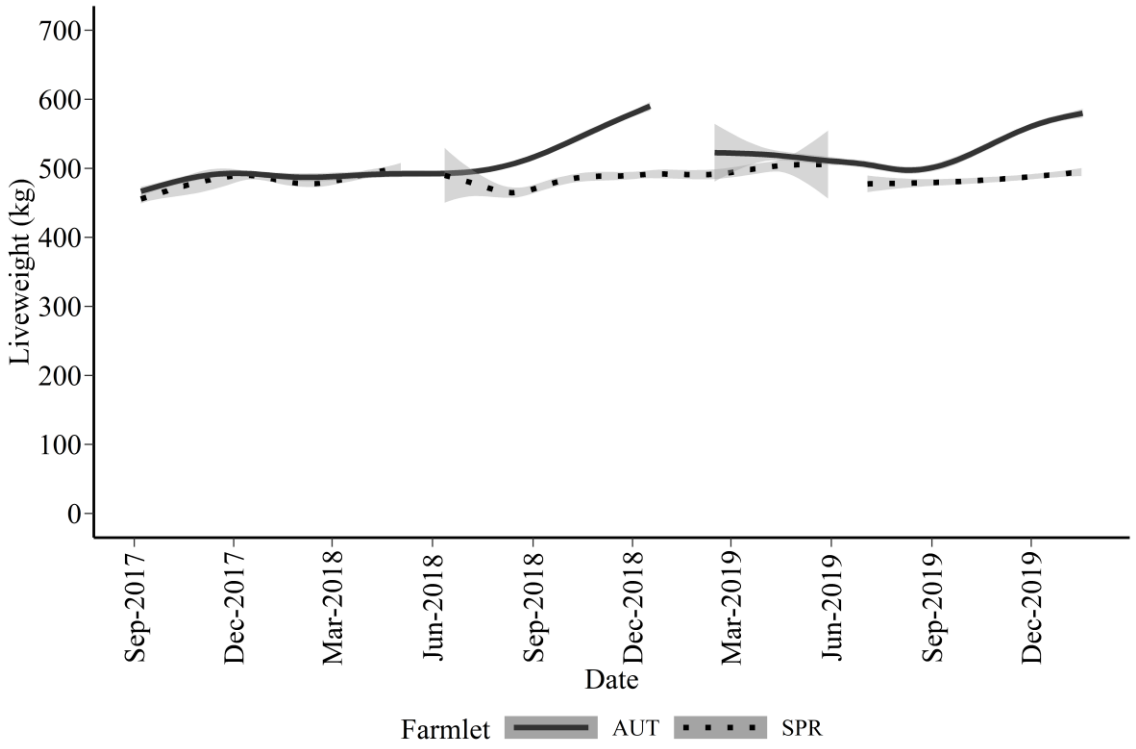

Figure 4.14. Average liveweight (kg) of lactating autumn-calving (AUT) and spring-calving (SPR) farmlet cows by date during the experimental period (June 2017–January 2020). Grey ribbon indicates 95% confidence interval.

4.2.2.1 Heifer liveweight

The LWT of AUT heifers (e.g., primiparous) was similar to that of SPR heifers at the start of L1 (Table 4.7). However, as would be expected with an extended lactation, at the time of drying off in L1, AUT heifers were 23% heavier (99 kg; $P < 0.01$) and had gained LWT at a greater rate compared with SPR heifers ($P < 0.05$). Furthermore, as expected when extending the interval between birth and first calving, AUT heifers started L2 at a heavier LWT ($P < 0.01$), were heavier at the time of drying off ($P < 0.01$) and gained greater total LWT ($P < 0.05$). Daily LWT gain was similar however, between farmlets during L2 ($P = 0.25$). Average LWT of farmlet heifers by DIM and by date is presented in Figure 4.15 and Figure 4.16, respectively. During L1, heifer LWT diverged between farmlets at ~280 DIM (Figure 4.16). Throughout L2, average AUT heifer LWT was greater than SPR heifer LWT (Figure 4.15).

Table 4.7. Liveweight (LWT) at the start of lactation[1], drying off[2], change and daily gain[3] of lactating primiparous cows (i.e., heifers) in the autumn-calving (AUT) and spring-calving (SPR) farmlet herds during lactation, lactation two and lactation three. Lactation three is presented for the SPR farmlet, with LWT at the end of the experimental period (January 2020) presented instead of at the time of drying off. SED = standard error of the difference; "-" = data not applicable.

		AUT	SPR	SED	P value
Lactation one	Start of lactation	404	396	10.7	0.48
	Drying off	539	439	17.0	<0.01
	Change	136	43	12.1	<0.01
	Daily gain	0.30	0.19	0.03	<0.05
Lactation two	Start of lactation	486	399	6.4	<0.01
	Drying off	536	437	7.7	<0.01
	Change	50	37	4.6	<0.05
	Daily gain	0.18	0.16	0.02	0.25
Lactation three	Start of lactation	-	425	-	-
	End of experiment	-	441	-	-
	Change	-	17	-	-
	Daily gain	-	0.11	-	-

[1] First recorded LWT post-calving
[2] Last recorded LWT before drying off
[3] Change in LWT divided by the number of days between the first and last recorded LWT

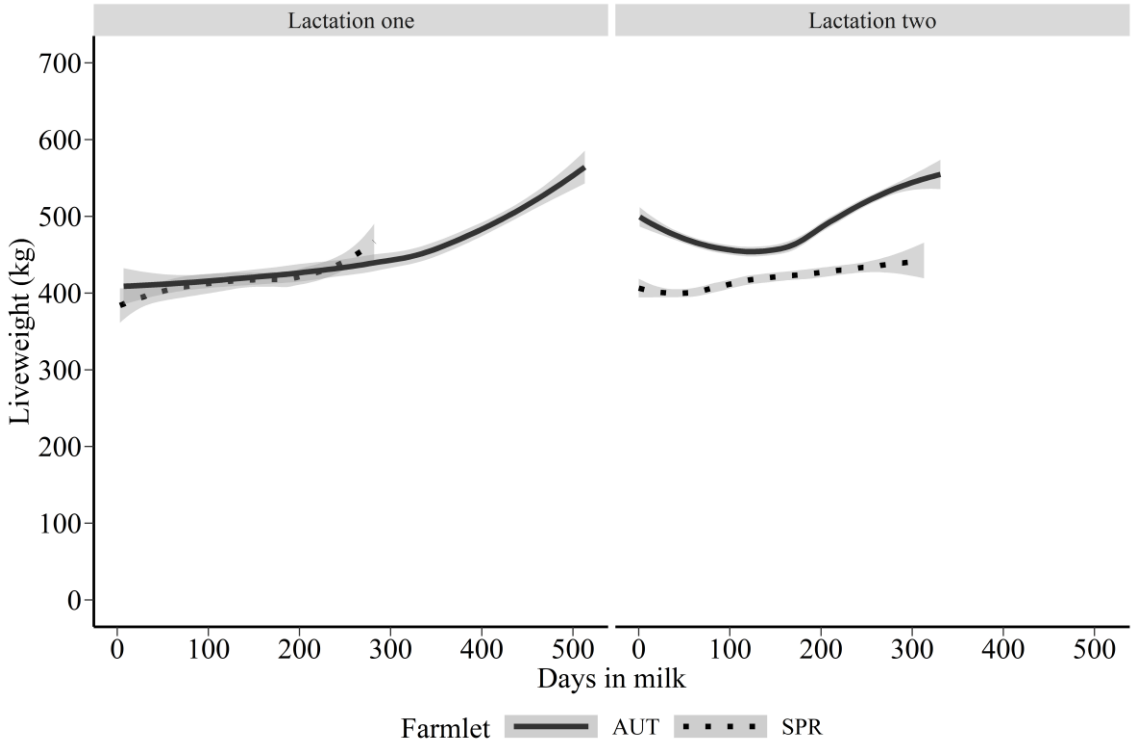

Figure 4.15. Average liveweight (kg) of lactating primiparous cows (i.e., heifers) in the autumn-calving (AUT) and spring-calving (SPR) farmlet herds during lactation one (L1; heifers born in 2015) and lactation two (L2; heifers born in 2016) by days in milk. A different cohort of primiparous cows are represented in L1 and L2. Grey ribbon indicates the 95% confidence interval.

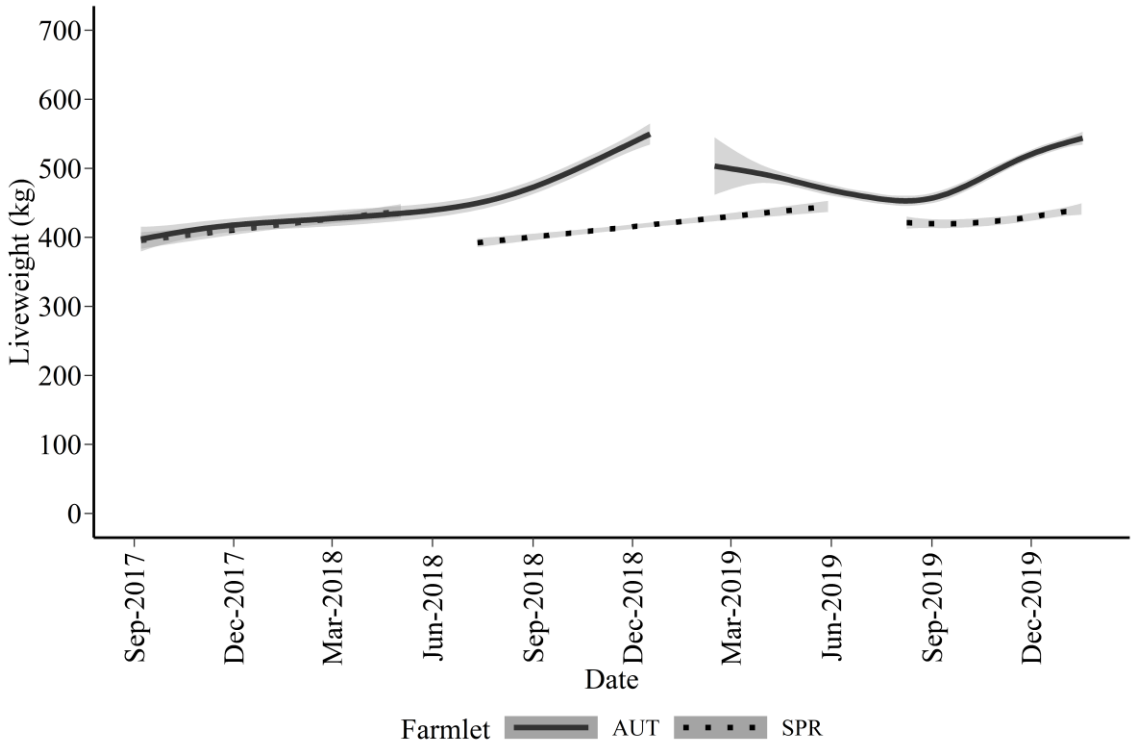

Figure 4.16. Average liveweight (kg) of lactating primiparous cows (i.e., heifers) in the autumn-calving (AUT) and spring-calving (SPR) farmlet herds during the experimental period (June 2017–January 2020). A different cohort of primiparous cows are represented in each subsequent line within each farmlet. Grey ribbon indicates the 95% confidence interval.

4.2.3 Body condition score

Body condition score of lactating cows in the AUT and SPR farmlets is presented in Table 4.8. Except for the start of L1, when BCS was similar, cows in the AUT farmlet ended L1, started L2 and ended L2 with greater condition ($P < 0.01$), and gained more condition during L1 and L2 ($P < 0.01$). Body condition score profile for each farmlet by DIM and by date is presented in Figure 4.17 and Figure 4.18, respectively. During L1, from the beginning of the experiment until ~350 DIM, BCS did not differ between farmlets (Figure 4.17). Subsequently, there was a greater BCS gain in the AUT farmlet after this point of the lactation. During L2, BCS loss was greater in the AUT farmlet herd compared with the SPR farmlet herd, however, both herds were a similar BCS at the time of drying off (Figure 4.18). Prior to calving, at the start of L2, BCS loss was greater in the AUT farmlet herd, and these cows continued to lose BCS during the first 60 days of their lactation (Figure 4.19). Only at approximately 50 DIM did BCS converge to be similar between farmlets, indicating that the AUT farmlet cows lost more BCS at the start of L2, compared with the SPR farmlet cows.

Table 4.8. Body condition score[1] (BCS) at the start of lactation[2], drying off[3] and change[4] in BCS of autumn-calving (AUT) and spring-calving (SPR) farmlet cows during lactation one and lactation two. Lactation three is presented for the SPR farmlet, with BCS at the end of the experimental period (January 2020) presented instead of at the time of drying off. SED = standard error of the difference; "-" = data not applicable.

		AUT	SPR	SED	P value
Lactation one	Start of lactation	4.2	4.1	0.04	0.35
	Drying off	5.4	4.2	0.06	<0.01
	Change	1.3	0.0	0.06	<0.01
Lactation two	Start of lactation	4.7	4.2	0.05	<0.01
	Drying off	4.6	4.3	0.04	<0.01
	Change	−0.1	0.1	0.05	<0.01
Lactation three	Start of lactation	-	4.3	-	-
	End of experiment	-	4.3	-	-
	Change	-	0.0	-	-

[1] 1–10 scale (Roche et al., 2009a)
[2] First recorded BCS after calving
[3] Final recorded BCS prior to drying off
[4] First recorded BCS subtracted from the final recorded BCS

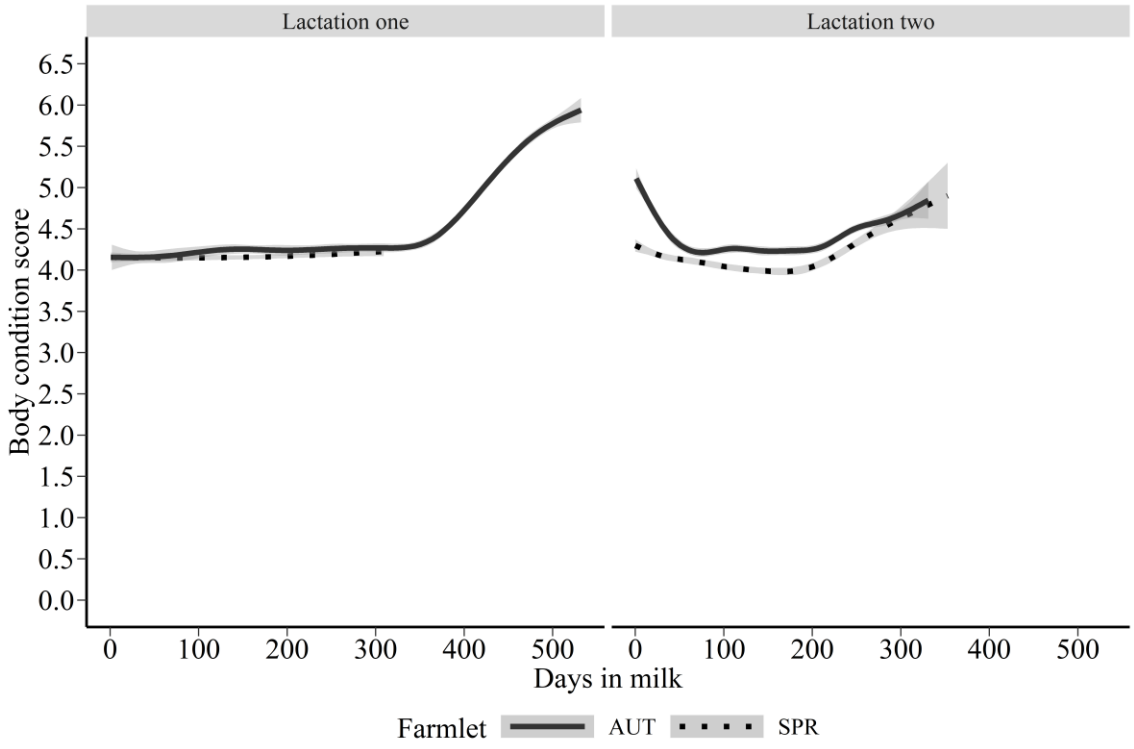

Figure 4.17. Average body condition score (BCS) of lactating autumn-calving (AUT) and spring-calving (SPR) farmlet cows by days in milk during lactation one and lactation two. 1–10 BCS scale (Roche et al., 2009a). Grey ribbon indicates the 95% confidence interval.

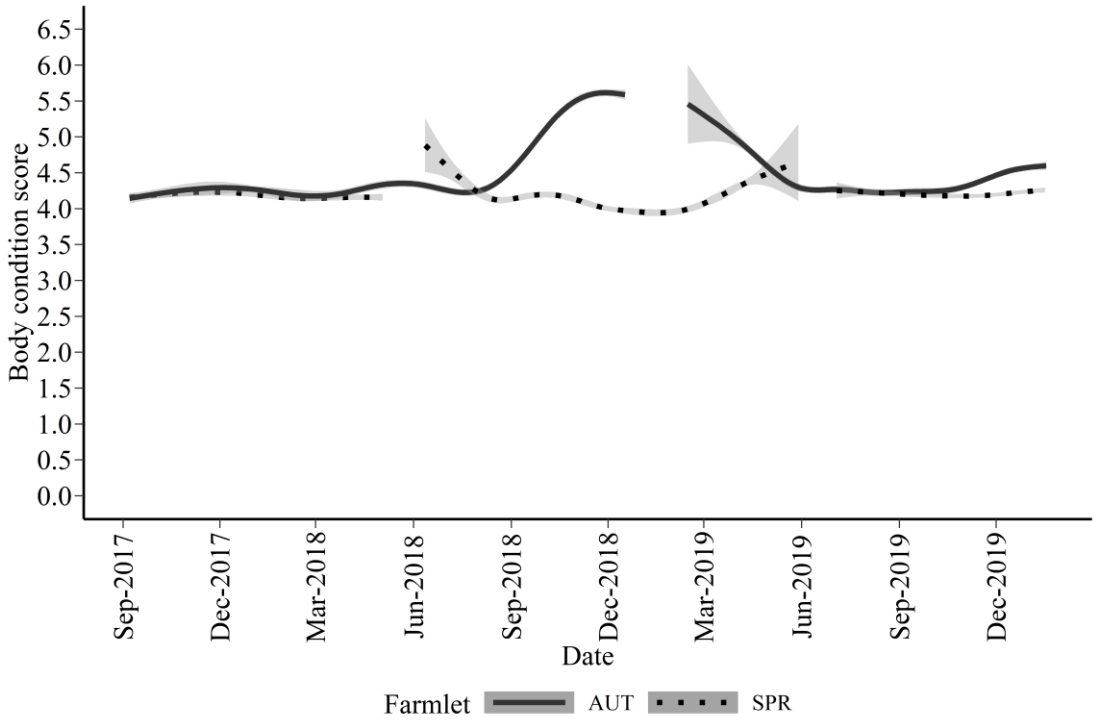

Figure 4.18. Average body condition score (BCS) of lactating autumn-calving (AUT) and spring-calving (SPR) farmlet cows by date during the experimental period (June 2017–January 2020). 1–10 BCS scale (Roche et al., 2009a). Grey ribbon indicates the 95% confidence interval.

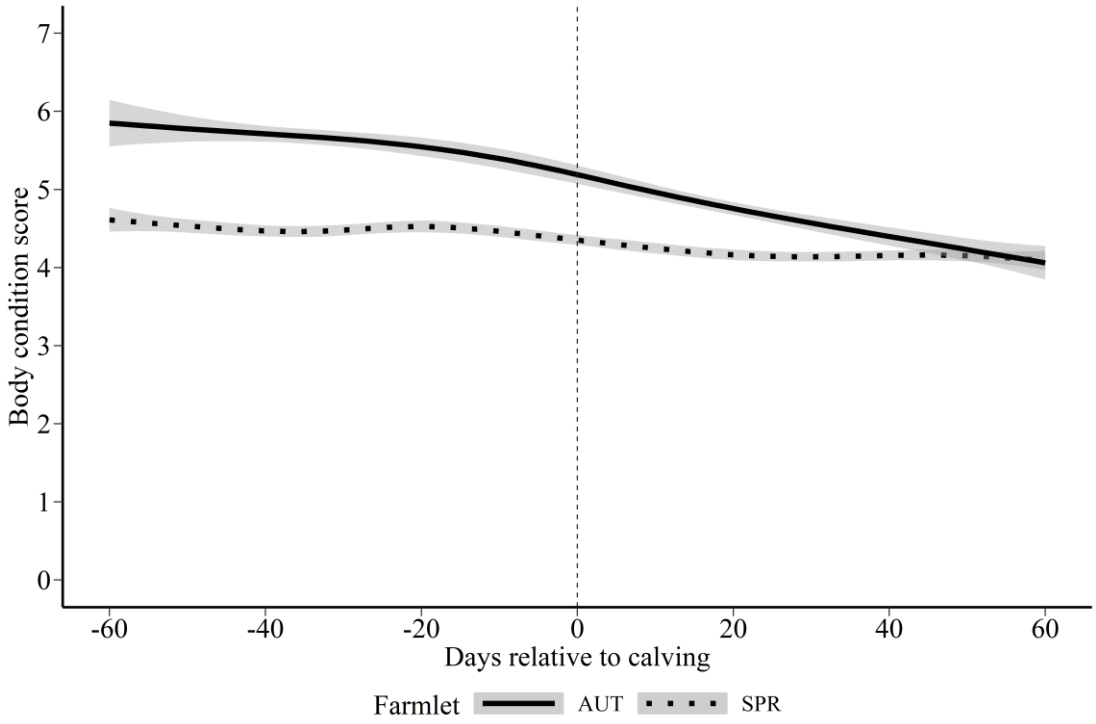

Figure 4.19. Body condition score (BCS) of autumn-calving (AUT) and spring-calving (SPR) farmlet cows 60 days prior and 60 days after their day of calving at the beginning of their respective lactation two. 1–10 BCS scale (Roche et al., 2009a). Grey ribbon indicates the 95% confidence interval. Vertical dashed line indicates the day of calving.

4.2.3.1 Heifer body condition score

The AUT farmlet heifers started L1 with a similar BCS as the SPR farmlet heifers (Table 4.9). However, during L1, the AUT heifers gained BCS ($P < 0.01$), whereas the SPR heifers decreased BCS ($P < 0.01$). Although the AUT heifers started L2 at a greater BCS ($P < 0.01$), and had a greater BCS at the time of drying off ($P < 0.01$), they decreased by more BCS ($P < 0.05$) compared with the SPR heifers during L2. Heifer BCS profile by DIM and by date is presented in Figure 4.20 and Figure 4.21, respectively. During L1, the AUT farmlet heifer BCS increased after 300 DIM, and AUT heifers decreased BCS at a greater rate during the first 100 DIM of L2, compared with the SPR heifers (Figure 4.20).

Table 4.9. Body condition score[1] (BCS) at the start of lactation[2], drying off[3] and change[4] in BCS of lactating primiparous cows (i.e., heifers) in the autumn-calving (AUT) and spring-calving (SPR) farmlets during lactation one, lactation two and lactation three. Lactation three is presented for the SPR farmlet, with the BCS at the end of the experimental period (January 2020) presented instead of at the time of drying off. SED = standard error of the difference; "-"= data not applicable.

		AUT	SPR	SED	P value
Lactation one	Start of lactation	4.5	4.5	0.2	0.64
	Drying off	5.3	4.2	0.2	<0.01
	Change	0.8	−0.3	0.2	<0.01
Lactation two	Start of lactation	5.0	4.5	0.1	<0.01
	Drying off	4.6	4.4	0.1	<0.01
	Change	−0.4	−0.2	0.1	<0.05
Lactation three	Start of lactation	-	4.5	-	-
	End of experiment	-	4.3	-	-
	Change	-	−0.2	-	-

[1] 1–10 scale (Roche et al., 2009a)
[2] First recorded BCS after calving
[3] Final recorded BCS prior to drying off
[4] First recorded BCS subtracted from the final recorded BCS divided by the number of days between recordings

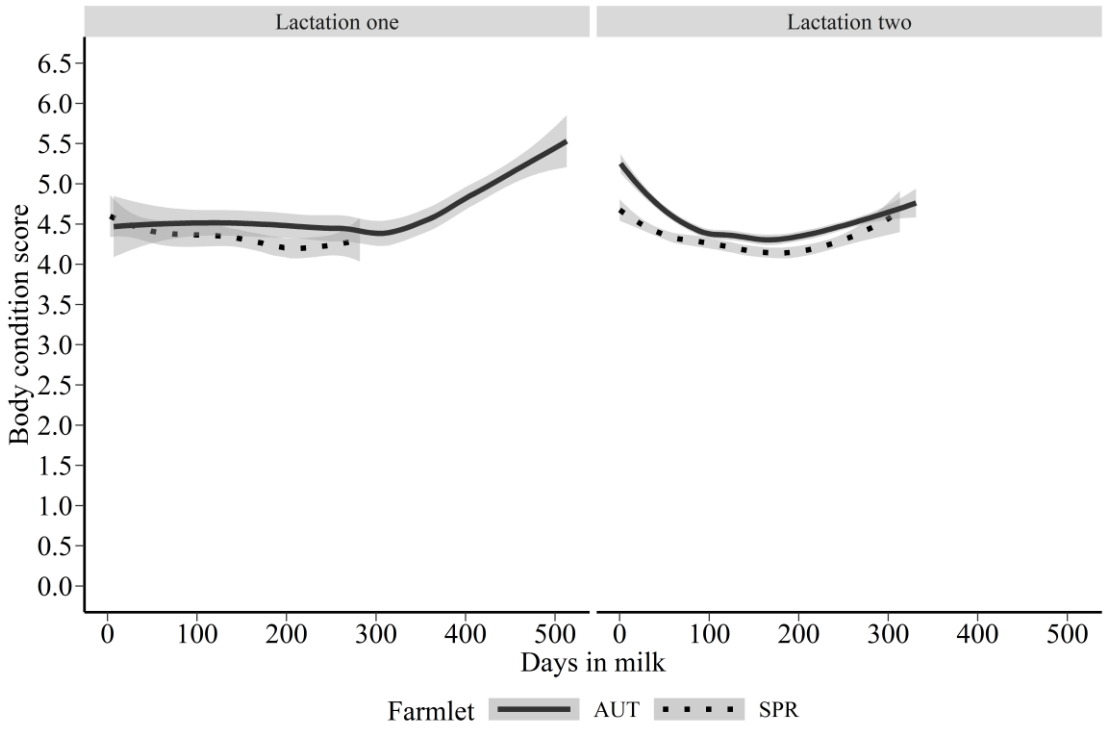

Figure 4.20. Average body condition score (BCS) of lactating primiparous cows (i.e., heifers) in the autumn-calving (AUT) and spring-calving (SPR) farmlet herds by days in milk during lactation one (heifers born in 2015) and lactation 2 (heifers born in 2016). 1–10 BCS scale (Roche et al., 2009a). Grey ribbon indicates the 95% confidence interval.

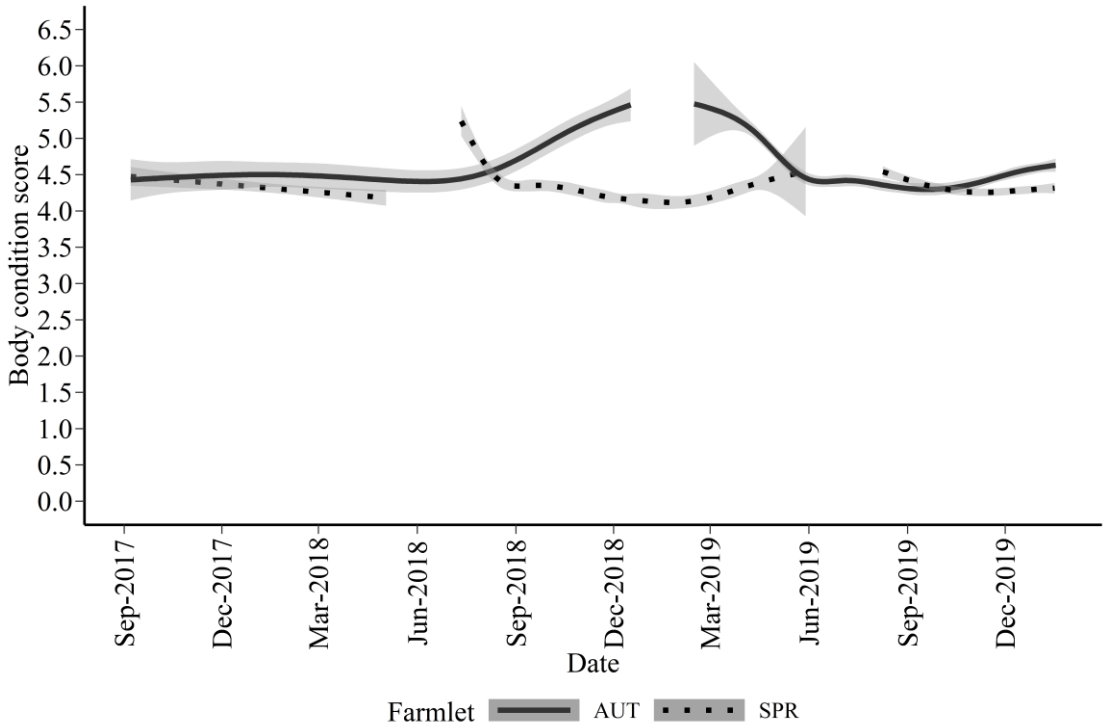

Figure 4.21. Average body condition score (BCS) of lactating primiparous cows (i.e., heifers) in the autumn-calving (AUT) and spring-calving (SPR) farmlet herds by date during the experimental period (June 2017–January 2020). A different cohort of primiparous cows are represented in each subsequent line within each farmlet. 1–10 BCS scale (Roche et al., 2009a). Grey ribbon indicates the 95% confidence interval.

4.2.4 Reproduction

Reproductive performance of the AUT and SPR farmlet herds in each lactation is presented in Table 4.10. Due to the recording of the data, statistical tests could not be performed, hence the relative difference between farmlets is presented instead. Numerically, during L1, the AUT farmlet had a greater 3-week submission rate, 6-week in-calf rate, and conception rate, and a lower not-in-calf rate compared with the SPR farmlet. However, this reversed during the L2 mating period, and the AUT farmlet performed worse in all four measures compared with the SPR farmlet, albeit the relative difference was less than in L1. From L1 to L3, reproductive performance improved in the SPR farmlet. During L1, the calving pattern of both herds was similar (Figure 4.22). However, in L2, more AUT farmlet cows calved closer to the PSC compared with SPR farmlet cows.

Table 4.10. 3-week submission rate, 6-week in-calf rate, conception rate and not-in-calf rate for autumn-calving (AUT) and spring-calving (SPR) farmlet cows during lactation one, lactation two and lactation three (applicable for the SPR farmlet only) mating periods. "-" = data not applicable.

		AUT	SPR	Difference
3-week submission rate	Lactation one	88%	72%	16%
	Lactation two	80%	81%	−1%
	Lactation three	-	86%	
6-week in-calf rate	Lactation one	80%	64%	16%
	Lactation two	65%	66%	−1%
	Lactation three	-	74%	
Conception rate	Lactation one	73%	51%	22%
	Lactation two	54%	57%	−3%
	Lactation three	-	58%	
Not-in-calf rate	Lactation one	8%	16%	−8%
	Lactation two	14%	12%	2%
	Lactation three	-	11%	

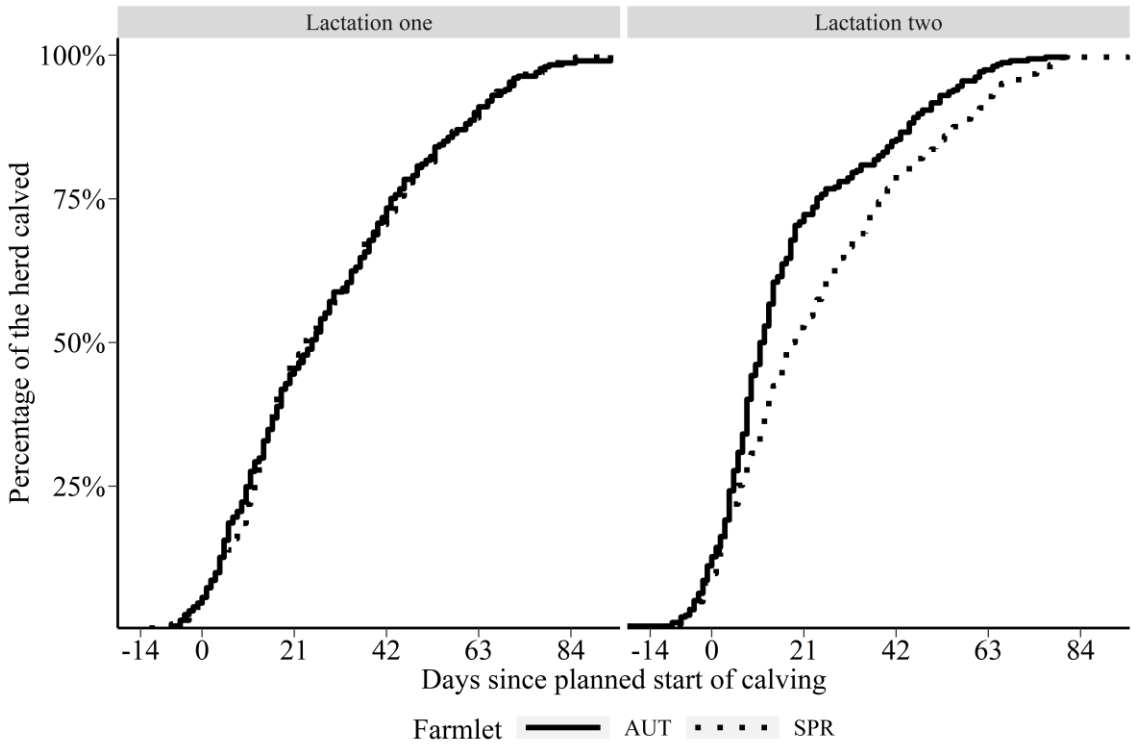

Figure 4.22. Empirical cumulative probability functions of the calving pattern, displayed as the percentage of the herd that has calved since the planned start of calving, in the autumn-calving (AUT) and spring-calving (SPR) farmlet herds during lactation one and lactation two.

4.2.4.1 Heifer reproduction

During L2, heifers in the AUT farmlet had a greater 3-week submission rate and 6-week in-calf rate compared with heifers in the SPR farmlet (Table 4.11). However, they also had a greater not-in-calf rate. During L3, heifers in the SPR farmlet performed relatively better in all three measures compared with heifers in L2.

Table 4.11. 3-week submission rate, 6-week in-calf rate, and not-in-calf rate for primiparous cows (i.e., heifers) in the autumn-calving (AUT) and spring-calving (SPR) farmlet herds during the lactation two and lactation three (applicable for the SPR farmlet only) mating periods. Lactation one and conception rate data were not available. "-" = data not applicable.

		AUT	SPR	Difference
3-week submission rate	Lactation two	85%	82%	3%
	Lactation three	-	89%	
6-week in-calf rate	Lactation two	67%	65%	2%
	Lactation three	-	80%	
Not-in-calf rate	Lactation two	12%	8%	4%
	Lactation three	-	6%	

4.2.5 Animal health

There was no difference in the recorded incidence of hypocalcaemia or facial eczema between farmlets. However, between L1 and L2, during the non-lactation period for the AUT farmlet (January–March), episodes of ryegrass staggers were reported in the AUT farmlet but not in the SPR farmlet. The number of effected individual animals was not reported.

The average age of cows when culled in the AUT and SPR farmlets is presented in Table 4.12. Data from L3 is not presented for the SPR farmlet cows because their lactation was ongoing. Except for cows culled for being not-in-calf during L2, the average age of cows culled did not differ between farmlets. During L2, cows culled for being not-in-calf in the AUT farmlet tended (P = 0.06) to be 1.3 years older than SPR farmlet cows.

Table 4.12. Average age of cows in the autumn-calving (AUT) and spring-calving (SPR) farmlets when culled, and when grouped by culling reason for each lactation. SED = standard error of the difference. "-" = data not applicable.

	AUT	SPR	SED	P value
Lactation 1				
Average age	7.0	7.0	0.3	0.90
Not-in-calf	6.8	6.8	0.6	0.95
Mastitis	8.7	7.4	0.9	0.16
Low production	7.4	7.0	1.0	0.68
Lactation 2				
Average age	7.0	6.6	0.5	0.38
Not-in-calf	7.1	5.8	0.7	0.06
Mastitis	8.5	7.2	1.3	0.34
Low production	-	-	-	-

4.3 Feed performance

This section describes the feed-related results during the experimental period on each farmlet. Pasture-related variables are presented as measured over a 365-day period (i.e., one year) and for seasons (e.g., winter) within each year, so that they are applicable to the temporal pattern of pasture growth. Accordingly, year one (Y1) is 1 June 2017–31 May 2018, and year two (Y2) is 1 June 2018–31 May 2019. Year three (Y3) refers to the 7-month period between 1 June 2019–31 January 2020. Conversely, supplementary feed variables are presented for each lactation for each farmlet, as they relate to the biological lactation for each farmlet herd.

4.3.1 Pasture growth

Annual and seasonal pasture growth during the experimental period for each farmlet are presented in Table 4.13. For both farmlets, annual pasture growth was greater in Y2 than in Y1, however, annual pasture growth between farmlets did not differ. In the AUT farmlet, winter pasture growth tended (P = 0.07) to be greater during Y1, and in Y2 was 454 kg DM/ha greater

(P < 0.01) than the SPR farmlet. There was an overall trend (P = 0.08) for winter pasture growth to be greater in the AUT farmlet compared with the SPR farmlet. During Y2, autumn pasture growth was 303 kg DM/ha less (P = 0.02) in the AUT farmlet, and there was an overall trend for autumn pasture growth to be less (P = 0.09) in the AUT farmlet. Summer and spring seasonal pasture growth did not differ between farmlets.

Table 4.13. Mean seasonal[1] pasture growth [kg dry matter (DM)/ha] and total pasture growth for year one (Y1), year two (Y2) and year three (Y3) of the experimental period for the autumn-calving (AUT) and spring-calving (SPR) farmlets. "-" = Results not presented for summer, autumn, and in total for Y3 as data were incomplete for these periods. SED = standard error of the difference.

	AUT	SPR	SED	P value
Winter				
Y1	1,929	1,681	136	0.07
Y2	2,367	1,913	110	<0.01
Y3	2,508	2,583	145	0.61
Mean	2,333	2,164	94	0.08
Spring				
Y1	3,602	3,416	271	0.50
Y2	5,260	5,027	204	0.26
Y3	4,893	5,189	217	0.18
Mean	4,850	4,869	166	0.91
Summer				
Y1	2,302	2,208	131	0.48
Y2	3,556	3,504	159	0.75
Y3	-	-	-	-
Mean	2,961	2,851	135	0.42
Autumn				
Y1	3,753	3,720	138	0.81
Y2	2,835	3,138	123	0.02
Y3	-	-	-	-
Mean	3,352	3,518	96	0.09
Total				
Y1	11,512	10,878	508	0.22
Y2	13,707	13,349	516	0.49
Y3	-	-	-	-
Mean	12,722	12,114	404	0.14

[1] Winter (June to August, inclusive), spring (September to November, inclusive), summer (December to February, inclusive), autumn (March to May, inclusive)

The profile of APC and average PGR between farmlets during the experimental period are presented in Figure 4.23 and Figure 4.24, respectively. Average pasture cover was similar between farmlets at the beginning of the experimental period before it began to diverge in approximately April 2018 (Y1), where it decreased in the AUT farmlet and increased in the SPR farmlet (Figure 4.23). Average pasture cover increased from December 2017 (Y1) until

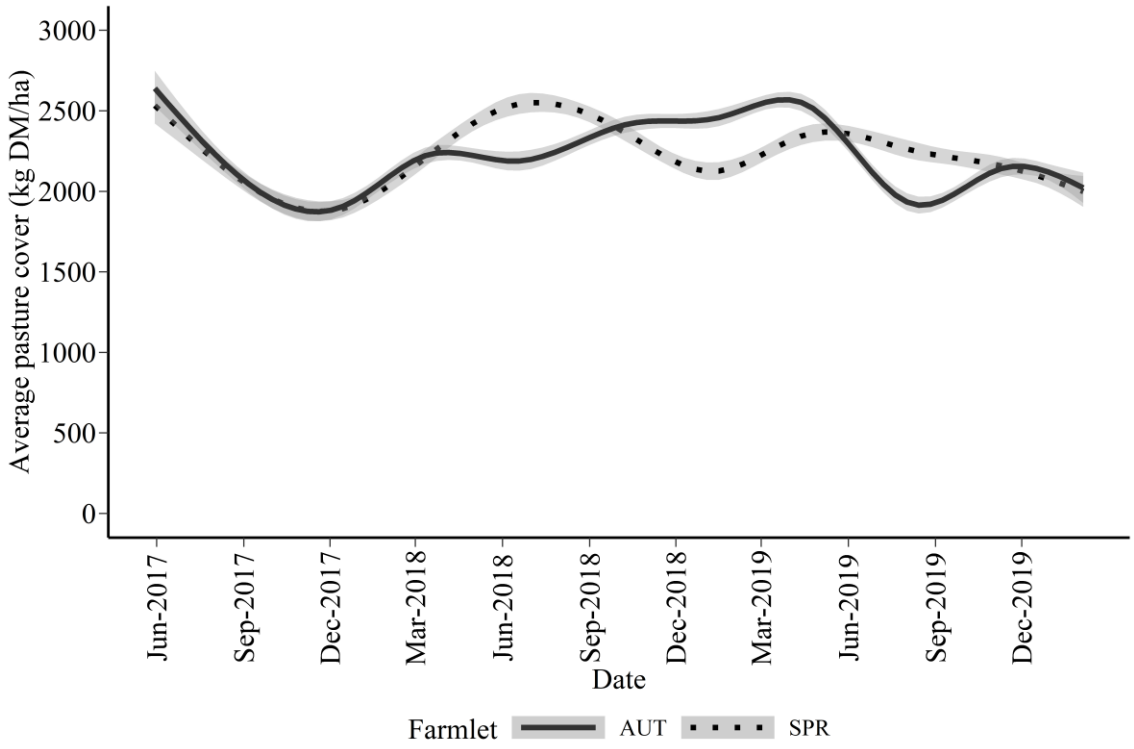

Figure 4.23. Average pasture cover [kg dry matter (DM)/ha] on the autumn-calving (AUT) and spring-calving (SPR) farmlets by date during the experimental period (1 June 2017–31 January 2020, inclusive). Grey ribbon indicates the 95% confidence interval.

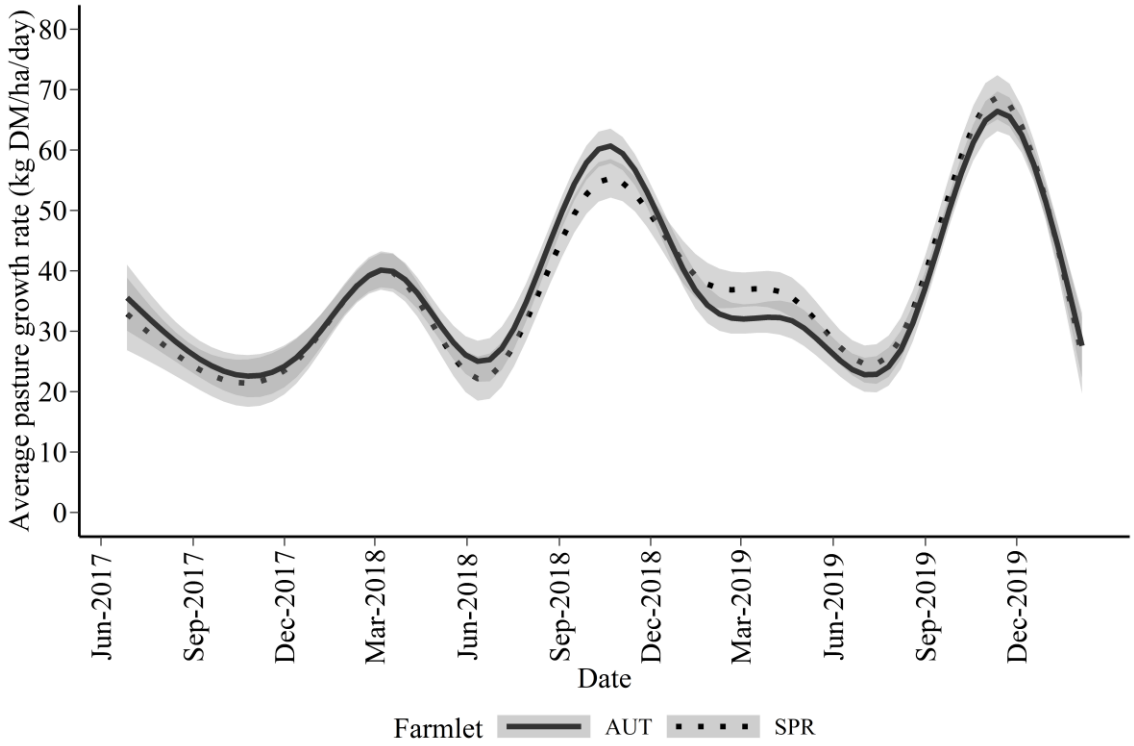

Figure 4.24. Average pasture growth rate [kg dry matter (DM)/ha/day] on the autumn-calving (AUT) and spring-calving (SPR) farmlets by date during the experimental period (1 June 2017–31 January 2020). Grey ribbon indicates the 95% confidence interval.

April 2019 (Y2) in the AUT farmlet. In contrast, in the SPR farmlet, there was a peak in APC in July 2018 (Y2), a nadir in December 2018 (Y2) and then another peak in April 2019 (Y2). For both farmlets, average PGR peaked around March 2018 (Y1), October 2018 (Y2) and November 2019 (Y3), and did not differ between farmlets during the experimental period (Figure 4.24).

Pre-grazing covers on the AUT farmlet were 804 and 781 kg DM/ha less ($P < 0.01$) during winter in Y2 and Y3 compared with the SPR farmlet, respectively (Table 4.14). However, during summer and autumn in Y2, pre-grazing covers were greater in the AUT farmlet compared with the SPR farmlet (953 and 401 kg DM; $P < 0.01$ and $P = 0.02$, respectively). Post-grazing residuals did not differ between farmlets in any season of any experimental year (Table 4.14).

4.3.2 Supplementary feeds

The type and amount of supplementary feed offered to both farmlet herds during each lactation is presented in Table 4.15. Due to the nature of the supplementary feed data, statistical analyses could not be performed between farmlets. During L1, AUT farmlet cows were offered more supplementary feed than SPR farmlet cows (147%; 625 kg DM/cow), of which, PKE, pasture silage and meal formed the majority of the increase (276, 234 and 72 kg DM/cow, respectively). Supplementary feed offered to cows in both farmlets prior to 1 October 2017 was not recorded by farm staff, hence, data presented on total supplementary feed offered during L1 is lower than what was actually offered. However, as both herds were equally managed prior to this date, differences in supplementary feed represent differences that occurred subsequent to the initiation of the farmlets.

During L2, meal was offered solely to the AUT farmlet cows while turnips were offered solely to the SPR farmlet cows (Table 4.15). Overall, during L2, AUT farmlet cows were offered 33% (331 kg DM/cow) more supplementary feed compared with SPR farmlet cows.

During L3, to the end of the experimental period, cows in the SPR farmlet had been offered 521 kg DM/cow of supplementary feed, consisting mainly of meal (198 kg DM/cow). In total across the experimental period, cows in the AUT farmlet were offered 22% more supplementary feed (435 kg DM/cow) compared with cows in the SPR farmlet (2,371 vs. 1,936 kg DM/cow).

Table 4.14. Mean pre-grazing cover and post-grazing residual [kg dry matter (DM)/ha] in each season[1] in year one (Y1), year two (Y2) and year three (Y3) of the experimental period for the autumn-calving (AUT) and spring-calving (SPR) farmlets. "-" = Results not presented for summer and autumn of Y3 as data were incomplete for this period. SED = standard error of the difference.

	AUT	SPR	SED	P value
Pre-grazing cover				
Winter				
Y1	3,433	3,273	293	0.60
Y2	2,670	3,474	128	<0.01
Y3	2,660	3,441	147	<0.01
Spring				
Y1	2,789	2,817	204	0.90
Y2	3,196	3,170	139	0.85
Y3	2,892	2,968	205	0.72
Summer				
Y1	2,295	2,241	51	0.30
Y2	3,744	2,791	220	<0.01
Y3	-	-	-	-
Autumn				
Y1	3,014	3,181	136	0.23
Y2	3,356	2,955	157	0.02
Y3	-	-	-	-
Post-grazing residual				
Winter				
Y1	1,347	1,340	75	0.93
Y2	1,528	1,465	47	0.23
Y3	1,547	1,464	47	0.10
Spring				
Y1	1,573	1,595	67	0.75
Y2	1,682	1,680	32	0.95
Y3	1,531	1,565	26	0.19
Summer				
Y1	1,514	1,567	32	0.11
Y2	1,529	1,618	52	0.10
Y3	-	-	-	-
Autumn				
Y1	1,671	1,666	40	0.89
Y2	1,557	1,581	57	0.69
Y3	-	-	-	-

[1] Winter (June to August, inclusive), spring (September to November, inclusive), summer (December to February, inclusive), autumn (March to May, inclusive)

4.3.3 Offered feed

Average monthly DMI of pasture and supplementary feed in both farmlet herds is presented in Figure 4.25. During their extended lactation (L1), AUT farmlet cows were offered supplementary feed continuously from January 2018 until October 2018. The proportion of supplementary feed in the diet then decreased during late lactation as the PGR increased.

During L2, the timing of supplementary feed differed between farmlets. Supplementary feed was offered to AUT farmlet cows from calving until late lactation, whereas SPR farmlet cows

were offered supplementary feed in two different periods: firstly for three months during early lactation; and then secondly for five months in mid to late lactation. The DMI of pasture had a similar trend to the PGR in both farmlets during the experimental period.

Table 4.15. Total quantity per farmlet [tons of dry matter; t DM) and *total quantity per cow[1] [kg dry matter (DM)/cow/lactation]* of supplementary feed offered to autumn-calving (AUT) and spring-calving (SPR) farmlet herds during lactation one, lactation two and lactation three. "-" = data not applicable. PKE = palm kernel expeller. Totals may not equal due to rounding.

	Lactation one[2]		Lactation two		Lactation three	
	AUT	SPR	AUT	SPR	AUT	SPR
Pasture silage (t DM)	90	19	162	136	-	9
Per cow (kg DM/cow)	*299*	*64*	*532*	*446*		*28*
Maize silage (t DM)	21	10	81	77	-	20
Per cow (kg DM/cow)	*70*	*32*	*265*	*254*		*63*
Turnips (t DM)	49	49	-	52	-	25
Per cow (kg DM/cow)	*161*	*161*		*171*		*82*
Meal (t DM)	72	50	147	-	-	61
Per cow (kg DM/cow)	*238*	*166*	*482*			*198*
PKE (t DM)	83	-	-	20	-	-
Per cow (kg DM/cow)	*276*			*64*		
Hay (t DM)	1	-	13	17	-	47
Per cow (kg DM/cow)	*5*		*43*	*56*		*150*
Total (t DM)	316	128	403	302	-	162
Per cow (kg DM/cow)	*1,049*	*424*	*1,322*	*991*		*521*

[1] Total quantity of supplementary feed offered divided by the number of peak cows during each lactation

[2] Excludes supplementary feed offered prior to experiment establishment on 1 October 2017

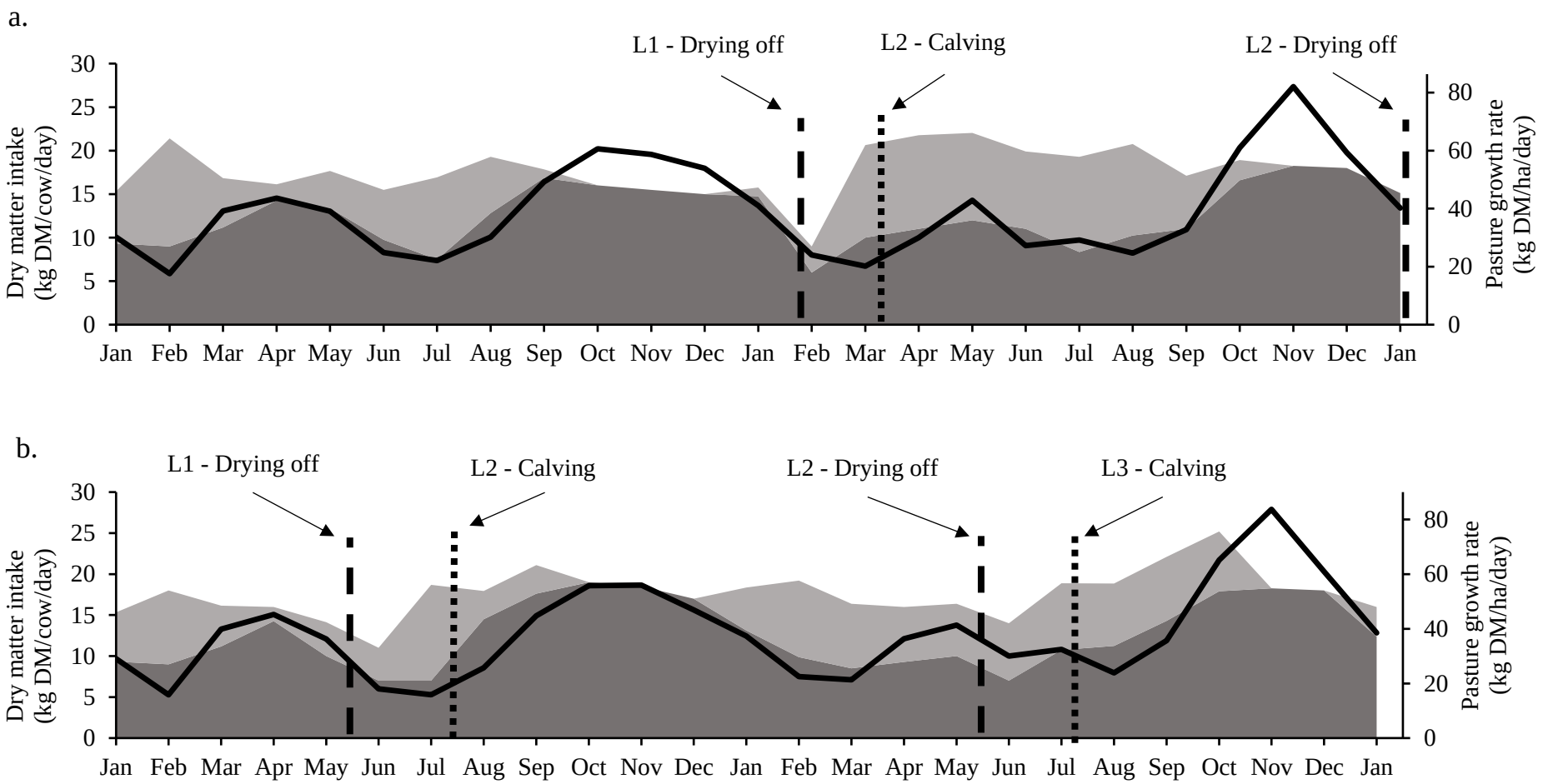

Figure 4.25. Monthly dry matter intake [DMI; kg dry matter (DM)/cow/day] of pasture (dark grey shade) and supplementary feed (light grey shade), and pasture growth rate (black line; kg DM/ha/day) in the autumn-calving (*a.*) and spring-calving (*b.*) farmlets between January 2017 and January 2020. Vertical dashed lines indicate calving and drying-off dates for each farmlet for lactation one (L1), lactation two (L2), and lactation three (L3). Data are not presented for pre-January 2017 as both farmlets were managed the same between 1 June 2017–1 October 2017, and there was no supplementary feeding to either farmlet between 1 October 2017 and 1 January 2018.

Chapter 5 Economic Results

Economic analysis for both farmlets are presented in the following sections. Unlike the biophysical data, the economic data encompass financial years (1 June–31 May). As the timeframe of the experiment was two years and eight months, biophysical performance during the final four months of Y3 was assumed (see section 3.6). A fourth year (Y4) was modelled, based on Y1–Y3 data, to provide economic results for a NPV analysis (see section 3.6.3). Results are presented for years one to four, and the 10-year investment horizon.

It must be noted that the results presented here were calculated from one non-replicated experiment (i.e., one farm in one region, with one extended lactation and one 12-month CI lactation), and thus includes assumptions. Therefore, these results may not be applicable to farm businesses in different contexts. The limitations to this experiment and the economic analysis are discussed in greater detail in Chapter 7.

5.1 Gross revenue

Farmlet gross revenue was relatively stable for the SPR farmlet but differed markedly for the AUT farmlet over the period analysed (Figure 5.1). Gross revenue of the AUT farmlet decreased by $526/ha from $8,299/ha in Y1 to a minimum of $7,773/ha in Y2. This was due to a decrease in MS production of 193 kg MS/ha from 1,180 kg MS/ha in Y1 to 987 kg MS/ha in Y2 (Table 5.1). Gross revenue then increased by $3,794/ha from $7,773/ha in Y2 to $11,567/ha in Y3. This was due to an increase in MS production of 539 kg MS/ha, from 987 kg MS/ha in Y2 to 1,526 kg MS/ha in Y3. There was a predicted increase of $129/ha from Y3 to the maximum gross revenue of $11,696/ha in Y4 (total range across all four years was $3,923/ha; Table 5.1). In comparison, gross revenue was relatively constant in the SPR farmlet in all four years, increasing from a minimum of $8,249/ha in Y1 to a maximum of $9,122/ha in Y3 (a range of $873/ha; Table 5.1), then decreasing slightly in Y4 based on predicted performance.

5.2 Expenses

Dairy operating expenses in the AUT farmlet were $278/ha and $267/ha greater than the SPR farmlet during Y1 and Y2, respectively (Table 5.1). Dairy operating expenses in both farmlets increased between Y2 and Y3 (Figure 5.2). However, dairy operating expenses increased by $1,075/ha (20%) in the AUT farmlet compared with $361 (7%) in the SPR farmlet, leading to dairy operating expenses being $981/ha (18%) greater in the AUT farmlet compared with the SPR farmlet in Y3. This difference was predicted to increase to $1,248/ha (24%) in Y4.

Table 5.1. Revenue, expenses and profit for the autumn-calving (AUT) and spring-calving (SPR) farmlets for year one (Y1; 2017/18), year two (Y2; 2018/19), and year three (Y3; 2019/20), and predictions for year four (Y4; 2020/21). MS = milksolids.

	AUT				SPR			
	Y1	Y2	Y3	Y4	Y1	Y2	Y3	Y4
Average milk price ($/kg MS)	6.51	7.09	7.00	7.00	6.43	6.43	6.42	6.42
MS production (kg MS/ha)	1,180	987	1,526	1,526	1,148	1,257	1,279	1,239
Revenue ($/ha)								
Milk revenue	7,681	6,996	10,685	10,685	7,380	8,074	8,211	7,960
Other revenue	618	777	882	1,011	870	884	911	866
Gross revenue	8,299	7,773	11,567	11,696	8,249	8,958	9,122	8,826
Expenses ($/ha)								
Total labour expenses	1,163	1,115	1,183	1,189	1,097	1,006	1,024	1,004
Total stock expenses	665	665	663	663	654	651	648	650
Total grazing expenses	733	770	728	733	663	687	706	729
Total feed expenses	1,017	711	1,688	1,688	983	896	1,141	963
Total other farm working expenses	1,037	1,199	1,231	1,230	987	1,024	1,073	1,019
Total administration expenses	954	945	986	986	905	874	908	876
Total dairy operating expenses	5,568	5,405	6,480	6,488	5,290	5,138	5,499	5,240
Purchase of additional shares			1,755					
Effluent infrastructure capital cost	718							
Total profit ($/ha)	2,013	2,368	3,333	5,207	2,959	3,820	3,622	3,586
Total expenses ($/kg MS)	5.33	5.48	5.40	4.25	4.61	4.09	4.30	4.23

One-off capital expenses on effluent infrastructure and additional processing company shares contributed to an increase in total expenses in the AUT farmlet (Table 5.1). In particular, the purchase of $1,755/ha of shares in Y3 increased total expenses to $8,235/ha (Figure 5.3). Total expenses per kg MS were greater in the AUT farmlet during all years compared with the SPR farmlet. In particular, AUT farmlet expenses per kg MS were $0.72–1.39/kg MS greater during the first three years compared with the SPR farmlet. However, during Y4 total expenses per kg MS were predicted to only be $0.02/kg MS greater in the AUT farmlet.

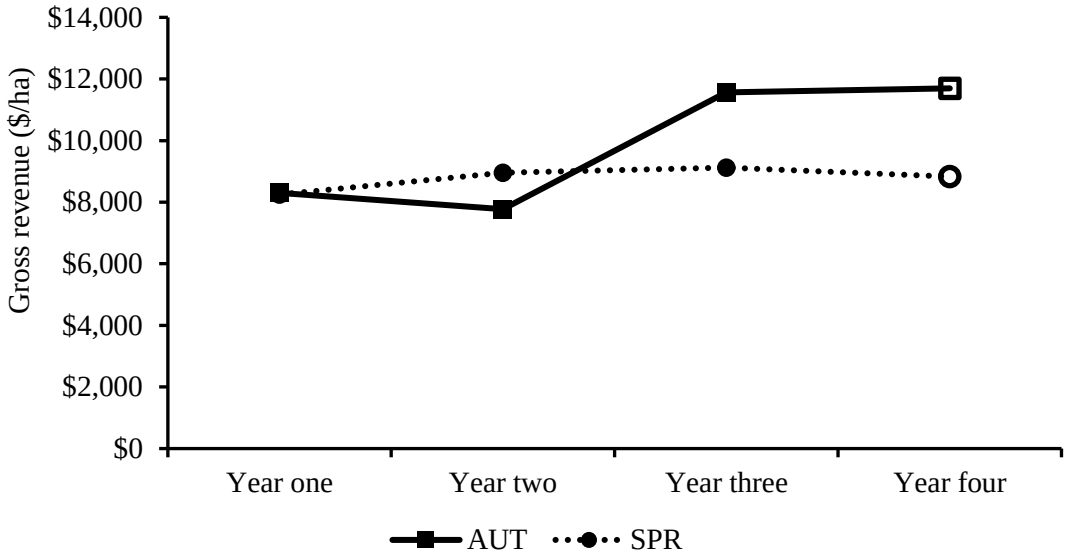

Figure 5.1. Gross revenue ($/ha) of the autumn-calving (AUT) and spring-calving (SPR) farmlets during the four years. Open symbols indicate the modelled year four data.

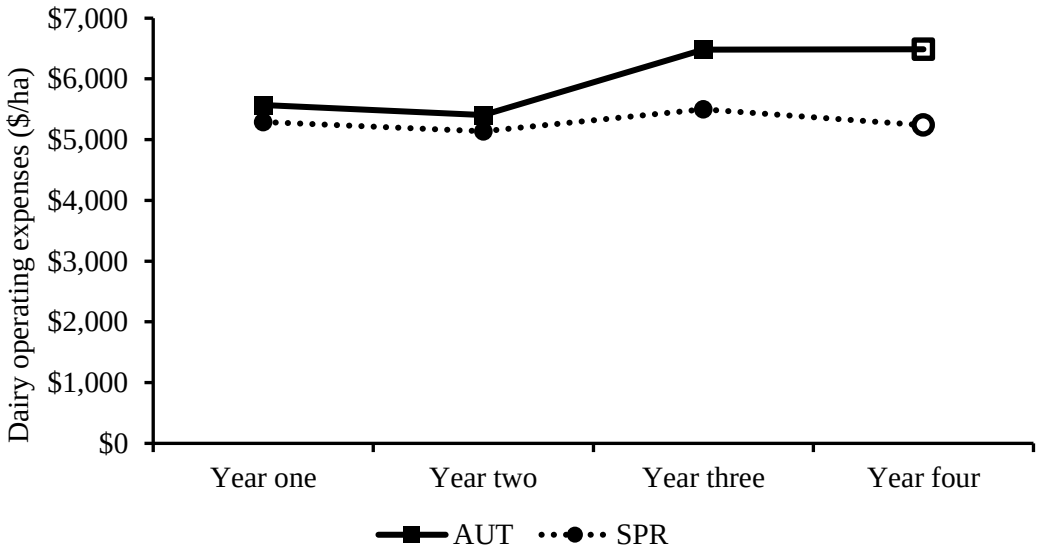

Figure 5.2. Dairy operating expenses ($/ha) of the autumn-calving (AUT) and spring-calving (SPR) farmlets during the four years. Open symbols indicate the modelled year four data.

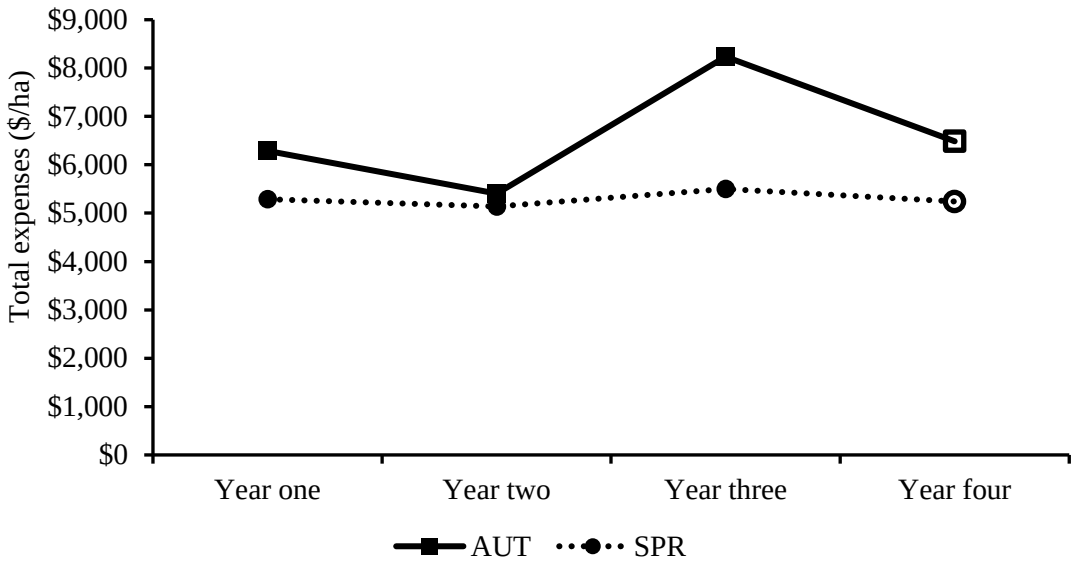

Figure 5.3. Total expenses ($/ha) for the autumn-calving (AUT) and spring-calving (SPR) farmlets during the four years, including the effluent infrastructure capital cost in year one and the purchase of additional company shares in year three for the AUT farmlet. Open symbols indicate the modelled year four data.

5.3 Profit

Compared with the SPR farmlet, the AUT farmlet had a lower yearly profit during the first three years (Figure 5.4), however, in Y4, AUT farmlet profit was predicted to be $1,621/ha (45%) greater (Table 5.1). Year four also represented the largest increase in between-year profit in the AUT farmlet, with a predicted increase of $1,874/ha (56%) from Y3. In contrast, profit remained relatively consistent in the SPR farmlet during all four years.

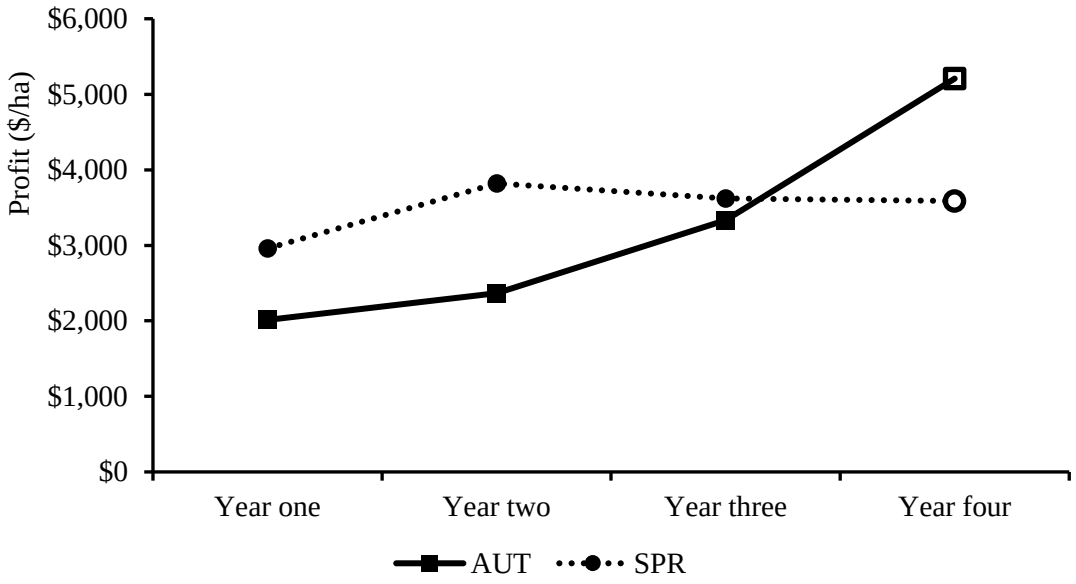

Figure 5.4. Profit ($/ha) of the autumn-calving (AUT) and spring-calving (SPR) farmlets during the four years. Open symbols indicate the modelled year four data.

5.4 Year four performance

Estimated profitability of the AUT and SPR farmlets during Y4 in the different scenarios is presented in Table 5.2. Under all winter milk premium scenarios, the AUT farmlet in the base economic model, S1, and S2, was predicted to be more profitable during Y4 compared with the SPR farmlet. However, predicted profitability in the AUT farmlet, relative to the SPR farmlet, decreased as the winter milk premium decreased.

Table 5.2. Profit ($/ha) during year four for the autumn-calving (AUT) and spring-calving (SPR) farmlet in the base economic model (Base), and in Scenario 1 (S1) and Scenario 2 (S2) for the AUT farmlet, at a full, half (i.e., 50%) and no (i.e., 0%) winter milk premium. S1 = AUT farmlet Y4 milksolids (MS) production is the average of the AUT and SPR Y4 MS production. S2 = AUT farmlet Y4 MS production is equal to SPR Y4 MS production. Supplementary feed has been pro rata reduced in S1 and S2 assuming a marginal MS response of 80 g MS/kg dry matter (Roche et al., 2017b).

	AUT			SPR
Winter milk premium	Base	S1	S2	Base
Full	5,207	5,386	4,755	3,586
50%	4,722	4,947	4,363	3,586
0%	4,335	4,598	4,051	3,586

The predicted economic performance of the AUT farmlet during Y4 under the base economic model, in comparison with S1 and S2, is presented in Figure 5.5. Across the two scenarios, as the predicted MS production during Y4 decreased, gross revenue, total feed expenses and total dairy operating expenses also decreased. However, profit was predicted to be greater in S1 during Y4 compared with the base economic model and S2. A similar trend between scenarios was predicted when the winter milk premium was 50% and 0%, hence, those results are not presented here.

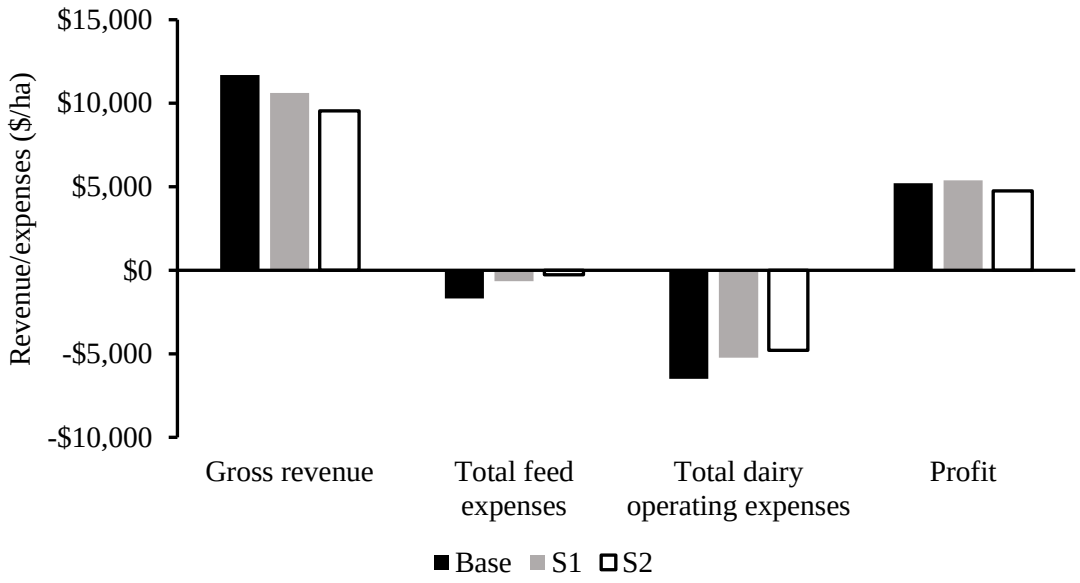

Figure 5.5. Gross revenue, total feed expenses, total dairy operating expenses, and profit ($/ha) during year four (Y4) in the autumn-calving (AUT) farmlet assuming a full winter milk premium. Base = base economic model. S1 = Scenario 1, AUT farmlet Y4 milksolids (MS) production is the average of the AUT and spring-calving (SPR) Y4 MS production. S2 = Scenario 2, AUT farmlet Y4 MS production is equal to SPR Y4 MS production. Supplementary feed has been pro rata reduced in S1 and S2 assuming a marginal MS response of 80 g MS/kg dry matter (Roche et al., 2017b).

5.5 Investment and sensitivity analysis

The NPV ($/ha) of both farmlets over a 10-year investment horizon, at three different winter milk premiums, and using two different MS production scenarios[5] for the AUT farmlet, is presented in Table 5.3. In the base economic model, NPV of the AUT farmlet was predicted to be greater than the SPR farmlet when the winter milk premium was full or 50%, but less when there was no winter milk premium. At a full winter milk premium, the NPV of the AUT farmlet was predicted to be $5,172/ha (20%) greater than the SPR farmlet; however, this advantage reduced to $2,115/ha (8%) when the winter milk premium was halved (i.e., 50%). When there was no winter milk premium in the base economic model, the NPV of the AUT farmlet was predicted to be −$317/ha (1%) less than the SPR farmlet.

In S1, the AUT farmlet was predicted to have a greater NPV than the base economic model of both the AUT and SPR farmlets under all three winter milk premiums (Table 5.3). Compared with the AUT farmlet base economic model, the NPV for S1 in the AUT farmlet was $1,574/ha (5%), $1,795/ha (6%), and $1,970/ha (8%) greater when the winter milk premium was full, 50% and 0%, respectively. In comparison, the NPV for S1 in the AUT farmlet was $6,746/ha (26%),

[5] Scenario 1 (S1) assumes that AUT farmlet Y4 MS production is the average of the AUT and SPR Y4 MS production. Scenario 2 (S2) assumes that AUT farmlet Y4 MS production is equal to SPR Y4 MS production. Supplementary feed has been pro rata reduced in S1 and S2, assuming a marginal MS response of 80 g MS/kg DM (Roche et al., 2017b).

$3,910/ha (15%), and $1,653/ha (6%) greater than the SPR farmlet base economic model when the winter milk premium was full, 50% and 0%, respectively.

Table 5.3. Net present value ($/ha) of the autumn-calving (AUT) and spring-calving (SPR) farmlets in the base economic model (Base), and Scenario 1 (S1) and Scenario 2 (S2) for the AUT farmlet, under a full, half (i.e., 50%) and no (i.e., 0%) winter milk premium. S1 = AUT farmlet Y4 milksolids (MS) production is the average of the AUT and SPR Y4 MS production. S2 = AUT farmlet Y4 MS production is equal to SPR Y4 MS production. Supplementary feed has been pro rata reduced in S1 and S2 assuming a marginal MS response of 80 g MS/kg dry matter (Roche et al., 2017b).

	AUT			SPR
Winter milk premium	Base	S1	S2	Base
Full	31,212	32,786	30,563	26,040
50%	28,155	29,950	27,947	26,040
0%	25,723	27,693	25,866	26,040

In S2, the predicted NPV of the AUT farmlet was less than the AUT farmlet base economic model and S1 (Table 5.3). Compared with the SPR farmlet base economic model, the NPV of S2 in the AUT farmlet was $4,523/ha (17%) and $1,907/ha (7%) greater when the winter milk premium was full and 50%, respectively. However, at a 0% winter milk premium, the NPV for S2 in the AUT farmlet was $174/ha less than the SPR farmlet base economic model.

The predicted cumulative discounted cash flow over the 10-year investment horizon for both farmlets for the full, 50%, and 0% winter milk premiums are presented in Figure 5.6, Figure 5.7, and Figure 5.8, respectively. Under a full winter milk premium, AUT farmlet cumulative discounted cash flow in the base economic model, S1, and S2, was lower than that of the SPR farmlet base economic model between Y1 to Y4, but then was greater than the SPR farmlet from Y5 onwards (Figure 5.6). Compared with the AUT farmlet base economic model and S1, cumulative discounted cash flow in S2 was greater to the end of Y4, but this advantage was eroded between Y5 to Y10, and it was lower in comparison in Y10.

Under a 50% winter milk premium, AUT farmlet cumulative discounted cash flow in S1 and S2 was predicted to be less than the SPR farmlet base economic model between Y1 to Y5 (Figure 5.7). Cumulative discounted cash flow in the AUT farmlet base economic model was lower than that of the SPR farmlet base economic model between Y1 to Y6.

When the winter milk premium was removed (i.e., 0%), AUT farmlet cumulative discounted cash flow in the base economic model and in S2 was predicted to not exceed the SPR farmlet cumulative discounted cash flow in any year (Figure 5.8). Furthermore, AUT farmlet cumulative discounted cash flow in S1 was less than the SPR farmlet between Y1 to Y8, and only exceeded the SPR farmlet in Y9.

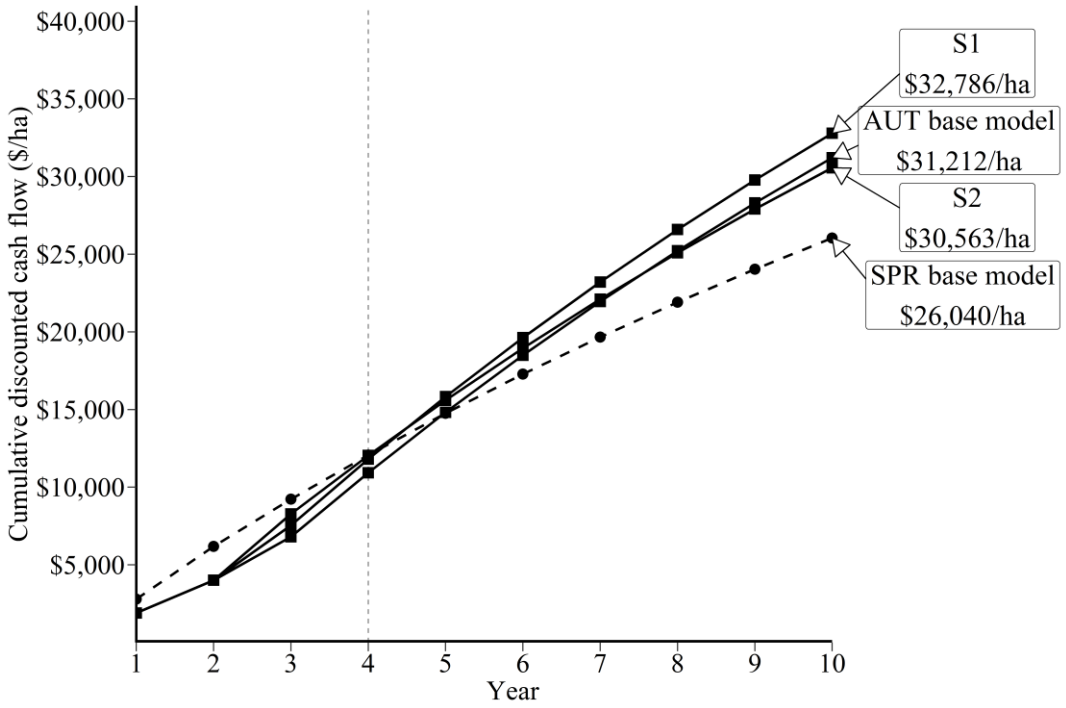

Figure 5.6. Cumulative discounted cash flow (6% discount rate; $/ha) of the economic base model with a full (i.e., 100%) winter milk premium, for the autumn-calving (■; AUT) and spring-calving (●; SPR) farmlets over 10 years, assuming the year four (Y4) cash flow is an annuity for years 4–10 (vertical grey dashed line). Year 10 values are the net present value of the farmlet. S1 = Scenario 1, AUT farmlet Y4 milksolids (MS) production is the average of the AUT and SPR Y4 MS production. S2 = Scenario 2, AUT farmlet Y4 MS production is equal to SPR Y4 MS production. Supplementary feed has been pro rata reduced in S1 and S2 assuming a marginal MS response of 80 g MS/kg dry matter (Roche et al., 2017b).

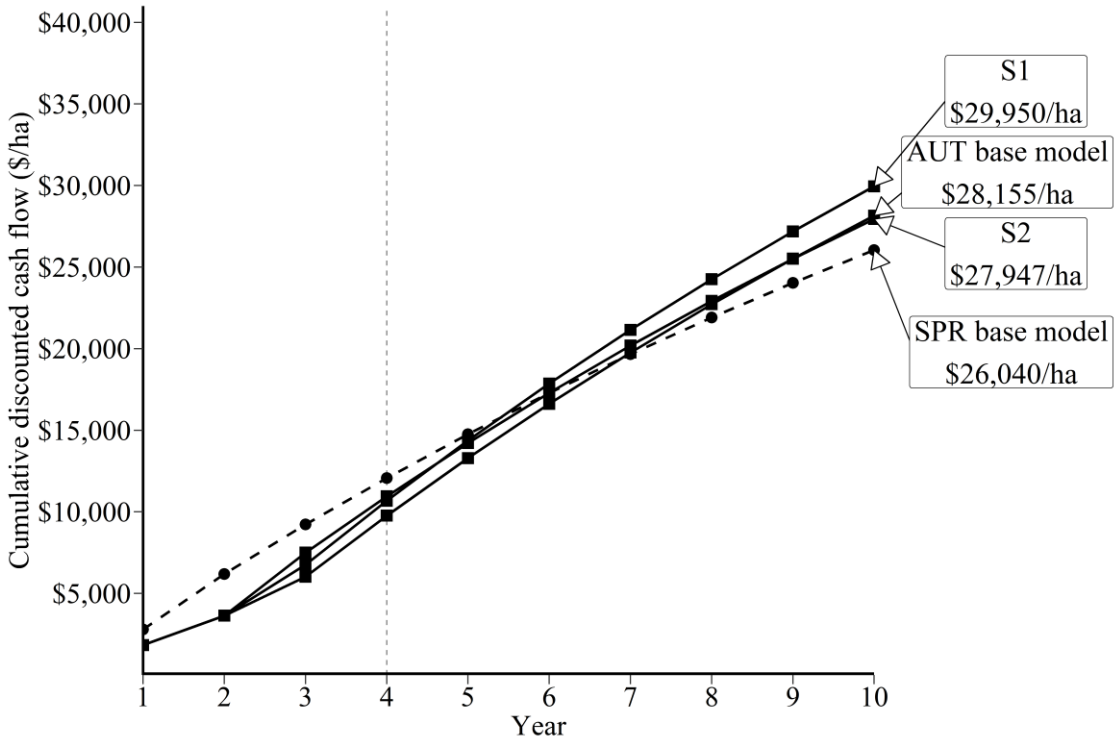

Figure 5.7. Cumulative discounted cash flow (6% discount rate; $/ha) of the economic base model with a half (i.e., 50%) winter milk premium, for the autumn-calving (■; AUT) and spring-calving (●; SPR) farmlets over 10 years, assuming year four (Y4) cash flow is an annuity for years 4–10 (vertical grey dashed line). Year 10 values are the net present value of the farmlet. S1 = Scenario 1, AUT farmlet Y4 milksolids (MS) production is the average of the AUT and SPR Y4 MS production. S2 = Scenario 2, AUT farmlet Y4 MS production is equal to SPR Y4 MS production. Supplementary feed has been pro rata reduced in S1 and S2 assuming a marginal MS response of 80 g MS/kg dry matter (Roche et al., 2017b).

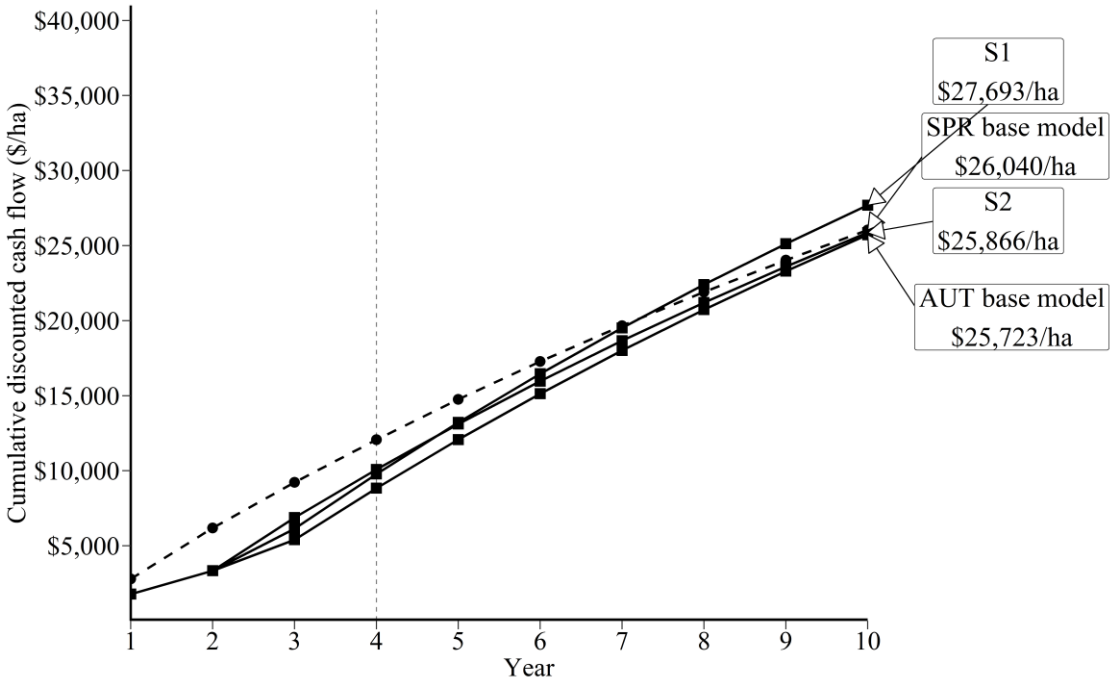

Figure 5.8. Cumulative discounted cash flow (6% discount rate; $/ha) of the economic base model with no (i.e., 0%) winter milk premium, for the autumn-calving (■; AUT) and spring-calving (●; SPR) farmlets over 10 years, assuming year four (Y4) cash flow is an annuity for years 4–10 (vertical grey dashed line). Year 10 values are the net present value of the farmlet. S1 = Scenario 1, AUT farmlet Y4 milksolids (MS) production is the average of the AUT and SPR Y4 MS production. S2 = Scenario 2, AUT farmlet Y4 MS production is equal to SPR Y4 MS production. Supplementary feed has been pro rata reduced in S1 and S2 assuming a marginal MS response of 80 g MS/kg dry matter (Roche et al., 2017b).

Chapter 6 Discussion

The current experiment provided a unique opportunity to analyse the impacts of a change in calving season to a whole-farm system at a commercial farm scale. Independent and balanced farmlets were managed on the same research farm according to consistent decision rules. The experiment compared a farmlet, where cows underwent an extended lactation to change from spring to autumn calving (AUT farmlet), with a farmlet that maintained a traditional spring-calving system (SPR farmlet). Chapter 4 quantified the biophysical performance of the AUT farmlet during the change of calving season and compared this with the performance of the SPR farmlet over the same period (two years and eight months). Chapter 5 quantified the economic performance of the AUT farmlet during the change of calving season and compared this with the performance of the SPR farmlet over four financial years, and modelled outcomes from a 10-year investment analysis. The following section discusses climatic changes, which are partially responsible for farmers' decisions to change the calving season of their herds, and then discusses the differences in performance between the two farmlets, the reasons behind these differences, and the implications of the biophysical and economic impacts, both in the present and under future scenarios.

6.1 Changing climatic variables

Anecdotal evidence indicates that over the past 20 years, the climate in South Taranaki, NZ, has changed, with greater variability of summer rainfall and warmer winter temperatures. Weather data collected from the VCSN support the perceived warmer temperatures, but do not support the belief that rainfall has become more variable. Fitted linear regressions indicated that on average, both the daily minimum and maximum air temperatures increased at Kavanagh farm since 1980, and in particular, winter daily minimum air temperature increased 1.41°C ±0.03 during this period. However, there was no reported heteroskedasticity of rainfall variation over this period.

Since 1860, average daily air temperature has increased in Taranaki, however there is large variation in the magnitude of the change across this period [Figure 6.1; Berkeley Earth (2020)]. Random year to year variation was at times greater than the long-term trend, so this must be considered when using timeseries data to draw conclusions. Dataset selection is important, as choosing different start and end points, depending on the between-year variation, can influence the magnitude of change. For example, Figure 6.1 indicates that average annual temperatures increased substantially between 1980 and 1988. Therefore, if 1988 was used as the start point for the current analysis instead of 1980, the increase in daily minimum air temperature would be less (-0.05°C; 1.57°C vs. 1.62°C). However, regardless of starting year, minimum and

maximum air temperatures (and therefore the estimated average air temperature[6]) at Kavanagh farm in South Taranaki are greater now than they were historically.

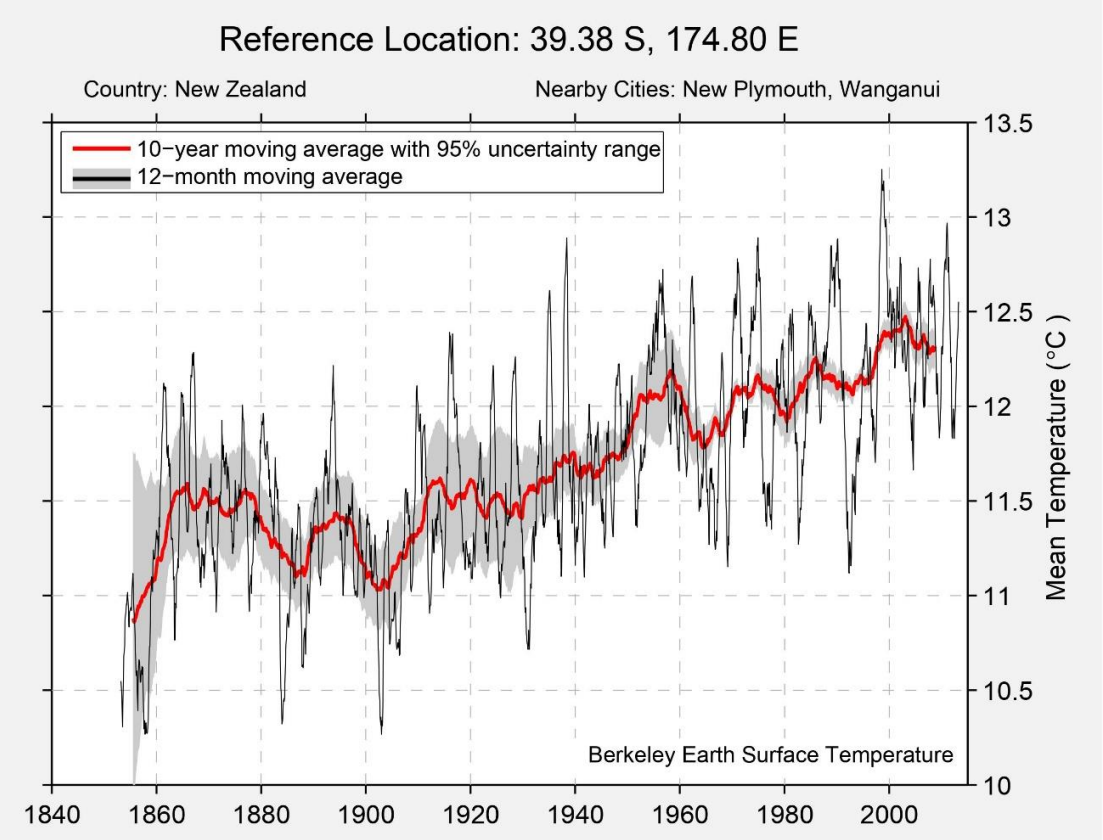

Figure 6.1. Historic average daily air temperature in South Taranaki, New Zealand. From Berkeley Earth (2020).

The change in both daily minimum and maximum air temperatures over the years in South Taranaki may be impacting PGR. Low temperatures during winter restrict perennial ryegrass and white clover growth (Wingler & Hennessy, 2016), and growth of both tends to be inactive below a minimum of 4°C air temperature (Hutchinson et al., 2000). The impact of air temperature on pasture growth is highlighted by the different PGR in regions throughout NZ. Average PGR for warmer regions such as Northland can be as high as 30–40 kg DM/ha/day during winter, compared with 20 kg DM/ha/day in the lower North Island and as low as zero in colder regions of the South Island (DairyNZ, 2010). Previous research has identified the strong positive association between GDD and PGR (Baars, 1982; Hutchinson et al., 2000). Since the minimum and maximum air temperature have increased at Kavanagh farm, annual GDD and winter GDD have also increased over the timeframe analysed. Therefore, this may have led to an increase in winter PGR during the last 39 years, providing an opportunity to increase feed

[6] In the current research, estimated average temperature is defined as the difference between the daily maximum and minimum temperature.

supply for the herd during winter, and supporting the anecdotal evidence reported by South Taranaki farmers.

The historic weather trends in South Taranaki are expected to continue due to the influence of predicted climate changes. It is expected there will be further impacts on PGR, and as a response, changes to farm systems. The Ministry for the Environment (2018) predict that in Taranaki by the 2031–2050 period, daily mean temperature will increase between 0.6 to 1.1°C, the number of hot days (>25°C) will increase from six to between 12 to 15 days, and the number of cold nights (<0°C) will decrease from six to between two to three nights. It is expected that PGR will be impacted by these climatic changes and subsequently alter the pasture supply curve (Clark et al., 2012; Lee et al., 2013). Winter PGR will likely increase, while summer PGR will likely decrease and become more variable. Since pasture-based dairy systems aim to match pasture supply with herd feed demand (Roche et al., 2017b), changes to the pasture supply curve may provide reason for farmers to consider changing their farming system. Historically, spring-calving systems are the most popular (Blackwell et al., 2010), but autumn calving may become more common in certain regions that are experiencing, or are expected to experience, changes to the pasture-supply curve. Farmers considering a change to calving season require information regarding the performance of their farm system as this change occurs. The following sections highlight important farm system implications from both a biophysical and economic perspective when calving season is changed from spring to autumn, utilising an extended lactation.

6.2 Implications of changing calving season on feed supply and demand

Changing the calving season from spring to autumn altered the relationship between pasture feed supply and herd feed demand. Spring calving in NZ was established to best match herd demand for energy and nutrients with pasture supply (Roche et al., 2017b). The timing of calving and length of the lactation are managed so that the herd feed demand profile matches as close as possible the 365-day seasonal pasture growth profile (Roche et al., 2018). For example, spring-calving cows calve approximately two months prior to the spring peak of pasture supply, so that the peak in demand for energy and protein by cows in early lactation is matched to the large supply of these nutrients as spring PGR also peaks. Hence, changing calving season in this current experiment caused the profile of herd feed demand to shift over time relative to the profile of pasture supply. This had biophysical and economic consequences for the AUT farmlet during both the extended lactation and the first autumn-calving 12-month CI lactation. The implications of these are discussed below.

6.2.1 Implications of feed deficits

The AUT farmlet required greater supplementary feed to be incorporated into the farm system in response to more severe and longer feed deficits. This caused differences in farmlet performance, from both a biophysical and an economic perspective. Cows in the AUT farmlet were offered greater quantities of supplementary feed in both L1 and L2 compared with SPR farmlet cows. Although the SPR farmlet cows underwent a third lactation during the experimental period, AUT farmlet cows were offered greater supplementary feed in total. Decision rules in both farmlets meant that supplementary feed was offered to fill feed deficits created when herd feed demand exceeded pasture supply, which primarily occurred during winter (June–August). By firstly undertaking an extended lactation, and then calving in autumn, AUT farmlet cows were milking during the winter months, exacerbating the difference in herd feed demand and pasture supply when pasture growth was low (Figure 4.25), indicated by the decrease in APC during these months in the AUT farmlet (Figure 4.23). Thus, more supplementary feed was required through this period to fill the more severe feed deficit, as previously concluded by Spaans et al. (2019). To minimise the impact of this winter feed deficit, methodology in previous literature has reduced the SR of the autumn-calving farmlet relative to the spring-calving farmlet (Fulkerson et al., 1987; Garcia et al., 2000). However, in the current experiment, SR was approximately equal between farmlets, and hence was not used as a lever to manipulate feed demand differences.

In addition to the greater amount of supplementary feed that was required by the AUT farmlet, the timing of use of supplementary feed during lactation was different (Figure 4.25). During L2, cows in the AUT farmlet received supplementary feed continuously from calving until late lactation, while cows in the SPR farmlet received supplementary feed in two distinct periods, early lactation and late lactation, which is consistent with previous literature (Roche et al., 2017b; Spaans et al., 2019). The increase in quantity and the difference in timing, of supplementary feeding, when changing season of calving, had three important implications on AUT farmlet biophysical and economic performance:

- increased system intensity (e.g., greater imported supplementary feeds);
- proportional increase in wastage of supplementary feed; and
- increased limitations to early lactation MS production.

These are discussed in turn in the following sections.

6.2.1.1 Implications of an increased system intensity

System intensity increased in the AUT farmlet during the experimental period because of the increase in use of supplementary feed, specifically, feed imported from an area other than the

milking platform. In NZ, five broad production systems have been defined, based on the strategic decision (e.g., long term) regarding the quantity and timing of imported supplementary feed that is to form part of the total feed supply ('DairyNZ systems', Hedley et al., 2006; Ho et al., 2013). A high system intensity (i.e., System 4 and 5) refers to a farm where imported supplementary feed contributes >~20% of the total feed supply, and the system is arranged accordingly (e.g., a high SR, a long lactation length). An increase in intensity, then, refers to a farm system that increases the relative proportion of imported supplementary feed in the total feed supply and deliberately changes factors of the overall system.

There are limitations to classifying the wide range of unique farm systems that exist in NZ into five discrete categories based on their use of imported supplementary feed. For example, low winter PGR result in dairy farms in Canterbury sending cows off the milking platform during winter, while milder winters mean that cows can be wintered on the milking platform in the Waikato, leading to differences in the amount of imported supplementary feed between farms, but not necessarily any difference in other parts of their system (Neal & Roche, 2020). In addition, year to year weather variation can result in low PGR, leading to importation of additional supplementary feed which can change the level of intensity for that season. Notwithstanding those limitations, system intensity is a key concept to consider in pasture-based dairy system analysis due to the impact that imported supplementary feed has on other parts of the system (e.g., SR, breed, pasture utilisation, expenses, and profitability)

In the current experiment, total imported supplementary feed per cow remained approximately the same in the SPR farmlet for all four years (Figure 6.2)[7]. Back calculation of cow energy requirements in the SPR farmlet indicated that imported supplementary feed contributed ~7–9% to total cow energy requirements each year. In addition, cows were wintered on the milking platform, thus, the SPR farmlet would be classified as System 2.

In the AUT farmlet, the same calculations indicated that imported supplementary feed contributed ~8–10% to total cow energy requirements in Y1 and Y2, slightly greater than the SPR farmlet cows. However, during Y3 in the AUT farmlet the total quantity of imported supplementary feed increased ~70% (Figure 6.2), and imported supplementary feed contributed ~13% to total cow energy requirements in Y3 and Y4. Consistent with the SPR farmlet, AUT farmlet cows were wintered on the milking platform, so in Y1 and Y2 the AUT farmlet would be classified as System 2. However, upon beginning Y3, with a seasonal autumn-calving pattern

[7] Imported supplementary feed described in Figure 6.2 differs to supplementary feed offered to each farmlet, reported in section 4.3.2, because the former includes assumptions for supplementary feed use in Y1 and Y3, while the latter describes the actual quantity of supplementary feed that was offered by farm staff.

established, there was greater reliance on imported supplementary feed within the total feed supply. This was because the lactation peak for those cows, and so peak herd feed demand, occurred during winter when PGR was low and imported supplementary feed was required to fill the feed deficit. Therefore, the AUT farmlet in Y3 and Y4 would be classified as System 3.

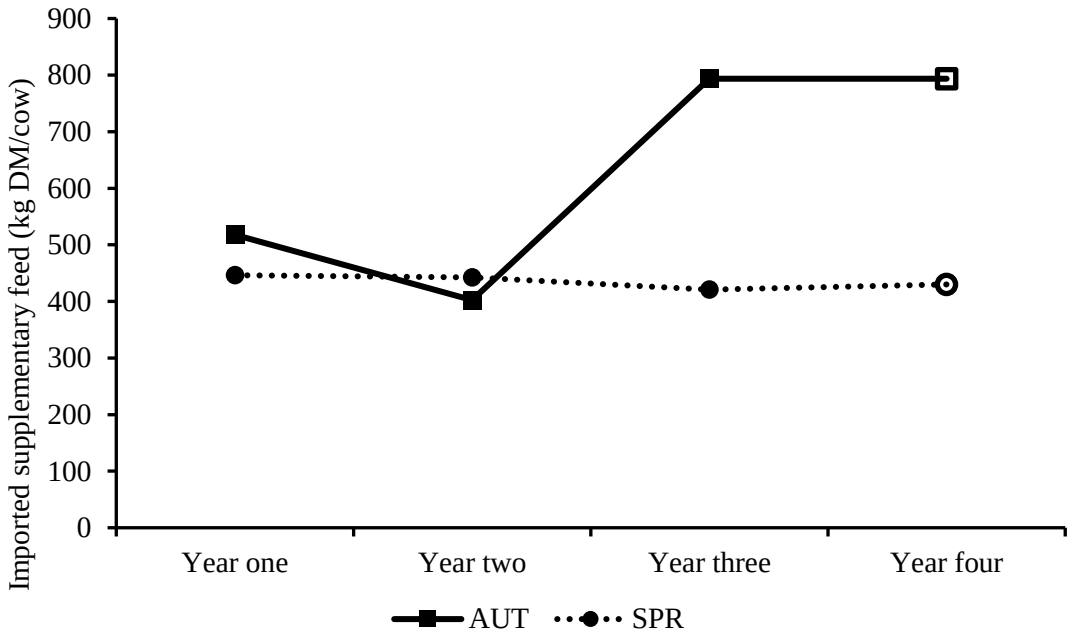

Figure 6.2. Imported supplementary feed per cow [kg dry matter (DM)/cow] for autumn-calving (AUT) and spring-calving (SPR) farmlet herds in each financial year of the economic analysis. Open symbols indicate the modelled year four data.

The different production systems defined during Y3 and Y4 for the AUT and SPR farmlets in the current experiment suggests that changing calving season alters system intensity; however, there is inconsistency in the literature on the relationship between calving season and system intensity. Reasons for this inconsistency are most likely due to differences in farm system set up and design (i.e., materials and methods). For example, in the current experiment there were differences in sources, amount and timing of use of the supplementary feed, and in previous experiments, those differences have occurred alongside differences in SR (Fulkerson et al., 1987; Ryan et al., 1998; Garcia et al., 2000). In addition, in many experiments, the source (i.e., home grown or imported) of supplementary feed is not well-documented.

Spaans et al. (2019), purposefully restricted their experimental farmlets to System 1 (i.e., no imported supplementary feed; Hedley et al., 2006), so that the different calving seasons could be compared in isolation to changes in imported supplementary feed and SR. They reported that a spring-calving system (July calving) produced greater MS and profit compared with an autumn-calving system (April calving). Whereas in the experiment conducted by Garcia et al. (2000), the autumn-calving system had a lower SR than the spring-calving system (2.0 vs. 2.4 cows/ha),

and the source and quantity of supplementary feed were not restricted. They reported that cows in the autumn-calving system were offered greater quantities of imported supplementary feed and produced greater MS compared with cows in the spring-calving system. Thus, in Garcia et al. (2000), the autumn-calving system could be predicted to have a greater system intensity; however, the authors did not report whether the difference in imported supplementary feed was large enough for the autumn-calving farmlet to be considered as a different production system based on the 'DairyNZ systems'. Furthermore, Garcia et al. (2000) hypothesised that an autumn-calving system may be able to utilise the increase in harvested home-grown feed to fill feed deficits, rather than importing additional supplementary feed. If this did occur, then the autumn-calving system may not have intensified as predicted. It is important to understand the relationship between changing calving season and system intensity because it may be linked with farm economic performance (Shadbolt, 2012; Ma et al., 2019).

A fundamental aim of pasture-based dairy farming is that pasture forms the majority of the cows' diet such that the cost of production is minimised (Roche et al., 2017b). The inclusion of imported supplementary feed can be used to support this aim through its impact on both the biophysical and economic performance of the system. Previous research on the use of imported supplementary feeds in pasture-based systems have reported on the impact to MS production (Penno et al., 1999; Macdonald et al., 2017), gross revenue (Shadbolt, 2012), total dairy operating expenses (Ramsbottom et al., 2015; Neal & Roche, 2020) and profitability (Hedley et al., 2006; Ma et al., 2019). Furthermore, the impact of changing system intensity on biophysical and economic performance has also been reported [Figure 6.3; Ma et al. (2019)]. However, it must be noted that conclusions from the former authors relate predominantly to spring-calving systems. There is no literature that details system intensity, and its effects, on a farm system that changes calving season from spring to autumn calving, or is already autumn calving. Hence, it is important to consider the farmlet performance in the context of system intensity in this current research.

Changes in biophysical and economic performance of the AUT farmlet as it moved from System 2, in Y1 and Y2, to System 3, in Y3 onwards, are mostly consistent with published responses. As system intensity increased, MS production and expenses increased, however, in contrast to previous literature, profit also increased. In the current experiment, when the AUT farmlet moved from System 2 to System 3, there was a 41% and 18% average increase in MS production and dairy operating expenses, respectively. This is greater than the 6% and 11% increase in MS production and dairy operating expenses reported by Ma et al. (2019). Inconsistent with the results from Ma et al. (2019), profit also increased in the current research by 52% between System 2 and System 3. A possible explanation for the differences reported here is that Ma et al. (2019) reported biophysical and economic trends from a large sample (n =

2,832 yearly farm records) of commercial farms, whereas the current results are from one individual farm during three seasons.

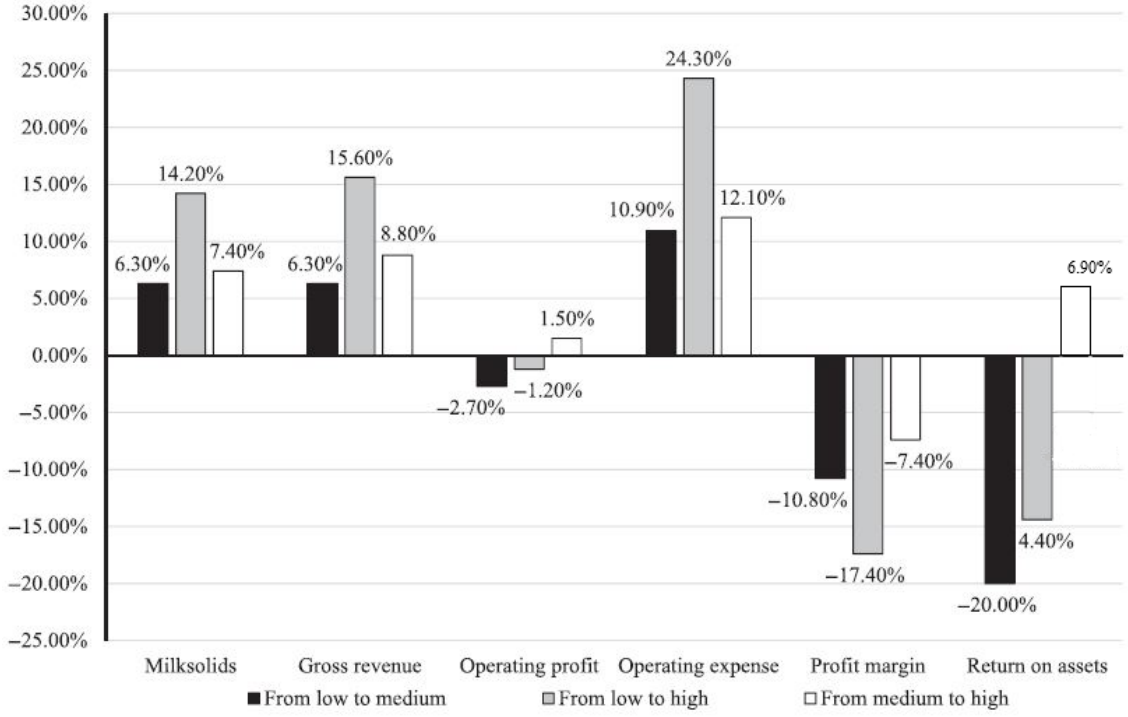

Figure 6.3. Effects of increasing system intensity (low, medium, high) on milksolids, gross revenue, operating profit, operating expense, profit margin and return on assets. Systems categorised based on the DairyNZ 'Five production systems' (Hedley et al., 2006), where 'low' = System 1 and 2; 'medium' = System 3; 'high' = System 4 and 5. From Ma et al. (2019; pg 751), and corrected for the error in the original publication.

Another possible explanation is that the timeframe and design of the current experiment meant that a combination of confounding factors also influenced biophysical and economic performance. The current experiment only reported results from approximately three years, and only reported results from a single autumn-calving lactation. As this single autumn-calving lactation formed the basis of the steady-state system assumptions, any climatic influence on performance during Y3 would have impacted on the results. Above average rainfall during April 2019 (112% above average) followed by below average rainfall during May and June (37% and 39% below average, respectively) may have contributed to lower PGR during this period, which may have required additional imported supplementary feed during Y3 relative to a 'normal' year. In addition, changes in production system did not occur in isolation; CI was extended and then calving season changed. Therefore, further analysis of both farmlets as they progress in their respective steady-state systems is required to accurately understand the drivers of biophysical and economic performance, and to assess whether the increase in system intensity in the AUT farmlet persists.

6.2.1.2 Implications of offering more supplementary feed during the winter

Wastage of supplementary feed fed out in the paddock, is greater during winter, and in the current experiment, likely contributed to the AUT farmlet requiring more supplementary feed, both during winter and in total throughout the experimental period. Compared with using a feed pad or in-shed feeding, in-paddock feeding is associated with the greatest wastage of supplementary feed, typically between 9 to 45%, because cows have greater opportunity to defecate, trample and urinate on the feed (Stockdale, 2010). This is exacerbated in wet weather that leads to muddy conditions, typical of winter in NZ (Kay et al., 2016). For both farmlets in the current experiment, all supplementary feed, except for PKE and meal, was offered in the paddock year-round. Compared with the SPR farmlet, the AUT farmlet received more total supplementary feed during the winter months (June–August, inclusive) in both 2018 and 2019 (Table 6.1), and in particular, more pasture and maize silage, which was feed out on the paddock. Therefore, although feed utilisation and thus wastage, was not measured in the current experiment, it would be expected that supplementary feed wastage was greater in the AUT farmlet, and likely contributed to the greater quantities of supplementary feed offered in this farmlet to fill the feed deficit during winter.

Wastage of supplementary feed is a pertinent consideration for autumn-calving systems because of the opposing requirements of needing to offer supplementary feed during the wetter winter months to fill the feed deficit, while minimising the total cost of supplementary feeding. The greater the wastage, the more supplementary feed required to fill the feed deficit, and thus, the greater cost of filling this deficit. Therefore, wastage also influences the profitability of supplementary feeding due to its impact on the cost.

Profitable supplementary feeding relies on a high milk price, low cost of the supplementary feed and high MMPR to the supplementary feed (Laborde et al., 1998), so that the marginal return from the additional MS production is greater than the marginal cost of offering the supplementary feed (Ho et al., 2018). High amounts of wastage will reduce the MMPR (Holmes & Roche, 2007) and increase the cost of delivering the supplementary feed. Because the AUT farmlet received a winter milk premium, the marginal return generated from marginal MS produced in winter was greater than at other times of the season, however, the increased wastage of supplementary feed may have offset this advantage and resulted in less profitable use of supplementary feed during this period.

One means to reduce wastage is to offer supplementary feed in the milking parlour, however, delivering feed through an in-shed facility is usually more expensive. Wastage from in-shed feeding can be as low as 5% compared with 9–45% when fed in the paddock (Stockdale, 2010;

Kay et al., 2016). In both farmlets, meal was offered via an in-shed feeding facility, and this was the most expensive supplementary feed used throughout the experiment ($600/t DM). The AUT farmlet fed 190 kg DM/cow more meal than the SPR farmlet during the 2019 winter (Table 6.1) and fed consistently more meal in total in each lactation (Table 4.15). So, in addition to offering greater quantities of supplementary feed during winter (due to the greater feed deficit and greater wastage), the cost per kg DM supplementary feed offered was also greater, due to feeding more of the expensive supplementary feed in shed.

Offering supplementary feeds on a feed pad is an alternative approach to feeding out in the paddock during winter. It can reduce wastage to ~10% (Kay et al., 2016), but can also increase the cost of delivering the supplementary feed. In the current experiment, the total quantity of supplementary feed offered to both farmlets would have most likely reduced if a feed pad had been available on both farmlets. The effect would have been greater in the AUT farmlet because it would have reduced the impact of wastage of supplementary feed during winter. But the cost of installing a feed pad, and the on-going yearly costs of using a feed pad, add to the effective cost of the supplementary feed. Open-air loafing pads can cost $400/cow, while enclosed barns can cost $1,500/cow (Beukes et al., 2011). In addition, there are increased expenses associated with using the infrastructure (Ramsbottom et al., 2015; Neal & Roche, 2020). Combined, these increase the cost of supplementary feeding. So, if the farm already has feeding infrastructure (e.g., a feed pad) in place, the increase in supplementary feeding costs may be less than expected. Therefore, the availability and suitability of current on-farm infrastructure for winter feeding should be considered during the decision-making process when changing the calving season to autumn.

Table 6.1. Supplementary feed offered per cow [kg dry matter (DM)/cow] during winter (June–August, inclusive) to the autumn-calving (AUT) and spring-calving (SPR) farmlet herds. PKE = palm kernel expeller. Data was unavailable for winter 2017.

	Winter 2018[1]		Winter 2019[2]	
	AUT	SPR	AUT	SPR
Pasture silage	253	182	378	25
Maize silage	0	0	71	63
Meal	0	0	279	89
PKE	276	38	0	0
Hay	0	28	0	142
Total	529	247	727	319

[1] Corresponds to the extended lactation (lactation one) for the AUT farmlet and lactation two (L2) for the SPR farmlet

[2] Corresponds to L2 for the AUT farmlet and lactation three for the SPR farmlet

6.2.1.3 Implications of supplementary feed in the diet of early lactation cows

Differences in the nutrient content of the diet during early lactation may explain the lower peak in MS production of the AUT farmlet cows compared with the SPR farmlet cows during L2 (Figure 4.6). This is consistent with the lower peak in MS production in autumn-calving cows in other research (Garcia & Holmes, 2001). The differences in MS production profiles between autumn- and spring-calving herds may be partially due to differences in pasture quality and quantity, and the proportion of supplementary feed in the diet.

During peak lactation, autumn-calving cows typically receive a diet that contains poorer quality pastures and a greater proportion of supplementary feed (Garcia & Holmes, 2001). In the current research, AUT farmlet cows received more supplementary feed during early lactation of L2 compared with L2 and L3 of SPR farmlet cows (Table 6.2). In particular, AUT farmlet cows were offered greater quantities of pasture and maize silage. Generally, metabolisable energy (ME) is the most limiting nutrient to MS production in total pasture diets (Kolver & Muller, 1998). However, it is acknowledged that the low crude protein (CP) content of maize silage (6–8%; Macdonald et al., 1998; Kolver et al., 2001) can limit MS production when it forms a large proportion of the diet. This can occur if maize silage is being fed at the same time as when the CP content of pasture is low due to seasonal changes (Roche et al., 2009c), and/or if cows are in early lactation when their metabolisable protein (MP) requirements are greatest (National Research Council, 2001). During early lactation of L2, AUT farmlet cows were grazing autumn-grown pasture whereas SPR farmlet cows were grazing spring-grown pasture. Although pasture quality was not recorded in this experiment, ME and CP are usually lower in autumn-grown pasture compared with spring-grown pasture (Garcia & Holmes, 2005; Roche et al., 2009c). The reduced quality (energy and protein) of the autumn pasture, combined with the increased amount of maize silage in the diet, indicate that ME and CP may not have met requirements for peak MS production, therefore, during early lactation, the energy and/or protein content of the diet may have limited MS production in the AUT farmlet cows (non-nutritional factors of the lower peak MS production are discussed further in section 6.3.1.2).

Table 6.2. Supplementary feed offered per cow [kg dry matter (DM)/cow] during early lactation to the autumn-calving (AUT; March–June, inclusive) and spring-calving (SPR; July–October, inclusive) farmlet herds for lactation two (L2) and lactation three (L3). PKE = palm kernel expeller.

	Early lactation – L2		Early lactation – L3
	AUT	SPR	SPR
Pasture silage	153	62	28
Maize silage	264	0	0
Meal	120	0	195
PKE	0	64	0
Hay	37	28	118
Total	574	154	341

Alleviating any diet-induced limitations to MS production in early lactation would enable greater MS production from autumn-calving cows, and thus, increase the revenue from the winter milk premium. However, profitably achieving this is challenging, as high ME and high CP supplementary feeds (e.g., dried distillers' grains, canola meal, soybean meal) are usually the most expensive types of supplementary feed. In addition, these feeds are often fed via in-shed feeding facilities to limit wastage and ensure consistent animal intake. However, this places a limitation on the amount that can be offered to cows on a daily basis, due to milking speed restrictions, and has cost implications (Ramsbottom et al., 2015; Neal & Roche, 2020). Further research is required to determine the cost/benefit of altering the ME and CP content of the diet in early lactation of pasture-based autumn calving systems.

6.2.2 Implications of feed surpluses

Misalignment of feed supply and herd feed demand in the AUT farmlet resulted in periods of feed surpluses, which again influenced the biophysical and economic performance of the farmlet in comparison to the SPR farmlet. Feed surpluses occurred during late spring and early summer in every year for both farmlets because of the increase in PGR. These were either harvested as pasture silage or hay, or deferred to be grazed later in the season. The difference between PGR and herd feed demand in the AUT farmlet during Y2 was greater, increasing the amount of surplus feed available, and thus, the amount of pasture silage and hay that was harvested on the milking platform was greater compared with the SPR farmlet (Figure 6.4).

During Y1, there was no difference in the feed demand and feed supply relationship between the farmlets in early and mid-lactation, as both farmlets calved during spring. Feed demand prior to late spring and summer was similar, resulting in a similar quantity of supplementary feed harvested (73 t DM for both farmlets).

During Y3, there was only a small difference in the quantity of supplementary feed harvested, with the SPR farmlet harvesting 6% (8 t DM) more pasture silage and hay than the AUT farmlet (Figure 6.4). This was unexpected, considering prior research has reported that autumn-calving systems tend to conserve more pasture compared with spring-calving systems (Ryan et al., 1998; Garcia & Holmes, 1999; Garcia et al., 2000). During Y3, both farmlet herds were undergoing 12-month CI lactations, but the AUT farmlet had calved in autumn whereas the SPR farmlet had calved in spring. There was an increase in the PGR in both farmlets during late spring and summer of Y3 (Figure 4.24), and both farmlets had ceased supplementary feeding at this time (Figure 4.25). Although not directly measured in the current research, the feed demand of the AUT farmlet would have been expected to be lower than that of the SPR farmlet because the AUT farmlet was in late lactation while the SPR farmlet was in mid-lactation. This suggests that there would have been a greater feed surplus in the AUT farmlet, which would have led to

an increase in the amount of pasture requiring conservation relative to the SPR farmlet. However, the APC during spring in the AUT farmlet was lower compared with the SPR farmlet, so although the lower feed demand would have normally meant that there was a pasture surplus, the lower APC meant that this surplus first contributed to increasing the APC before it was then able to be conserved as silage. These current results support the contrasting conclusion reported by Spaans et al. (2019), that there is no difference in the quantity of pasture harvested between autumn- and spring-calving systems. As the experiments by the former and latter authors are confounded by SR and grazing management decisions, and are subject to between-year climatic variability, it is unclear as to why, in the current research, the AUT farmlet did not conserve more surplus pasture compared with the SPR farmlet during Y3.

Conversely, during Y2 there was a large difference in the feed demand and feed supply relationship between farmlets. Cows in the AUT farmlet were undergoing the later stages of their extended lactation (L1) during late spring and summer of Y2 so many cows were producing low levels of MS or were already dry, while SPR farmlet cows were in early lactation of L2. Hence, feed supply and demand differed dramatically between farmlets, with much greater herd feed demand in the SPR farmlet compared with the AUT farmlet. Thus, in this year the AUT farmlet harvested 260% (70 t DM) more pasture silage and hay than the SPR farmlet. The consequences of the imbalance between feed supply and demand during the extended lactation, and the implications on the biophysical and economic performance of the AUT farmlet are discussed in the following sections.

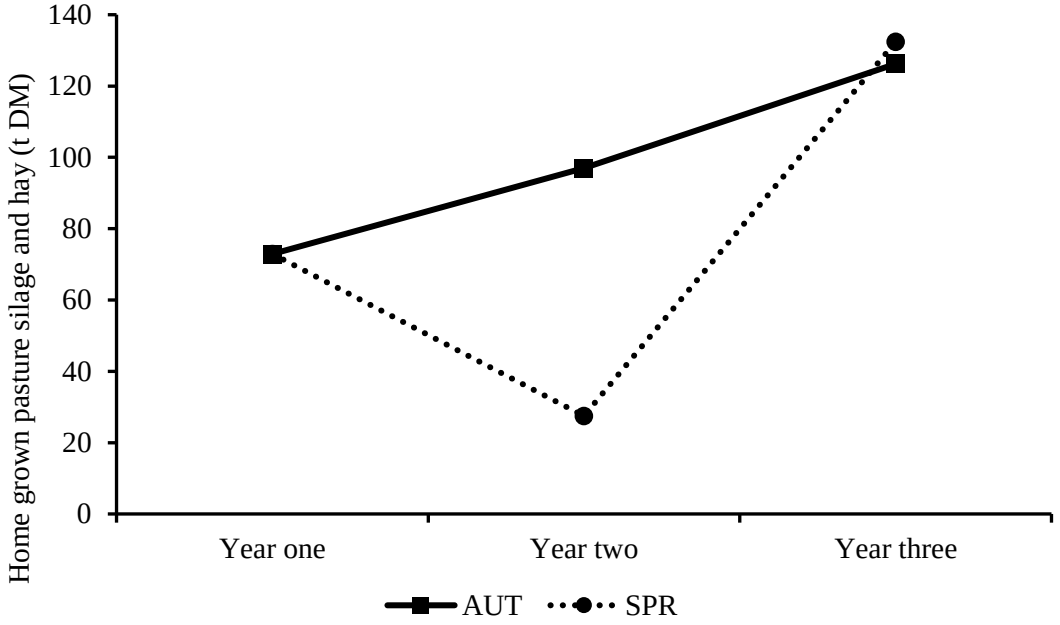

Figure 6.4. Total harvested amount of home grown (i.e., from the milking platform) pasture silage and hay [t dry matter (DM)] in the autumn-calving (AUT) and spring-calving (SPR) farmlets in each year (i.e., 1 June–31 May).

6.2.2.1 Implications from implementing grazing management targets during the extended lactation

The imbalance of feed supply and demand, plus the additional days non-lactating, combined with the implementation of grazing management targets in the later stages of the extended lactation, led to the AUT farmlet cows gaining greater than optimal LWT and BCS. During this stage of the extended lactation, there was the desire to maximise DIM (and thus MS production) of the AUT farmlet cows, however, these cows were producing low quantities of MS (<1.5 kg MS/cow/day; Figure 4.7), and by 15 August 2018 (408 days since PSC), 43 cows had been dried off (14% of the herd), and by 15 November 2018 (500 days since PSC), 67 cows had been dried off (22% of the herd), reducing the feed demand of the whole herd. During this same period (late spring and early summer) PGR peaked at approximately 60 kg DM/ha/day (Figure 4.24), and the grazing management targets, outlined in the decision rules, required balancing the competing aims of achieving the pre-determined post-grazing pasture residual, by restricting the grazing area of the herd, and meeting the rotation length target (i.e., a 1/24th rotation), by increasing the grazing area of the herd. These cows were offered relatively large pasture allocations (~16 kg DM/cow/day), and as a result, feed supply (i.e., energy input) exceeded the energy output from the MS produced during the second spring of the extended lactation.

Cows selectively bred for 12-month CI preferentially convert this excess energy to adipose tissue rather than milk production, thus, increasing BCS during the second spring (Kolver et al., 2007). The BCS of AUT farmlet cows was approximately equal to that of the SPR farmlet cows until about August 2018 (Y2), and then increased rapidly to the end of the extended lactation (Figure 4.18). One month prior to the PSC in L2 (i.e., 14 February 2019), AUT farmlet cow condition was on average 5.9 BCS, where 109 cows (36% of the herd) had BCS greater than 6.0 BCS and 6 cows (2% of the herd) had greater than 7.0 BCS. Auldist et al. (2007) and Kolver et al. (2007) both reported a similar increase in BCS in cows during an extended lactation. These cows spent an extended period in a positive energy balance after peak milk production, so were able to conserve more energy as body tissue compared to cows in 12-month CI lactations (Auldist et al., 2007). However, this led to management implications and increased health risks in the current and subsequent lactations (Kolver et al., 2007).

In response to the increased risk of periparturient metabolic disease caused by excessive BCS at calving (e.g., hypocalcaemia; Roche et al., 2013b), non-lactating cows in the AUT farmlet were offered a restricted diet by reducing pasture allocation and slowing the rotation length. This started at the end of January when the herd was dried off and continued until all cows had calved again. This reduced their energy intake and reduced their BCS, as their BCS at calving in L2 was lower than when drying off in L1 (Figure 4.19). This led to no difference in incidence of

periparturient hypocalcaemia between farmlets, which is consistent with reports in the literature (Roche et al., 2015b).

However, the restricted pasture allocation may have been a factor in increasing the incidence of ryegrass staggers. Farm staff reported an increase in episodes of ryegrass staggers in AUT farmlet cows compared with the SPR farmlet cows during March and April, which was the time immediately preceding calving for the AUT farmlet cows. Ryegrass staggers is a nervous system disease which is primarily caused by high levels of lolitrem B in ryegrass (Smith & Towers, 2002; di Menna et al., 2012). The levels of this mycotoxin generally peak during the summer and autumn months, and are greatest in leaf sheaths and reproductive tillers near the bottom of the sward and in the seeds of ryegrass that has been allowed to mature (di Menna et al., 2012). Restricting DMI will normally cause cows to graze lower into the sward (Cosgrove & Edwards, 2007), and therefore increase their intake of lolitrem B. Hence, the increase in incidence of ryegrass staggers in the AUT farmlet may have been due to cows eating lower into the sward during their non-lactating period when they were offered a restricted pasture allocation. However, the post-grazing residual did not significantly differ between the AUT and SPR farmlets in the summer of Y2 (Table 4.14). There are then two possible explanations for the difference between farmlet incidence of ryegrass staggers without difference between farmlet post-grazing residual.

One possible cause may be that 4 ha of surplus pasture in the AUT farmlet was deferred grazed from January–March in Y2 due to it being deemed unprofitable to convert this surplus feed to silage. An adequate amount of pasture silage had already been harvested in the AUT farmlet during Y2 (Figure 6.4), and this surplus pasture was of lower quality compared with pasture ensiled earlier in the year (e.g., spring-harvested pasture silage). As the cost of making silage remains the same regardless of pasture quality, ensiling surplus summer/autumn pasture increases the cost of this feed on a c/MJ ME basis. Additionally, because autumn-calving systems require supplementary feed in early lactation during winter, there is a greater importance on harvesting high quality supplementary feed compared with a spring-calving system where this supplementary feed would predominantly be fed to non-lactating cows during winter. Hence, deferred grazing is a cheaper method of conserving lower quality surplus pasture. It requires paddocks to be not grazed for a prolonged period of time (typically from November–March; Thomson et al., 1989; McCallum et al., 1991), and allows the ryegrass plant to enter a reproductive stage, increasing the number of seed heads and reproductive tillers, and therefore, increasing the risk of grazing high lolitrem B ryegrass. It leads to a greater pre-grazing residual, and potentially explains the difference between pre-grazing residuals between farmlets during summer in Y2. The non-lactating cows, instead of the lactating cows, grazed the deferred-grazed paddocks, and it was in these cows that ryegrass staggers occurred. Hence, the

decision to defer graze in the AUT farmlet but not the SPR farmlet may have led to greater incidence of ryegrass staggers. This highlights the risk of deferred grazing in a farm system where cows are undergoing an extended lactation and have a restricted pasture allowance during summer.

The other possible reason is the difference in post-grazing residual targets between lactating and non-lactating cows. To achieve the relatively lower post-grazing residual for non-lactating cows, specified in the decision rules, these cows were allocated restricted pasture allocations compared with lactating AUT and SPR farmlet cows. As these non-lactating cows grazed lower into the sward they would have likely increased their exposure to higher lolitrem B concentration ryegrass, which may explain the increase in incidence of ryegrass staggers. Unfortunately, the state of the herd (i.e., lactating or non-lactating) was not recorded with the pasture mass data. As the reported post-grazing residual was the average of multiple paddocks, some of which would have been allocated to lactating cows and some to non-lactating cows, the likely lower post-grazing residuals of the non-lactating cows may have been masked by the greater post-grazing residuals of the lactating cows during this period. Traditionally, a lower target for non-lactating cows has been a result of extending the rotation length during winter, when PGR are low, so that APC targets at calving can be achieved in spring-calving systems (Macdonald et al., 2010). However, in autumn-calving systems PGR during the non-lactating period are most likely to be greater compared with the non-lactating period of spring-calving systems, and there is likely to be less pressure on achieving APC targets at calving. Therefore, grazing decision rules for the non-lactation period, developed for spring-calving systems, may not be suitable for autumn-calving systems.

This highlights that during the later stages of the extended lactation, the feed surplus that occurs creates challenges for both animal and grazing management. An alternative grazing management strategy to the one used here may be to reduce the pasture allocation to cows during the later stages of their extended lactation to minimise body condition gain, however, this would most likely lead to even greater quantities of pasture being conserved. This demonstrates the increased complications associated with managing an extended lactation period in pasture-based systems with NZ dairy cows bred for 12-month CI (Kolver et al., 2007).

6.2.3 Climate change impacts on pasture growth profiles and alignment with autumn-calving systems

Predicted climatic changes may impact positively on the relationship between feed demand and supply for a farm changing to autumn calving. Under predicted climate change scenarios for NZ, the feed deficit traditionally experienced during the winter months may become less severe in the future due to the increasing winter PGR (Clark et al., 2012; Lee et al., 2013). An increase

in pasture grown during winter would likely reduce the supplementary feed requirements during these months, potentially decreasing the system intensity and supplementary feed wastage, while providing a higher quality feed to cows during early lactation. As the winter feed deficit impacts both the extended lactation and autumn-calving lactation, any climatic changes influencing winter PGR will have a continued impact on both the period over which the herd changes calving season and when it is in a steady state.

In contrast, feed surplus implications were mainly identified during the extended lactation when the herd changed calving season. This feed surplus predominantly occurred during late spring and early summer when the herd feed demand was reduced at the end of the extended lactation. Compared with a feed deficit, the feed surplus is more easily managed in the farm system so decreased and more variable summer PGR will have less of an impact on a farm that is changing calving season. In addition, the implications caused by the feed surplus mainly apply to the extended lactation, so only apply once to the farm system. Reduced summer PGR may reduce the amount of surplus pasture that is required to be harvested and aid grazing management decisions. In severe cases, supplementary feed would be able to be imported to offset any feed deficit. In contrast, if summer PGR variability results in increased PGR, then any surplus is able to be harvested.

6.3 Implications of changing calving season on animal performance

As expected, performance of AUT farmlet cows was different to SPR farmlet cows. Firstly, as the CI was extended to change from spring to autumn calving, there were consequences of the extended lactation on animal performance. Then, as cows returned back to a 12-month CI (L2), after their first autumn calving, animal performance was affected due to calving in a different season (i.e., autumn) and the carry-over effects from the extended lactation.

The relative success of using an extended lactation to change calving season depends on cow performance during the extended lactation, particularly the conversion of feed to MS, and so revenue. Therefore, the aim is to maximise DIM and minimise the period when cows are not lactating during the extended lactation. Even though the extended lactation is a temporary change to the farm system, rather than a new status quo, the implications on the following 12-month CI must be managed so that the carry-over effects are minimised. So, the success of the extended lactation is, in part, linked to the minimisation of detrimental implications and the optimal preparation of the system to enter the new autumn-calving 12-month CI lactation. The following section details the implications that undergoing an extended lactation had on productive and reproductive performance of multiparous and primiparous animals, both during

the extended lactation period and the first 12-month CI autumn-calving lactation, and considers these effects on the economic performance of the system.

6.3.1 Lactational performance

The timeframe of the current experiment enabled collection and analysis of results from two lactations from the AUT farmlet cows. The first was the extended lactation (L1) and the second was the 12-month CI following the first autumn-calving (L2; Figure 3.3). In both lactations, AUT farmlet cows produced more MS and had greater DIM compared with either L1 and L2 of SPR farmlet cows (both 12-month CI lactations; Table 4.1).

Across the whole experimental period (June 2017–January 2020) there was no overall benefit to MS production when changing calving season to autumn. Although the SPR farmlet completed two and a half lactations compared with two lactations in the AUT farmlet, total MS production was approximately the same between farmlets (1% greater in the AUT farmlet). This, to my knowledge, has not been investigated previously. Data from the current experiment indicate that the greater MS production from the first 12-month CI autumn-calving lactation offset the lower annualised MS production during the extended lactation, and combined with one less non-lactating period, led to total MS production being similar between the two farm systems.

6.3.1.1 Individual cow performance varies when undergoing an extended lactation

Lactational performance of the AUT farmlet cows is consistent with literature where pasture-based dairy cows have undergone an extended lactation. Milksolids production from the AUT farmlet cows during L1 peaked in early lactation (~80 DIM) and then decreased as lactation progressed. Milksolids yield then peaked again during the second spring (~400 DIM), which is a profile similar to that reported by Kolver et al. (2007) and Auldist et al. (2007).

A change in composition of the diet in the AUT farmlet is most likely the cause of the second peak in MS production. Spring-grown pasture is greater quality than winter-grown pasture (Roche et al., 2009c), and typically greater quality than supplementary feed. Thus as PGR during spring increased, and the ratio of pasture to supplementary feed in the diet of AUT farmlet cows increased (Figure 4.25), cows were provided with greater ME and CP, relative to their winter diet, and produced more MS. In systems that are not pasture based (e.g., when a high quality and quantity TMR is offered), winter MS production was greater and there was no second spring MS production peak (Kolver et al., 2007; Grainger et al., 2009). Hence, the MS production profile from the current experiment is a consequence of a ‘restricted’ winter diet followed by an increasingly high-quality diet (e.g., grazed spring pasture; Grainger et al., 2009). Thus, in pasture-based systems, MS production during winter of the extended lactation may be increased if more high-quality supplementary feed is offered. This would result in greater MS

production during the applicable period of the winter milk premium, increasing gross revenue. However, this would also increase the total amount of supplementary feed offered, and particularly as winter is the time of the greatest feed wastage (see section 6.2.1.2), would increase both the direct cost and the associated costs of supplementary feeding (Ramsbottom et al., 2015; Neal & Roche, 2020).

The annualised MS production of the AUT farmlet cows during the extended lactation was similar to the total MS production of the SPR farmlet cows in L1 (Table 6.3). Annualising production allows comparisons between extended lactations and 12-month CI lactations, and can be calculated as the total lactation yield multiplied by 12/CI (Auldist et al., 2007). Annualised MS production during L1 was 3 kg MS/cow greater in the AUT farmlet compared with the SPR farmlet. However, annualised MS production in L1 for both farmlets was less than in L2. This may be due to climatic differences between the years and could be attributed to the low rainfall during early summer of Y1, reducing PGR (Figure 4.24). Auldist et al. (2007) reported that there is a negative relationship between CI and annualised MS production, such that as CI increases, annualised MS production decreases, which disagrees with the current experiment. Feeding management decisions in the experiment reported by Auldist et al. (2007) meant that supplementary feed was utilised during pasture supply deficits so that cows were offered a minimum of 180 MJ ME/day, and cows were unrestricted in their access to pasture during pasture supply surpluses so were able to consume greater than 180 MJ ME/day, and were effectively being ad-lib fed. Hence, the conclusions reported by Auldist et al. (2007) may not be applicable to extended CI systems when cows are subject to feed restrictions. Furthermore, an explanation as to why annualised MS production in the AUT farmlet was similar to the SPR farmlet in L1, is that the reduction in PGR and MS production that occurred as a result of the low rainfall in early summer of Y1 had a greater influence on SPR L1 than AUT L1. Milksolids production for the AUT farmlet occurred over a longer period (because it was an extended lactation), so the impact of low PGR at the start of that lactation was offset by better climatic conditions in later stages of the lactation. If the extended lactation had occurred in another year, the annualised MS production may have been less than the SPR farmlet.

Table 6.3. Total and annualised milksolids (MS) production per cow (kg MS/cow) of the autumn-calving (AUT) and spring-calving (SPR) farmlet cows in lactation one (L1) and lactation two (L2), where annualised production is the total lactation MS yield multiplied by 12/CI, and CI is the calving interval (Auldist et al., 2007). Total MS production equals annualised MS production for the SPR farmlet in L1 and L2, and the AUT farmlet in L2, as these were 12-month CI lactations.

	L1		L2	
	AUT	SPR	AUT	SPR
Total MS production	661	395	533	428
Annualised MS production	397			

During the extended lactation, DIM varied for the AUT farmlet cows, indicating that some cows may be more suited to extended lactations due to their genetic makeup and age. Cows in NZ are bred predominantly for 12-month CI systems, as such, there is large variation in the ability of cows to continue lactating beyond a typical 305-day lactation (Kolver et al., 2007). During the extended lactation (~20-month CI), 76% of AUT farmlet cows were still lactating at 400 DIM and 52% were still lactating at final dry off (577 DIM). Greater persistency of lactation has been reported, where 96% of cows reached dry off during an 18-month CI lactation (485 DIM) and 83% of cows reached dry off during a 21-month CI lactation (561 DIM; Auldist et al., 2007). However, cows in that experiment were dried off when their average weekly milk yield was <30 kg/week for two consecutive weeks, which was a much lower threshold compared with the current experiment (<10 L/day at a monthly herd test), and in addition, cows in the study by Auldist et al. (2007) were not subject to feed restrictions. Furthermore, those cows were NA HF which due to their ancestry (Harris & Kolver, 2001), are more suited to extended lactations (Kolver et al., 2007), compared with the HF x Jersey crossbred cows in the current experiment. In the current experiment, there was no correlation between the proportion of HF genetics in the cow and their DIM or MS production. Instead, there was a correlation between MS production and BW. This may have been confounded due to the older cows, which had a lower BW and tended to have greater HF proportion, being preferentially culled prior to reaching their potential maximum DIM and MS production.

Because individual cows vary in their ability to undergo an extended lactation, the performance of farms utilising an extended lactation when changing calving season will also vary. Cows that are less suited to an extended lactation will potentially dry off earlier and produce less MS, which will reduce their total MS production during the extended lactation. This loss in MS production, which occurs during Y2 (i.e., the later stages of the extended lactation), is a major factor of the severity of the initial net costs when changing calving season (discussed further in section 6.5.1). Increasing total herd MS production during the extended lactation could be achieved by increasing the DIM of individual cows, through additional feed inputs. However, as discussed previously (see section 6.2.2.1), there is a tendency for the type of cow in the current experiment to partition this energy towards body condition rather than MS production. Thus, the physiological constraints of the cow may limit potential production during an extended lactation. This genetic by environment interaction is highlighted by Kolver et al. (2007), where NA HF cows (e.g., cows from ancestors bred for non-confinement to a 12-month CI) had greater DIM and produced more MS if fed more supplementary feed during an extended lactation, whereas NZ HF cows produced less MS and gained more body condition when additional supplementary feed was offered during the extended lactation. However, as the extended lactation only occurs once when changing calving season, there is no worthwhile

incentive to change the makeup of the herd so that extended lactation MS production is optimised. Instead, farmers must take into consideration the unique attributes of their current herd and factor in potential limitations to maximising the length of the extended lactation, to maximise MS production and revenue, whilst managing pastures, LWT and BCS to minimise any negative carry-over effects to the following lactation.

6.3.1.2 Autumn-calving cows produce more milksolids compared with spring-calving cows

During L2, AUT farmlet cows produced more MS compared with SPR farmlet cows. In both farmlets, L2 was a 12-month CI lactation, however the profile of MS production differed. Cows in the AUT farmlet had more DIM, compared with SPR farmlet cows, because of temporal differences in system performance relative to when drying-off decision rules were applied (Garcia & Holmes, 1999). In the current experiment, drying-off decision rules were the same between farmlets during L2, however, because pasture growth, and thus pasture supply, were greater during late lactation in the AUT farmlet compared with the SPR farmlet (Figure 4.25), there was more time to achieve BCS and APC targets, and cows were able to milk on for longer before drying-off decision thresholds were reached.

The greater DIM, and greater MS production during the later stages of L2 in the AUT farmlet produced a flatter MS production profile compared with the SPR farmlet, which indicates greater lactation persistency. As the cows in this experiment were balanced for BW at the beginning of this experiment, differences in MS production profiles was most likely mediated by differences in feeding. Greater pasture growth in mid- and late lactation leads to a greater proportion of pasture in the diet for autumn-calving cows (Garcia & Holmes, 2001). Cows in the AUT farmlet were offered spring- and early-summer grown pasture during mid- and late lactation, which likely contained higher ME and CP concentrations than both the autumn pastures and the supplementary feeds that were offered in mid- and late lactation to the SPR farmlet cows (e.g., pasture silage, maize silage, PKE; Roche et al., 2009c). This means that during mid- and late lactation, AUT farmlet cows were most likely receiving a diet of greater quantity and quality compared with the SPR farmlet cows at the same stage of lactation, leading to a greater persistency of MS production and greater DIM. The combination of greater persistency of MS production and greater DIM meant that AUT farmlet cows produced more MS during L2.

During L2, peak MS production was lower in the AUT farmlet compared with the SPR farmlet, potentially due to differences in early lactation diet, as discussed in section 0; however, there are also non-nutritional factors that may have influenced MS production:

Early lactation in the AUT farmlet occurred during winter, in contrast to spring for the SPR farmlet. As the winter solstice in the southern hemisphere occurs at the end of June, day length (i.e., photoperiod) decreased from the pre-partum period until peak MS production in early lactation for the AUT farmlet, whereas day length increased during this period for the SPR farmlet. Cows exposed to a short-day photoperiod during their dry period, followed by exposure to a long-day photoperiod during lactation, produce greater MS relative to cows exposed to long days during their dry period and short days during lactation (Dahl et al., 2000; Miller et al., 2000). Furthermore, there is a positive association between sunlight hours and MS production (Roche et al., 2009e). Hence, compared with autumn-calving systems, spring-calving systems are more favourably aligned with the positive photoperiodic influence on MS production. This may be one non-nutritional factor that contributed to the lower early lactation MS production in the AUT farmlet cows.

Contrasting climatic conditions during early lactation may have been another non-nutritional factor that contributed to the difference in peak MS production between the farmlets. Optimum cow performance occurs within a thermoneutral zone, outside of which heat or cold stress reduce performance. For a lactating cow producing 26 L milk/day, the lower critical ambient air temperature is about −26°C in dry and still air (Van Laer et al., 2013), but this can increase to 7.5°C in strong wind and rain conditions (Bryant et al., 2010) due to increased evaporative heat loss from wet coats, caused by rainfall, and convective heat loss, from wind chill (Van Laer et al., 2013). A cold stress index (CSI) has been formulated, which measures this combination of ambient temperature, rainfall and wind that a cow is exposed to, to identify when cows may be subject to conditions of cold stress. In NZ conditions, a negative association between the 3-day average CSI and MS production for HF x Jersey cows was reported to begin to occur when the CSI exceeded 1,000 kJ m^{-2} h^{-1}, which then increased in magnitude when the CSI exceeded 1,300 kJ m^{-2} h^{-1} (Bryant et al., 2007). For context, a CSI of 1,300 kJ m^{-2} h^{-1} is approximately equivalent to an average temperature of 10°C, a wind speed of 25 km/h and 20 mm of rainfall (Bryant et al., 2007). As early lactation occurred during winter for the AUT farmlet cows, when the CSI would be expected to be lower, compared with spring for the SPR farmlet cows, when the CSI would expected to be higher, this supports the hypothesis that peak MS production may have been climatically constrained in the AUT farmlet herd. However, Bryant et al. (2007) also reported that over their 3-year experimental period, only 2.9% of days per year in Taranaki exceeded a CSI of 1,300 kJ m^{-2} h^{-1}, highlighting that cold stress limitations to MS production are most likely limited. A related, and more likely climatic limitation to MS production in the AUT farmlet, is the effect of poor climatic conditions on DMI. In cold, wet, and windy conditions, cows are likely to seek shelter, stand with their heads down facing away from the

wind, and stop grazing (Bryant et al., 2010). Consequently, their DMI decreases and there will most likely be a concurrent decrease in MS production.

6.3.1.3 Milk composition differed between autumn- and spring-calving cows

Changing calving season to autumn altered the fat and protein percentage of milk which had economic implications for the AUT farmlet. During a typical 12-month CI lactation, milk fat and protein concentrations generally decrease from calving to a nadir at peak lactation, and then increase until drying off as milk volume reduces [Figure 6.5; Holmes et al. (2007)]. During both L1 and L2, fat and protein percentage of milk produced in the SPR farmlet followed a similar temporal pattern. In comparison, in the AUT farmlet during L2 (12-month CI lactation), the fat percentage of milk remained elevated during early lactation, decreased in mid- to late lactation, and then increased to the end of the lactation, and was greater on average compared with the SPR farmlet.

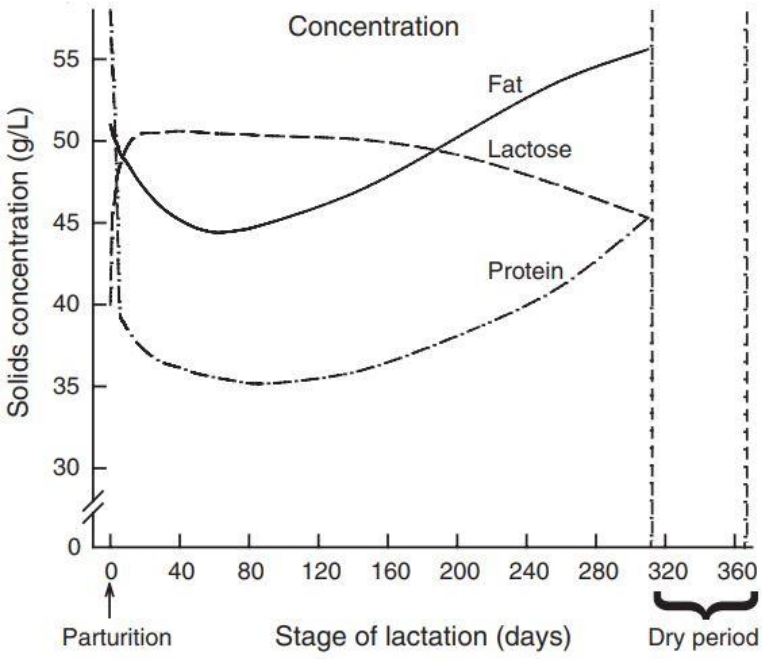

Figure 6.5. Idealised relationships between concentrations of milk fat, protein, and lactose over a lactation of 310 days. From Holmes et al. (2007, pg 351).

The greater milk fat percentage and atypical fat percentage profile from the AUT farmlet cows during L2 was likely a consequence of the different BCS at calving and the subsequent differences in BCS lost after calving between the farmlets. The AUT farmlet cows underwent an extended lactation to change calving season and they gained above-optimal BCS, which resulted in those cows having greater BCS at the start of L2 compared with the SPR farmlet cows. The AUT farmlet cows then lost relatively greater body condition during early lactation, which agrees with previous research (Roche et al., 2009a). Cows in relatively greater condition at calving have greater lipid metabolism during this early lactation phase (Roche et al., 2007a),

which leads to greater fatty acid availability and greater milk fat synthesis (Berry et al., 2007). Therefore, the greater fat content of milk from the AUT farmlet cows during L2 was influenced by the performance of the cows during the extended lactation in L1.

Consistent with the increase in milk fat and protein concentrations at the end of lactation (Figure 6.5), milk fat and protein concentrations of milk were elevated from the AUT farmlet cows during the later stages of the extended lactation (L1). Due to the milk fat and protein being elevated for a longer period in the AUT farmlet cows, the average milk fat and protein percentage of the whole lactation (L1; extended lactation) was greater in the AUT farmlet compared with the SPR farmlet (L1; normal 12-month CI lactation). Similar increases in milk fat and protein percentages in extended lactation cows have been reported previously (Kolver et al., 2007; Grainger et al., 2009; Auldist et al., 2010). As NZ farmers are paid for milk using a multiple component pricing structure that individually values the components of milk (i.e., fat and protein), differences in milk fat and protein concentrations influence the relative price of MS received by the farmer (Sneddon et al., 2013; Edwards et al., 2019). Because milk fat and protein concentrations were elevated during the later stages of the extended lactation and early stages of L2, the average milk price received by the AUT farmlet during Y2 was also elevated, primarily due to the use of the extended lactation to change calving season.

6.3.2 Reproductive performance

6.3.2.1 Extending the calving interval increased the reproductive performance of cows changing calving season

During L1, AUT farmlet cows had greater reproductive performance compared with SPR farmlet cows, and this had implications on the calving pattern and culling decisions for the farmlet. Although similar trends were reported by Butler et al. (2010) and Kolver et al. (2007), methods used to create the extended lactation in these experiments (e.g., synchronised mating and terminations), and small cow numbers, confound comparisons with the current research, and the underlying cause of greater reproductive performance during extended lactations is not detailed in the literature. Hence, potential causes of greater reproductive performance in this current experiment are presented in this section, along with the implications of this on the farm system.

An increase in the length of time between PSC and PSM is the most likely cause of the greater reproductive performance in the AUT farmlet herd. During L1, the CI of AUT farmlet cows was extended so that they next calved in autumn. Thus, there were 331 days between PSC and PSM for cows in the AUT farmlet, compared with the 83 days for cows in the SPR farmlet. This increase in days between PSC and PSM represents a major deviation to the production system

of cows selectively bred over the last 100 years to be seasonal breeders (i.e., 365-day CI; Roche et al., 2017a).

Increasing the duration between PSC and PSM allows the cow more time to regain a positive energy balance, and may be a possible explanation for the greater reproductive performance of the AUT farmlet herd compared with the SPR farmlet herd during L1. A negative energy balance occurs during early lactation as energy output from milk production exceeds energy input from DMI, and this can coincide with the mating period in a 12-month CI system (at ~80 DIM). If the negative energy balance is severe or prolonged, it is a risk factor for poor reproductive performance (Walsh et al., 2011; Berry et al., 2016). The negative energy balance suppresses hormones critical for ovulation, conception and oocyte development (Butler, 2003). Therefore, reducing the magnitude and duration of the negative energy balance can increase reproductive performance in 12-month CI systems (Roche et al., 2007b). Body condition score has been identified as an indirect measure of energy balance, and cows will only gain condition when they are in a positive energy balance (Roche et al., 2007b; Walsh et al., 2011). Therefore, the increase in BCS in the AUT farmlet cows during late lactation of L1 when their mating period occurred (Figure 4.17) indicates that these cows were in a positive energy balance, were partitioning nutrients to body tissue gain, and were not exposed to the hormonal suppression, and reproductive failure that can occur during negative energy balance (Lucy, 2008).

In addition, the greater duration between PSC and PSM may have provided AUT farmlet cows additional time to clear uterine infections. Although uterine contamination occurs in nearly all postpartum cows, most eliminate contamination voluntarily around 60 days postpartum, and only some cows develop uterine disease (Azawi, 2008). Uterine disease typically occurs within 21 days postpartum, but can persist for longer than 70 days, which supresses reproductive performance in the typical mating period for a 12-month CI system (Fourichon et al., 2000; Sheldon et al., 2009). Therefore, during L1, AUT farmlet cows had a greater length of time to voluntarily clear uterine contamination and recover from uterine disease prior to PSM. However, indicators of uterine contamination and disease at the onset of the mating period were not recorded in the current experiment, and this hypothesis is not mentioned in other extended lactation literature (Kolver et al., 2007; Butler et al., 2010), hence, it requires further research to substantiate.

Improved reproductive performance can lead to improved economic outcomes for the farm system through more culling flexibility. Reproductive failure (i.e., not in calf) is the major cause of involuntary culling on NZ dairy farms, and is a major economic cost to those farms (Kerslake et al., 2018). Having less cows not in calf enables the farmer to make more voluntary culling decisions, like removing genuine low-producing or older cows, or reducing the number of heifer

replacements (Blackwell et al., 2017). As the cost of replacing a cow with a heifer is estimated to be $1,445/cow (Kerslake et al., 2018), this can reduce expenses. The greater reproductive performance during the extended lactation also meant some cows that may have otherwise been culled for poor reproduction, remained in the herd for another season and had greater lifetime productivity (Burke et al., 2017). In the current experiment, when AUT farmlet cows were culled for being not in calf during L2, there was a tendency for them to be older compared with the SPR farmlet cows. This indicates that the greater reproductive performance in the AUT farmlet meant that cows were not involuntarily culled at a young age and had greater lifetime productivity. Therefore, by extending the CI to change calving season, there is a temporary reprieve from the reproductive pressures of a 12-month CI system.

It must be noted, however, that extending the CI may also result in undesirable cows remaining in the herd. The ability to get in calf every year is a critical requirement in 12-month CI systems (Roche et al., 2018), thus, a desirable cow has high reproductive performance every year. Fertility is under genetic control (albeit, with a relatively low heritability), so to this end it is included in the National Breeding Objective for NZ dairy cattle (NZAEL, 2013). As extending the CI temporally removes the reproductive pressures of a 12-month CI system, it may also be inadvertently selecting for cows with lower levels of fertility which may result in producing progeny that have a lower genetic fertility potential.

Greater reproductive performance during the extended lactation (L1) also condensed the calving pattern during L2 for AUT farmlet cows. For example, approximately three weeks after PSC, 72% of the AUT farmlet cows had calved compared with 53% of the SPR farmlet cows. Best-practice industry targets are for 67% of the herd to have calved within three weeks after PSC (Blackwell et al., 2017). This indicates reproductive performance for cows in the SPR farmlet was below industry targets, while cows in the AUT farmlet, undertaking an extended lactation, were above industry targets.

A more condensed calving pattern has implications on the farm system when changing calving season. In spring-calving systems a condensed calving pattern maximises herd feed demand when pasture supply peaks in late spring, and maximises the average DIM of the herd (Roche et al., 2017b). However, it can also increase the magnitude and duration of the early lactation feed deficit because of the increase in feed demand prior to the pasture supply peak, which Clark et al. (2009) suggests can be managed by:

- Targeting a greater APC at PSC;
- Offering more supplementary feed;
- Accepting a greater energy deficit during early lactation;
- Decreasing SR; or

- Moving PSC closer to the balance date.

In the context of the current research, changing SR was not an option. If other variables are altered between farmlets, in addition to the change of calving season, it is very difficult to interpret results and attribute any differences to a specific variable. Similarly, moving the PSC in respect to balance date is not an option because it is now an autumn-calving system and balance date occurs in mid- to late lactation. Accepting an increase to the energy deficit in early lactation is also ill-advised, as it may exacerbate the lower MS production peak displayed by autumn-calving cows during early lactation (Garcia & Holmes, 2001). Therefore, the only option may be to increase APC at PSC or offer more supplementary feed through early lactation. From a farmer perspective, although increasing the APC at PSC is a viable option, variable summer pasture growth due to variable rainfall means that achieving a higher APC target has downside risks. If supplementary feed is available this approach is less risky but will increase the cost of production (Ramsbottom et al., 2015; Neal & Roche, 2020). A more condensed calving pattern will also increase the workload for staff during the early part of the calving period, which is already the busiest period of the year with the highest level of stress (Tipples et al., 2010). Therefore, a farm changing calving season must be prepared for a condensed calving pattern in L2, and have adequate feed on hand and an appreciation for a greater workload during their first calving period in autumn.

6.3.2.2 Reproductive performance decreased when extended lactation cows returned to a 12-month calving interval

In L2, the reproductive performance of the AUT farmlet cows was substantially lower compared with L1, which may be due to the return to a 12-month CI. As previously mentioned, extending the CI can lead to improved reproductive outcomes because cows have more time to clear uterine disease and be in a positive energy balance before the mating period. Returning back to a 12-month CI during L2 in the AUT farmlet, meant there were 83 days between PSC and PSM instead of 331 days, so these cows returned to the reproductive pressures typical of 12-month CI systems.

In addition, the reproductive performance of the AUT farmlet cows during L2 may have been negatively influenced by their above-target BCS at calving and their subsequent BCS loss. Cows in the AUT farmlet were gaining BCS during the L1 mating period, whereas they were losing BCS during the L2 mating period. Increased magnitude and duration of the negative energy balance from greater BCS loss has been associated with poor reproductive outcomes (Roche et al., 2009a), in particular, the post-partum anoestrus period (Crowe, 2008). Therefore, BCS loss, combined with a return to the reproductive pressures characteristic of 12-month CI

systems, may have had a negative effect on the reproductive performance of AUT farmlet cows during L2 compared with L1.

Fulkerson & Dickens (1985) proposed that in 12-month CI systems, autumn-calving cows may have poorer reproductive performance compared to spring-calving cows because of negative influences that include day length, climate and energy balance. In the current experiment, in L2, the reproductive performance of the AUT farmlet herd was poorer compared with the SPR farmlet herd, albeit, by a relatively small amount. Autumn-calving cows compared with spring-calving cows had poorer reproductive performance in the studies reported by Fulkerson & Dickens (1985), Chang'endo (1996) and Ryan et al. (1998), whereas Pacheco-Navarro (2000) reported similar reproductive performance. The inconsistent results from the aforementioned authors are further confounded by differences in mating decision rules, SR, DMI, and BCS between farmlets, hence it is difficult to conclude if the results in the current research are indicative of autumn- and spring-calving systems. However, the factors outlined by Fulkerson & Dickens (1985) are worth considering. These authors report that:

Day length during the mating period may negatively influence reproductive performance of autumn-calving cows compared with spring-calving cows. Day length, mediated by photoperiodic signals through the eye, influences reproduction in dairy cattle (Hansen, 1985; Dahl et al., 2000). During L2 in the current experiment, mating begun in June for the AUT farmlet herd and occurred during the winter solstice (southern hemisphere; ~9h 25m day length), compared with October (~13h day length) for the SPR farmlet herd, thus, AUT farmlet cows were exposed to less light hours during their mating period. Greater day length may increase the secretion of reproductive hormones in cows (e.g., luteinizing hormone; Dahl et al., 2000), however to my knowledge, this relationship has not been quantified in pasture-based dairy systems. Considering the importance of reproductive performance for successful 12-month CI pasture-based systems (Roche et al., 2017b), future research should investigate the influence of day length on reproductive performance in autumn-calving cows, assuming that confounding factors like temporal changes in pasture quality and weather are able to be controlled.

As with early lactation peak MS production (see section 6.3.1.2), cold and wet climatic conditions during the mating period may also negatively influence the reproductive performance of autumn-calving cows. It would be expected that a June mating period would be colder and wetter than an October mating period due to temporal weather trends (Roche et al., 2009b). Under NZ conditions, Robinson (2015) reported a curvilinear relationship between the CSI and reproductive performance, where reproductive performance first increased and then decreased as the CSI increased above 1,000 $kJm^{-2}h^{-1}$. In that study, only spring-calving cows' reproductive

performance was measured, so it would add value to analyse the relationship between the CSI and reproductive performance in autumn-calving cows.

6.3.3 Heifer performance during their first lactation as a result of extending the calving interval

An extended period between birth and entering the herd for primiparous cows (i.e., heifers) is a consequence of extending the CI to change calving season and has implications on subsequent cow performance. In 12-month CI systems, heifers are generally mated for the first time at approximately 15 months old and enter the herd at 24 months old (Macdonald et al., 2007; McNaughton & Lopdell, 2012). Because the herd underwent a 12-month CI prior to the current experiment, heifers that entered the AUT and SPR farmlets in L1 were mated and then calved at those respective ages. However, extending the CI in the AUT farmlet during L1 meant that heifers entering the herd in L2 were born during spring but then did not calve until autumn. This meant they were approximately 31 months old (seven months older) at calving compared with heifers in the SPR farmlet.

Extending the CI meant that AUT heifers entered the herd heavier and with greater body condition compared with SPR heifers. At the start of L2, heifers in the AUT farmlet were 87 kg heavier and had 0.5 greater BCS units compared with heifers in the SPR farmlet (Table 4.7 and Table 4.9). This was expected because these heifers were approximately seven months older at calving, and is consistent with other literature (Lin et al., 1986). Industry targets are for heifers to be 80–90% of their mature LWT at their first calving (Roche et al., 2015a; Blackwell et al., 2017). Average LWT at the start of lactation and drying off for the SPR farmlet herd in L1 and L2 was 484 kg, which is between the industry reported mature LWT of 494 kg and 456 kg for HF and HF x Jersey crossbred cows, respectively (DairyNZ, 2019b). Therefore, assuming a mature LWT of 484 kg for cows in this experiment, AUT farmlet heifers were 100% and SPR farmlet heifers were 82% of their mature LWT when entering their respective herds at the start of L2. Because of their relatively greater size and BCS, the lactational and reproductive performance of these heifers in L2 compared with their counterparts in the SPR farmlet is important to quantify.

During L2, heifers in the AUT farmlet produced more MS compared with heifers in the SPR farmlet, however their DIM did not differ (Table 4.3). Compared with heifers in the SPR farmlet, heifers in the AUT farmlet produced more MS (+103 kg MS/cow; 28%) during L2. Results consistent with the current experiment were reported by Dobos et al. (2004), where heifers that were older or heavier at first calving produced greater MS in their first lactation. This is also supported by Chuck et al. (2018) who reported a positive association between age at first calving and first lactation MS production. The former authors identified that there was an

age at first calving x LWT at first calving interaction that is associated with MS production in the first three lactations. Hence, the greater MS production reported in the AUT farmlet is a factor of those heifers being both older and heavier at first calving. However, a multiple regression model of MS production as a function of age at first calving and LWT at first calving reported by Dobos et al. (2004) predicted a much smaller difference in MS production between farmlets (38 kg MS/cow) compared with what was reported in the current experiment (103 kg MS/cow). This difference may be due in part to experiment methodologies confounding results. Heifers in the experiment reported by Dobos et al. (2004) were managed as one herd after calving for the first time, hence, MS production may have differed due to heavier heifers socially dominating lighter heifers and preferentially accessing a greater quantity and quality of feed (Hussein et al., 2016). In contrast, heifers in the current experiment remained in separate farmlets so heavier heifers were unable to socially dominate lighter heifers. However, they did receive different quantities and qualities of supplementary feed which may have contributed to the greater difference in MS production. To the best of my knowledge there is no literature that compares age and LWT of heifers in contrasting calving systems.

One possible explanation for the greater MS production from heavier AUT farmlet heifers, is that they were more skeletally mature during their first lactation. Because heifers normally calve at 80–90% of their mature LWT in seasonal-calving systems, they are required to continue to grow in addition to producing milk during their first lactation (Holmes et al., 2007). Considering that AUT farmlet heifers were 100% of their mature LWT at calving, this infers that these heifers had to partition less energy to skeletal growth, meaning that more energy was available for lactation during L2 compared with SPR farmlet heifers. This has been previously hypothesised by Chuck et al. (2018). These heifers may have also metabolised greater energy for lactation from adipose tissue, as the ratio of fat to muscle in LWT gain increases as cows mature (Nicol & Brookes, 2007), which is supported by AUT farmlet heifers having a greater BCS at calving compared with the SPR farmlet heifers. Furthermore, larger cows have a greater voluntary feed intake (Holmes et al., 2007), thus, AUT farmlet heifers may have had greater dietary energy intake, and therefore MS production. Interestingly, the greater MS production advantage from heifers being older and heavier at the start of their first lactation is reported to decrease from their second lactation onwards and be non-existent in their fourth and subsequent lactations (Lin et al., 1986; Dobos et al., 2004; Macdonald et al., 2005). Therefore, extending the CI can increase MS production from heifers, however, any MS production advantage does not persist in future lactations.

There were minimal differences in reproductive performance during L2 between heifers in the AUT and SPR farmlets. The mating period in L2 was the second mating for all heifers (the first mating period was when they were both on agistment), and the time between PSC and PSM was

the same for both as they were both in 12-month CI. The six-week in-calf rate and three-week submission rate were numerically greater (2 and 3 percentage units, respectively) in the AUT farmlet heifers compared with the SPR farmlet heifers. In contrast, the not-in-calf rate was 4 percentage units more (Table 4.11). These relatively small numerical differences are consistent with the limited literature that reports no significant difference in reproductive performance in cows with different ages at first calving (Dobos et al., 2004).

6.3.3.1 Extending the calving interval increased grazing expenses for heifers in the autumn-calving farmlet

Extending the CI meant that heifers spent a longer time grazing off farm, which increased the grazing cost incurred by the AUT farmlet heifers. A common grazing arrangement for 12-month CI NZ dairy farms, and the arrangement used in the economic modelling in the current experiment, is that calves leave the milking platform at weaning ('yearlings'; at ~4 months old) and are agisted for approximately 19 months before returning to the farm as heifers to calve (DairyNZ, 2020b). Undertaking the extended lactation meant that for two cohorts of heifers that were born in spring but entered the herd in autumn, total time spent on agistment was approximately 27 months, an increase of eight months compared with the 12-month CI grazing arrangement. Assuming a grazing cost of $12.50/week/animal for those heifers that remained at grazing for the extended period ('post-heifers')[8], this increased the total cost of grazing for those heifers by an additional $437.50/animal for their lifetime.

However, unexpectedly, there was not a similar increase in the net total farmlet grazing expenses at a systems level for the AUT farmlet in Y2. Instead, the net increase in total grazing expenses for the AUT farmlet in Y2 compared with the SPR farmlet was only $62.50/animal ($83/ha). This was due to the grazing contract, used in this analysis, that applied the same grazing cost for each age class of animal (e.g., yearlings, heifers, post-heifers; J. Gunivin, personal communication, April 14, 2020). Although the AUT farmlet incurred a grazing cost for post-heifers during Y2, this was partially offset by there being no yearling grazing cost in Y2. The first cohort of autumn-born calves in the AUT farmlet were born beginning March of Y2, but these yearlings did not incur a grazing cost until Y3, as they were not sent away to grazing until they were ~4 months old (July of Y3). Hence, in Y2 there was no grazing expense for yearlings in the AUT farmlet, and in total, there was only an additional five weeks that replacement animals spent at grazing in the AUT farmlet (Figure 6.6). Furthermore, in Y3, although post-heifers in the AUT farmlet also incurred a grazing cost in Y3, the timing meant

[8] 'Post-heifers' refers to an age class of nulliparous animals on agistment that are between 23- and 29-months old. Due to the extension of the CI, these animals are older than nulliparous heifers (11- to 22-months old) that typically return to the milking platform at 22-months old in 12-month CI systems.

that heifers (born in autumn of Y2) only incurred 17 weeks of grazing expenses in this financial year (compared with 52 weeks in the SPR farmlet), thus, gross animal weeks at grazing was the same as the SPR farmlet. This, to my knowledge, has not been previously reported in the literature.

It must be noted that the unit cost of grazing was equal between age classes in this current analysis. This meant that only the relative difference in total weeks at grazing led to differences in grazing expenses between farmlets. Alternative grazing schemes exist that can charge a different price for different age classes and/or charge on a $/kg DMI basis. As the age structure of animals on agistment differed between farmlets in Y2 and Y3 in this current analysis, and post-heifers would be expected to have a greater DMI than yearlings, the actual net increase in grazing expenses may depend on the payment structure and contract that individual farms have with graziers. As there are many different grazing schemes, it is recommended that farmers identify the grazing expense that will apply to them and their unique situation when considering changing their herd's calving season.

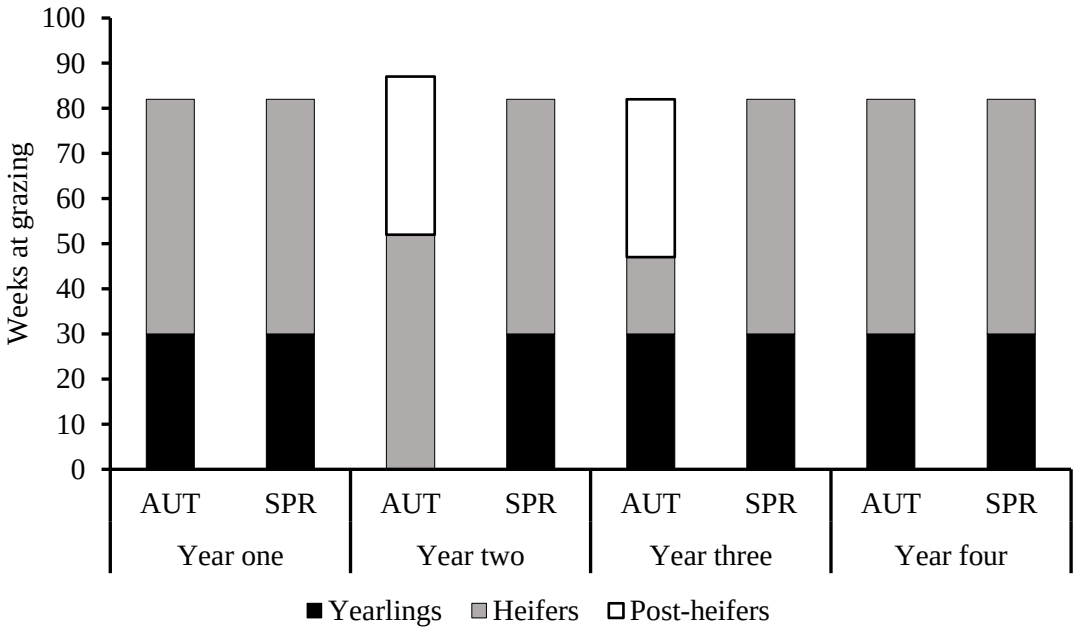

Figure 6.6. Number of weeks in each financial year that yearlings (4–10 months old), heifers (11–22 months old), and post-heifers (23–31 months old) in the autumn-calving (AUT) and spring-calving (SPR) farmlets were grazing off farm.

6.4 Defining the period affected when using an extended lactation to change calving season

Undertaking an extended lactation, by delaying mating, to change calving season had carry-over effects on the biophysical and economic performance of the first 12-month CI autumn-calving lactation in the AUT farmlet. As previously discussed (section 6.2.2), during the extended

lactation, AUT farmlet cows reached greater than optimal BCS, which affected grazing management, and their milk composition differed during the first autumn-calving lactation. Delaying the mating to extend the CI improved the reproductive performance of AUT farmlet cows (i.e., greater 6-week in-calf rate and lower not-in-calf rate; section 6.3.2), resulting in a more condensed calving pattern at the beginning of their first autumn-calving lactation compared with the SPR farmlet 12-month CI system. In addition, heifers entering the AUT farmlet herd during the first autumn-calving lactation were older, heavier, had a greater BCS, and produced more MS (section 6.3.3). Therefore, from a biophysical context, the first 12-month CI autumn-calving lactation cannot be considered a steady-state lactation due to these carry-over effects.

Furthermore, these factors, as well as the difference in age class of young stock on agistment, differences in the cost of supplementary feed, and differences in the cost of harvesting surplus pasture, mean that the third financial year (i.e., Y3) also cannot be considered a steady-state year. These current results provide biophysical evidence to support previous unsubstantiated hypotheses that changing calving season incurs costs during the period of change before the new steady state is reached (Fulkerson et al., 1987; Figueredo, 2003; Chikazhe et al., 2017). Yet this prior literature has not defined the period affected, when a farm system changes calving season. Thus, if mating is delayed, and an extended lactation is used, to change calving season from spring to autumn, I propose that the period that is affected by this system change includes both the extended lactation and the first 12-month CI autumn-calving lactation, and the first three financial years, and is herein referred to as the 'transition period'.

Although outside of the scope of the current experiment, the transition period may also include the second autumn-calving lactation and fourth financial year (i.e., L3 and Y4). This is because, although multiparous cows in the second autumn-calving lactation can be considered to be in a steady state because their previous lactation was a 12-month CI, primiparous cows (i.e., heifers) entering the herd in the second autumn-calving lactation are older than heifers in steady-state 12-month CI systems. Therefore, these heifers would be predicted to be heavier, have greater body condition and produce greater. However, differences in the performance of heifers alone will not have a large impact on the total herd performance and subsequent economic outcomes for L3 and Y4, respectively, thus when considering the transition period, I propose that this is restricted to the first two lactations (extended lactation and first 12-month CI autumn-calving lactation) and the first three financial years.

6.5 Investment considerations when deciding to change calving season

The NPV results indicate that within the assumptions of the data (i.e., farm, climate, and animal performance modelled from one season, and with a full winter milk premium, best management practice, and greater MS production) changing calving season from spring to autumn can be a better investment decision over a 10-year investment horizon compared with maintaining a spring-calving system in South Taranaki ($31,212 vs $26,040/ha cumulative discounted cash flow).

During the transition period, as the farm changed from a spring-calving to an autumn-calving system, the AUT farmlet had relatively lower profit during the first three years compared with the SPR farmlet. However, using assumptions based on AUT farmlet performance during L2 and Y3, the AUT farmlet was predicted to have a consistently greater profit in subsequent years ($1,621/ha greater profit in the base scenario). This meant that the AUT farmlet was predicted to have a greater NPV over the 10-year investment horizon considered in this analysis. Relative to the SPR farmlet, which can be considered a status-quo investment, changing calving season resulted in reduced cash flows during the early years of the investment which were then potentially offset by increased cash flows in later years. Hence, the investment performance was a factor of two different stages and the relative differences between them.

Furthermore, although these results indicate that autumn calving could potentially be a better investment decision than maintaining a spring-calving pattern in this experiment, it is more important to consider the fundamental factors that have influenced the result, rather than the result itself, so that this investment decision can be considered in a broader context. Net present value as an investment criterion is only as accurate as the estimates used in modelling the future cash flows of the investment, which is difficult in agricultural contexts (Debertin, 2012). Therefore, analysis of the various outputs from a distribution of various inputs is important in interpreting these results (Tauer, 2000). This analysis identified that within the scope of the experimental farm and climate, MS production and the winter milk premium, alongside other interacting factors, were critical to the results, both individually within the two distinct stages, and across the whole investment horizon.

6.5.1 Changing calving season causes a short-term reduction in profitability

The farm system, when changing calving season from spring to autumn using an extended lactation, was less profitable in the first three years (i.e., during the transition period) compared with a farm system that remained steady-state spring calving. During the first three years, the AUT farmlet cows underwent an extended lactation and then their first 12-month CI autumn-

calving lactation, while the SPR farmlet cows remained in a 12-month CI spring-calving pattern. As discussed in Chapter 5, compared with the SPR farmlet, AUT farmlet MS production, and hence gross revenue, decreased, and operating expenses increased, in some of the transition period years. In addition, the AUT farmlet required capital expenditure on effluent infrastructure and processing company shares during the transition period to facilitate the change to autumn calving. This increased total expenses and reduced profit. Relative to the SPR farmlet, profit was $948, $1,452, and $289/ha less in the AUT farmlet during Y1, Y2 and Y3, respectively. Once a steady-state autumn-calving system had been reached, profit in the AUT farmlet was predicted to be greater in Y4; albeit, cumulative discounted cash flow was still $1,144/ha less in the AUT farmlet to the end of Y4. In comparison, Chikazhe et al. (2017) hypothesised that changing calving season by selling the spring-calving herd and buying an autumn-calving herd would cost $640/ha in one financial year; however, they did not include in their discussion any associated capital infrastructure purchases.

Although there was no difference in MS production between farmlets during the experimental period, less MS production during Y2 reduced AUT farmlet gross revenue, and so profit, for this year. Extending the CI to change calving season meant that AUT farmlet lactations occurred across two financial years compared with the SPR farmlet lactations, which occurred within financial years. During L2, MS production from the AUT farmlet cows was less than the SPR farmlet cows. This was because AUT farmlet cows were in the later stages of their extended lactation (i.e., late-lactation period of L1) when daily MS production was low and a portion of the herd were already dried off (see section 6.3.1.1 for further discussion on extended lactation performance). This occurred during eight months of Y2 (June–January), and although the beginning of L2 for the AUT farmlet herd also occurred during Y2, it only occurred for three months of Y2 (March–May). Thus, total MS production, and in turn gross revenue and profit, during Y2 was less in the AUT farmlet due to the timing of the extended lactation.

The AUT farmlet did receive a greater average milk price during Y2 compared with the SPR farmlet, in part due to receiving the winter milk premium. However, this $0.66/kg MS increase was not enough to offset the decrease in total MS production. Therefore, greater MS production from cows during the extended lactation, without a concurrent increase in expenses (e.g., supplementary feed, labour) or incidental increase in negative biophysical implications (e.g., above optimal BCS gain; see section 6.2), is critical to improving profit during Y2 of the transition period. However, because of the genetic predisposition for cows bred in 12-month CI pasture-based systems to gain BCS rather than increase and/or persist their MS production (Kolver et al., 2007), there will continue to be limitations to achieving greater MS production from cows undergoing an extended lactation, highlighted by the performance of the AUT farmlet herd in this current experiment.

Capital investment is an important consideration when changing calving season because it reduces profit during the transition period. Autumn-calving systems require greater effluent storage and spreading infrastructure compared with spring-calving systems due to the time of the year that lactation occurs (Spaans et al., 2019). The extent to which the farm must invest to upgrade or replace this infrastructure has a direct influence on the investment decision (Chikazhe et al., 2017). In this current analysis, it was assumed that the AUT farmlet incurred a $718/ha capital cost ($75,246 total cost) in Y1 for an effluent infrastructure upgrade, and incurred a $43/ha depreciation cost (a proxy for capital replacement of assets) for this infrastructure in each subsequent year. This was greater than the costs incurred in the autumn-calving farmlet reported by Spaans et al. (2019), who calculated the effluent capacity of the spring- and autumn-calving farmlets individually, then calculated itemised associated costs based on the size of the effluent storage pond required for each farmlet, assuming a greenfield development. They then included the relative increase in capital cost and depreciation cost of the autumn-calving farmlet compared with the spring-calving farmlet, assuming a larger storage requirement by the autumn-calving farmlet, in their economic analysis. The capital expenditure in the current analysis was instead modelled on the average economic cost of upgrading current infrastructure to achieve environmental compliance from a survey of 35 dairy farms (MacDonald et al., 2015). Because of the environmental compliance requirements for a winter milk premium contract (Fonterra, 2018), this better reflects the assumption that a spring-calving farmer with existing effluent infrastructure is considering changing calving season, as is the case in the current research. Future trends to increase the level of environmental compliance in the agricultural industry may mean that the cost of compliance may be greater than that modelled in this analysis.

Although sources of funding and their associated implications were outside the scope of this analysis, they are important to consider because effluent infrastructure is usually debt funded and commonly viewed as a cost to the business, rather than a strategic investment (MacDonald et al., 2015). This means that unique farm attributes must be considered when deciding to change calving season. In particular, some farms may already have existing compliant infrastructure and so will not incur this cost in Y1, meaning that the cost to change calving season would be less than what was modelled in the current analysis. Conversely, farmers with non-compliant infrastructure may be required to increase their debt levels which would increase their interest and principal payments, reducing the level of free cash in the business and decreasing investment returns in the future. Therefore, the impact of capital expenditure, for upgrading existing effluent infrastructure, on the cashflow and investment returns of changing calving season will be unique to each farm.

A potential purchase of additional processing company shares is another consideration when changing calving season from spring to autumn. Because of the increased MS production that was predicted to occur in the AUT farmlet from Y3 onwards, a capital investment during Y3 in additional processing company shares was required. This was a larger capital purchase than the effluent infrastructure but provided an increase in gross revenue by way of a dividend from Y4 onwards. A criticism of some farm system comparison research is that the additional capital (e.g., additional processing company shares, supplementary feeding infrastructure) required by higher production systems is not accounted for in economic comparisons (Shadbolt, 2012). Hence, additional processing company shares were purchased in this analysis because the AUT farmlet produced more MS when it reached a steady-state autumn-calving system compared with the SPR farmlet. This cost would not be applicable to farmers who supply non-cooperative processing companies (Sneddon et al., 2013), so the cost of changing calving season would be less. However, the milk price and winter milk premium may then also be different, and potentially less, than that used in the current analysis, which were based on the Fonterra pricing structure. Hence, one-off purchases during the transition period (e.g., effluent infrastructure and processing company shares) may differ for each farm, as will the milk price and winter milk premium, so future returns from this investment decision will differ depending on the unique characteristics of each farm. Overall, using an extended lactation to change calving season reduced profits during the transition period, primarily due to the low MS production in Y2, as a consequence of the extended lactation, and increased expenses, as a consequence of capital expenditure.

6.5.2 Profitable milksolids production and the winter milk premium during the steady-state stage are critical success factors of the investment decision

Changing calving season from spring to autumn resulted in initial net costs during the transition period compared with maintaining a spring-calving pattern, which implies that the new system, once in a steady state (from Y4 onwards), must perform relatively better for several years to offset the initial investment cost. In the current analysis, the steady-state performance from Y5 to Y10 was modelled to be the predicted performance of the farmlet in Y4. Modelling outputs indicated that once in a steady state, AUT farmlet profitability was greater than the SPR farmlet. However, there are limitations of modelling farmlet performance. In the SPR farmlet, modelling was based on a weighted average of farmlet performance during Y1–Y3; whereas the AUT farmlet modelling was based on a single year's performance (Y3) because in Y1 and Y2 the farmlet was not autumn calving. Therefore, the predicted differences in AUT farmlet NPV compared with SPR farmlet NPV are dependent on assumptions from one farmlet during one

season, and these will differ with varying milk prices, climate, MS production, and supplementary feed use.

The winter milk premium was predicted to increase gross revenue in the AUT farmlet compared with the SPR farmlet, which meant that its availability and price affected relative profitability. In the base economic model when there was a full winter milk premium, the AUT farmlet had higher gross revenue and profit compared with the SPR farmlet, which meant that cumulative discounted cash flow increased at a greater rate in the AUT farmlet from Y4 to Y10. However, when the winter milk premium was reduced in the base economic model, the profitability advantage for the AUT farmlet was less. This also increased the initial net costs of changing calving season between Y1 to Y3, so combined with a 50% winter milk premium, the AUT farmlet required an additional year to generate greater cumulative discounted cash flow compared with the SPR farmlet. With a 0% winter milk premium, the relative difference in Y4–Y10 profitability did not overcome the greater initial net costs during Y1–Y3, such that the AUT farmlet had a lower cumulative discounted cash flow at the end of Y10.

Availability and price of the winter milk premium is a risk for farmers considering changing calving season (Chikazhe et al., 2017). A negative change to the demand for short shelf-life products alongside changes in processing company strategy regarding export product mix and best use of processing infrastructure may reduce the premium that is currently offered to farmer suppliers. Because a winter milk premium is not guaranteed in the future, autumn calving systems are only advisable for cautious farmers when their system would be more profitable than alternatives, without a winter milk premium (Chikazhe et al., 2017). In the current analysis, the AUT farmlet, once in a steady state, was predicted to be profitable at all levels of winter milk premium (i.e., 100%, 50% and 0% winter milk premium), indicating that autumn calving could be an economically-sustainable system. However, with no winter milk premium, the AUT farmlet was unable to offset the initial net cost of changing calving season, and it had a lower NPV compared with the SPR farmlet at Y10, hence, this investment choice (i.e., to change calving season) would be rejected by NPV criterion if there was no winter milk premium available. This ability to offset the initial net costs, incurred during the transition period, is a function of both the winter milk premium and the timeframe considered in the investment decision. Therefore, if farmers are considering changing calving season to autumn, in addition to considering the profitability of the steady-state autumn-calving system without a winter milk premium (Chikazhe et al., 2017), farmers should also consider the ability of this new system to offset the initial cost of changing calving season within their investment timeframe.

Another risk when changing calving season is the predicted greater MS production from the steady-state autumn-calving herd. In the current analysis, once in a steady state the AUT farmlet

produced more MS, and had greater gross revenue, which, combined with a smaller increase in operating expenses relative to the increase in gross revenue, led to greater profitability and a greater NPV compared with the SPR farmlet. The AUT farmlet was predicted to produce 287 kg MS/ha (23%) more during Y4 compared with the SPR farmlet. This led to $1,621/ha and $749/ha additional profit with a full winter milk premium and no winter milk premium respectively, during Y4 in the AUT farmlet compared with the SPR farmlet. Similar increases in MS production and gross revenue in autumn- compared with spring-calving systems have been reported in the literature (Garcia et al., 1998; Chikazhe et al., 2017), although SR and supplementary feed use (key drivers of operating expenses) have often differed between these calving systems. In contrast, when SR and supplementary feed use were similar, autumn-calving systems tended to produce less MS compared with spring-calving systems (Spaans et al., 2019). Therefore, as Y4 performance was modelled in this current analysis, two additional MS production scenarios[9] for the AUT farmlet were also considered, which affected the results and conclusions.

Under all winter milk premiums considered, the AUT farmlet performed better in Scenario 1 (S1) compared with both the AUT and SPR farmlet base economic models. There was a greater reduction in supplementary feed and total farmlet expenses than there was a reduction in gross revenue from decreased MS production, which meant that the AUT farmlet was more profitable in S1 than in the base economic model. Because there is a diminishing marginal benefit to supplementary feeding (Ho et al., 2018), this implies that in the AUT farmlet base economic model the input level of supplementary feed was greater than the point where the marginal cost of supplementary feed equalled the marginal return from additional MS. This highlights the importance of assessing any marginal benefit of supplementary feeding, which is particularly important for autumn-calving systems that tend to offer greater quantities of supplementary feed.

In Scenario 2 (S2), the AUT farmlet was less profitable compared with the base economic model and S1. In S2, the AUT farmlet had greater cumulative discounted cash flow at the end of Y4 compared with the AUT farmlet in the other scenarios because it had a smaller capital purchase on processing shares. But the lower MS production meant that it had lower profit from Y4 onwards and cumulative discounted cash flow increased at a slower rate, meaning that it had

[9] Scenario 1 (S1) assumes that AUT farmlet Y4 MS production is the average of the AUT and SPR Y4 MS production. Scenario 2 (S2) assumes that AUT farmlet Y4 MS production is equal to SPR Y4 MS production. Supplementary feed has been pro rata reduced in S1 and S2, assuming a marginal MS response of 80 g MS/kg DM (Roche et al., 2017b).

a lower NPV when there was a full and 50% winter milk premium. However, when the winter milk premium was removed, the AUT farmlet was more profitable in S2 than in the base economic model even though it produced less MS. However, it was still less profitable than the SPR farmlet base economic model. This indicates that in a high milk price environment (i.e., a winter milk premium is available) the investment to change calving season may be profitable because the greater MS production of the AUT farmlet can capitalise on the higher milk price. However, more importantly, it also indicates that in a low milk price environment (i.e., no winter milk premium available) the cost of supplementary feeding to facilitate the greater MS production in the AUT farmlet reduces profitability such that the system would not be an advisable investment.

In summary, the success of the investment in changing calving season from spring to autumn is dependent on the ability of the steady-state autumn-calving system to overcome the initial net costs during the transition period. The relatively greater profitable MS production and availability of the winter milk premium were critical in order for the AUT farmlet to have a greater NPV compared with the SPR farmlet. The risks for a farmer considering changing calving season are that MS production from an autumn-calving herd may be similar or less than from a spring-calving herd, with no reduction in operating expenses, or that the marginal operating expenses incurred to produce greater MS from the autumn-calving herd are greater than the marginal revenue from the MS production. This is particularly risky if the winter milk premium is reduced or becomes unavailable. This highlights the inherent uncertainty in biological investments; hence, it is recommended that the decision to change calving season includes an understanding of the downside risks of low MS production, high operating expenses, and future availability of winter milk premiums.

6.5.2.1 Additional risk factors when deciding to change calving season

In addition to MS production, operating expenses, and winter milk premium risk, the resilience of the autumn-calving system must also be considered when examining the investment decision to change calving season. Dairy farm businesses operate in an environment where externalities (e.g., milk price and input prices) are expected to be volatile in future years (Roche & Horan, 2013). A resilient dairy business is one that can withstand acute ‘shocks’ from both those external factors and also other internal factors (e.g., drought, flooding, disease; Shadbolt et al., 2017). A low cost of production (e.g., low operating expenses), mediated through high amounts of pasture and crop eaten along with a low reliance on imported supplementary feeds, has been consistently identified as the key driver of resilience (Ramsbottom et al., 2015; Roche & Horan, 2015; Hanrahan et al., 2018; Neal & Roche, 2020). Greater supplementary feed use increases the cost of production; both directly from greater feed costs, and indirectly through greater associated costs (e.g., labour and depreciation; Ramsbottom et al., 2015; Neal & Roche, 2020).

In the current analysis, the steady-state AUT farmlet was predicted to have a slightly greater cost of production, which was primarily caused by their greater reliance on supplementary feed, and so would be considered less resilient compared to the SPR farmlet. This is supported by previous research, where autumn-calving systems were reported as having a $290/ha, $0.19/kg MS, and $0.55/kg MS greater cost of production than spring-calving systems, as reported by Garcia et al. (1998), Chikazhe et al. (2017), and Spaans et al. (2019), respectively. A relatively higher cost of production exposes the farm business to business and financial risk during low milk price years (Neal & Cooper, 2016). It has previously been identified that the availability of the winter milk premium is a major influence on the NPV of the investment decision to change calving season (section 6.5.2), and so it holds that any reduction in the base milk price, onto which the winter milk premium is added, would also negatively influence the NPV of the investment.

In the current analysis, the same fixed milk price, an average of the 14-year inflation-adjusted milk price, was used in every year. However, the base milk price in NZ varies from season to season, sometimes drastically (Figure 6.7), and its future performance is unknown. Season to season variation in milk price was not included in this current analysis due to time constraints. The incorporation of milk price variation into the analysis, particularly from Y4 onwards, would be expected to influence the results, because a characteristic of high intensity systems (e.g., the AUT farmlet) is that they are able to maximise profitability when the base milk price is high, but may struggle to meet financial commitments when the base milk price is low (Neal & Roche, 2020). As the future base milk price cannot be accurately predicted, the greater exposure of the AUT farmlet to milk price volatility, due to its potentially grater cost of production, is another risk that farmers must consider in their decision-making process of changing calving season. Reducing the amount of imported supplementary feed could increase the resilience of the future autumn-calving system, however, this would also reduce MS production.

If the increasing farmer interest in changing to autumn-calving materialises as an increase in the production of winter milk across the NZ dairy industry, then the winter milk premium offered by milk processing companies may be reduced, removing a key factor of the profitability of the AUT farmlet. In its current form, the winter milk premium aims to attract consistent milk supply during the winter months so that fresh products can be provided to the market year round (Fonterra, 2018) and there is an increase in milk processing plant utilisation. Presently, stable demand for these products means that the required quantity of winter milk is also relatively stable (Stringleman, 2019). A farmer can only receive the winter milk premium if they are offered a winter milking contract from the processor. If the winter milk supply is adequate then there will be no winter milk contracts, and so no winter milk premiums, available for farmers changing calving season. Furthermore, faced with an oversupply of winter milk, processors may

reduce the winter milk premium they offer to all suppliers. This reinforces that changing calving season should only be considered by cautious farmers who do not require a winter milk premium to be economically sustainable, and can adequately offset the initial net costs during the transition period.

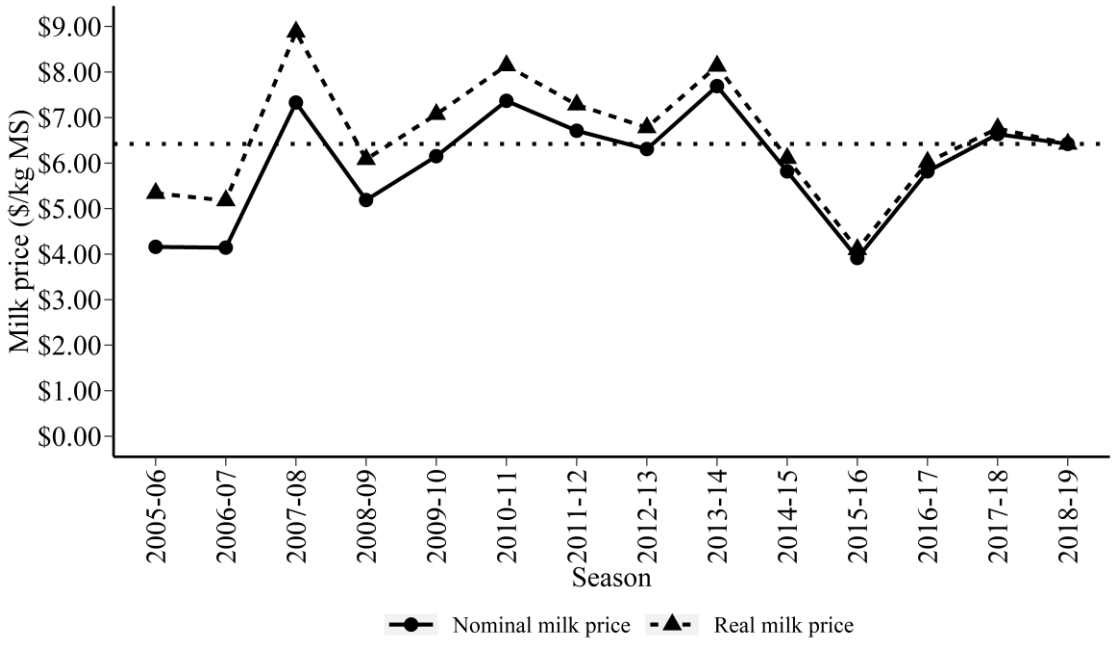

Figure 6.7. Historic nominal and real milk price [$/kg milksolids (MS)] for a large milk processing company in New Zealand. Horizontal dotted line is the 14-year inflation-adjusted average milk price ($6.42/kg MS). Data from Interest (2020) and Reserve Bank of New Zealand (2020).

6.5.2.2 Environmental considerations if changing calving season

Although not directly measured or modelled in the current experiment, differences in environmental impact between the AUT and SPR farmlets should be considered in the investment analysis of changing calving season. There is currently no broad nutrient limit or GHG emission limitation in Taranaki. However, at a regional and national level, with the introduction of the Climate Change Response (Zero Carbon) Amendment Act 2019 and Essential Freshwater programme, this is likely to change, adding regulatory risk to the investment in changing calving season.

I hypothesise that N leaching would be greater in the AUT farmlet compared with the SPR farmlet, due to the timing of lactation and DMI, relative to the risk period for N leaching. The period between late summer and autumn is the greatest risk period for N leaching, as it is urinary N deposited onto the soil during this time that eventually leaches below the root profile during winter and early spring (Shepherd et al., 2010). In the current experiment, the PSC for the AUT farmlet cows was 15 March, hence cows in this farmlet were in early lactation and the

herd was at peak DMI during the high-risk autumn period. Conversely, the SPR farmlet cows were in late lactation, and some cows had been dried off, reducing the number of cows that were lactating and the DMI of the herd during this period. Due to differences in the stage of lactation, DMI, and excretion of urinary N, it is expected that during the autumn period greater N would have been deposited onto the soil in the AUT farmlet, and N leaching during winter would have been greater. Depending on the absolute level of N leaching in the AUT farmlet, the AUT system would likely require mitigation options (e.g., stand-off pads, lower SR, reduced N fertiliser use) to reduce the amount of N leaching. In an extreme context, greater N leaching in the AUT farmlet may mean that changing to an autumn-calving system would be non-compliant and therefore unfeasible. Furthermore, assuming regulatory approval, greater N leaching may decrease the profitability of the AUT farmlet compared with the SPR farmlet in the future if an economic value is attached to the negative externality of N leaching [see McCahon (2019) for an example comparing costs of N leaching and GHG emissions in systems offering different types and quantities of supplementary feed in Northland, NZ].

It is also likely that GHG emissions were greater in the AUT farmlet compared with the SPR farmlet in the current experiment. There is a strong positive relationship between DMI and methane production in dairy cattle (Moe & Tyrrell, 1979; Ellis et al., 2007). In the current experiment, pasture growth was the same between farmlets but the AUT farmlet cows were offered more supplementary feed. As the AUT farmlet cows also produced more MS, it is hypothesised that those cows had greater DMI, and so greater methane emissions. With the recent introduction of methane reduction targets in the Climate Change Response (Zero Carbon) Amendment Act 2019, there is regulatory risk that the relative profitability of a change to autumn calving would be reduced by GHG emission regulations that limit the amount of supplementary feed that can be used, or penalise GHG emissions above a target threshold.

Chapter 7 Conclusions, limitations, and future research

In regions, such as South Taranaki, where current climatic conditions may not support pasture growth to consistently match herd feed demand from a spring-calving system, some farmers are considering changing their herd's calving season from spring to autumn. It is perceived that changing calving season from spring to autumn will result in a system that is better suited to local pasture growth profiles and is also potentially more profitable, due to milk supplied during winter receiving a winter milk premium. Extending the CI so that the spring-calving herd undergoes an extended lactation and next calves in autumn is one approach to changing calving season. Although changing calving season is a strategic decision for a farmer that has long-term impacts on their business, there is limited research on this approach to changing calving season, the performance of the farm system during the period of change, or the investment return from changing calving season. Therefore, the objectives of this research were:

1. To quantify the biophysical and economic effects on a farm system that undertakes an extended lactation to change from a spring-calving system to an autumn-calving system, compared with a steady-state spring-calving system; and
2. To evaluate the change of calving season from an investment context, and quantify the impact of the period of change on future system performance.

It was hypothesised that using an extended lactation to change calving season to autumn will negatively impact the whole farm system (biophysical and economic), due to reduced performance during and following the extended lactation, and that future cash flows would need to be greater than a spring-calving system to recover the initial cost of the investment.

7.1 Biophysical and economic effects on a farm system when undertaking an extended lactation to change from a spring-calving system to an autumn-calving system

Key climatic factors driving PGR are changing in South Taranaki, with a probable impact on the profile of pasture supply throughout the year. In the AUT farmlet, extending the CI and then entering an autumn-calving system shifted the profile of herd feed demand relative to the profile of pasture supply. During both the extended lactation and autumn-calving lactation, a feed deficit occurred during winter, which required filling with supplementary feed. As a result, imported and total supplementary feed offered was greater, and thus operating expenses were greater. In addition, the use of supplementary feed lower in quality than spring-grown pasture potentially led to a lower peak MS yield during early lactation (Garcia & Holmes, 2001). In contrast, during the later stages of the extended lactation, low herd feed demand combined with

the implementation of traditional spring-calving system grazing targets (i.e., a large pasture allocation and a fast grazing rotation) led to a greater feed surplus in spring and summer in the AUT farmlet compared with the SPR farmlet. Consequently, greater pasture was harvested as silage during late spring, and deferred grazing was used to conserve surplus pasture during summer. Offering a high pasture allocation to cows producing low quantities of MS during the later stages of their extended lactation resulted in AUT farmlet cows gaining BCS above an optimal level, which is typical of cows bred for 12-month CI that undergo extended lactations (Kolver et al., 2007). Consequently, the AUT farmlet cows were at greater risk of metabolic disease at subsequent calving (Roche et al., 2013b). They were offered a restricted diet during their non-lactating period in an attempt to reduce BCS and mitigate this risk, which was successful. However, during this same non-lactating period (late summer), AUT farmlet cows were reported to have episodes of ryegrass staggers. Notwithstanding the lack of evidence suggesting any difference in post-grazing residual level between farmlets, the likely cause of the ryegrass staggers was a combination of: the decision to defer graze some paddocks and then feed the deferred pasture to non-lactating cows, which would have increased the exposure of non-lactating cows to lolitrem B in the seed head; and the restricted grazing allocation offered to the non-lactating cows, which would have meant these cows grazed lower into the sward and also increased their exposure to lolitrem B in the plant base.

During the period between the start of the extended lactation and the end of the first autumn-calving lactation, total MS production was similar between farmlets, even though the AUT farmlet completed two lactations while the SPR farmlet had completed two and a half lactations. During the extended lactation, DIM for the AUT farmlet cows varied, and only 52% of the herd was still lactating at the final dry-off date. Gross revenue in the AUT farmlet during Y2 was reduced relative to the SPR farmlet because of a reduction in MS production, due to the AUT farmlet herd being in the later stages of their extended lactation, when some cows were producing low quantities of MS and some were not lactating. The ability of the cows to continue lactating through the extended lactation, to generate greater gross revenue, while minimising the detrimental effects on pasture and BCS on the following lactation, was identified as critical to the success of this approach to changing calving season.

During the first 12-month CI autumn-calving lactation, cows in the AUT farmlet had greater DIM and produced more MS compared with cows in the SPR farmlet. Cows in the AUT farmlet had a greater reduction in BCS during early lactation, which most likely increased the recorded milk fat concentration. This, combined with the availability of the winter milk premium, led to the AUT farmlet having a greater average milk price and greater gross revenue compared with the SPR farmlet during Y3. An implication of the AUT farmlet producing more MS once in a steady-state system compared with the SPR farmlet, was the requirement to purchase additional

milk processing company shares. This was a relatively large purchase which reduced cashflow during Y3 but provided additional income for this farmlet from Y4 onwards.

Extending the CI improved the reproductive performance of the AUT farmlet cows during L1 which had implications for L2. Extending the CI extended the time between PSC and PSM, allowing cows to enter a positive energy balance and clear any uterine disease prior to the beginning of the mating period. Improved reproductive performance enabled less involuntary culling, normally a major economic cost to dairy farms (Kerslake et al., 2018), and led to a more condensed calving pattern. An implication of this is that there will be a greater workload for staff during the early part of the calving period, and there needs to be more feed on hand. Reproductive performance of the AUT farmlet cows was similar to the SPR farmlet cows during the L2 mating period, indicating that reproductive benefits from extending the CI are unlikely to carry forward once cows return to a 12-month CI.

Extending the CI resulted in heifers entering the AUT farmlet herd that were older than heifers in the 12-month CI SPR farmlet. These AUT farmlet heifers were heavier, had a higher BCS and produced more MS compared with SPR farmlet heifers. The greater MS production of the AUT heifers may have been because they were more skeletally mature at calving and able to partition more energy to MS production rather than to growth (Chuck et al., 2018). Even though age and LWT differed, there was no large difference in reproductive performance of AUT farmlet heifers compared with SPR farmlet heifers, which is consistent with previous research (Dobos et al., 2004). Heifers in the AUT farmlet spent longer on agistment during Y2, which increased their grazing cost per animal, but because extending the CI meant that there were no yearlings grazing during Y2, total net grazing expenses for the AUT farmlet were less than predicted.

Data from this experiment indicates that extending the CI and undergoing an extended lactation had carry-over effects on the first 12-month CI autumn-calving lactation. Extending the CI reduced MS production during one year, had implications for grazing management, increased milk fat concentration in the following lactation, improved reproductive performance in one mating period, and resulted in heifers entering the herd that were older and produced more MS. A new ‘transition period’, over which a herd changes from a steady-state spring-calving system to a steady-state autumn-calving system, was defined as including both the extended lactation and the first 12-month CI autumn-calving lactation.

To my knowledge, this is the first dissemination of biophysical results from a farmlet experiment that compared a herd that changed from a spring- to an autumn-calving system, by undertaking an extended lactation, with a herd that remained in a spring-calving system in pasture-based dairying. There is increasing farmer interest in autumn-calving systems and

utilising an extended lactation to change the calving season of their herds, thus, the biophysical results reported in the current experiment contribute new knowledge to this gap in the literature.

7.2 Evaluation of changing calving season from an investment context, and quantification of the impact of the transition period on future system performance

During the transition period, lower MS production in Y2 alongside greater supplementary feed expenses, capital investment in effluent infrastructure in Y1, and purchase of additional processing company shares in Y3, reduced profit in the AUT farmlet such that at the end of Y4 cumulative discounted cash flow was less than the SPR farmlet. But the investment analysis concluded that within the assumptions of the data, that is, when a full winter milk premium was available, and the steady-state AUT farmlet produced 23% more MS, which led to an increase in the profit margin compared with the steady-state SPR farmlet, changing calving season from spring to autumn was a relatively better investment decision than to remain spring calving over the ten-year investment horizon considered. It was identified that the greater NPV of the AUT farmlet was impacted by two different stages: the transition stage (i.e., the transition period) when the herd was changing calving season and incurred higher net costs compared with a farm that remained spring calving; and the steady-state stage when the autumn-calving herd was in a steady state and needed to recoup the initial net costs. Moreover, this investment analysis identified that economic outcomes in the transition period are dependent on the level of capital investment required to change the business to an autumn-calving system, economic outcomes in the steady-state stage are dependent on the increase in MS production in the AUT farmlet relative to the SPR farmlet, and that economic outcomes in both stages are dependent on the availability of a winter milk premium.

Greater DIM during the extended lactation was regarded as important to increase MS production during Y2, assuming that additional gross revenue exceeded additional operating expenses. There are, however, many biophysical considerations that may have implications when attempting to extend DIM of these cows. Depending on existing farm attributes, some farmers may not require any additional capital infrastructure during or after the transition period, reducing their initial net costs and increasing the potential investment advantage of changing calving season.

During the steady-state stage, the AUT farmlet was predicted to outperform the SPR farmlet by producing more MS and earning a greater average milk price which offset the initial net costs. A major driver of the greater MS production was greater imported supplementary feed use, which increased the system intensity in the AUT farmlet. Scenario modelling of two different MS production levels in the AUT farmlet highlighted two important considerations for the

investment analysis. Firstly, that the marginal benefit of supplementary feeding must be considered, as it can influence the relative profitability of the steady-state autumn-calving system. Secondly, that if there is no winter milk premium available and MS production remains the same as the spring-calving system, then continuing to calve in spring is the better investment choice because the autumn-calving system is unable to offset the initial net cost of changing.

In both the transition period and the steady-state stage, the availability of the winter milk premium was critical to the investment decision to change calving season, but it also represents a major risk, as there is no guarantee that the winter milk premium will continue at its current price and structure in future years (Chikazhe et al., 2017). This current analysis demonstrated that when the winter milk premium was halved or removed entirely, the initial net costs of changing to autumn calving increased, and the steady-state autumn-calving system required more time to offset this initial cost relative to the spring-calving system. This led to the recommendation that only cautious farmers who can operate an economically-sustainable autumn-calving system without a winter milk premium, and with a low cost of production, should consider changing calving season.

7.3 Limitations

This experiment provided the opportunity to examine a controlled change to a dairy system at a commercial farm scale. The large number of cows in each farmlet provided confidence that the reported differences between farmlets were due to system-level variation and not cow-level variation. Although the research occurred in South Taranaki, the farmlet decision rules, system of production, soil type and climate are broadly representative of pasture-based dairy systems in other geographic locations, hence, the results reported here will be broadly applicable to farmers in many regions throughout NZ. However, it is also important to consider limitations to this experiment and analysis.

7.3.1 Experimental implementation and its timeframe

The cow or the paddock was the experimental unit for results reported with statistical significance. As there was a lack of replication at a system level (i.e., only one AUT and one SPR farmlet) in the current experiment, interpretation of these results could be more robust with replication of farmlets. However, as with any farm-systems research, there is a conflict between best-practice experimental design (e.g., replicated farmlets) and the cost, feasibility, and relevance of implementing these designs. For example, two farmlets with ~300 cows per farmlet is more representative of a commercial farm, compared with smaller farmlets where differences in animal interaction, pasture management, and labour allocations are less likely to be recorded at a systems level.

Excluding the initiation of the experiment, the number of cows in each farmlet herd was not balanced at the start of each lactation. This meant that the peak number of cows differed slightly in L2 and L3. The number of heifers reared, and then entering the herd, also differed from lactation to lactation. Ensuring that herd sizes were equal within and between lactations would reduce any potential variation due to differences in grazing pressure and MS production. Similarly, having the same number of heifer replacements would ensure identical grazing costs and, as much as possible, a similar age structure within the milking herd.

The timeframe of the experiment meant that data from only one autumn-calving lactation were recorded. As previously discussed, there were carry-over effects from the extended lactation on the performance of the AUT farmlet herd during this lactation. To offset this constraint, minor assumptions were made when modelling the steady-state AUT farmlet performance from this lactation. If the timing had been different, it would have been more favourable to use data from the second autumn-calving lactation to model future steady-state AUT farmlet performance, or alternatively, use this data to inform a mechanistic model, like the Whole Farm Model (Beukes et al., 2008), to model future performance.

7.3.2 Weather limitations

As with any multi-year farmlet experiment conducted at one site, data were influenced by the prevailing weather during the experimental period. In this case, there was below-average rainfall from October to December 2017, and a drought was declared in the Taranaki region. Pasture growth rates were negatively impacted, and it was hypothesised that this was the cause of the relatively lower MS production during L1 in the SPR farmlet. In addition, there was below-average rainfall during January 2020 which most likely reduced SPR farmlet MS production in L3.

Outputs from the scenario modelling of MS production for the AUT farmlet in Y4 (i.e., S1 and S2) may also have been influenced by the weather and consequent PGR. The modelling assumed a pro-rata decrease in supplementary feed use with the reduction in MS production. Modelling was based on supplementary feed use and MS production from the base economic model in Y4, which itself was based on Y3 performance. During Y3, favourable weather for the AUT farmlet may have increased the PGR and decreased the feed deficit, resulting in less supplementary feed use than may have been expected for an average year. In turn, the starting point for the reduction in supplementary feed in the scenario modelling would be greater than for an average PGR year. With the same MMPR assumption, the amount of supplementary feed remaining in S1 and S2 would be predicted to be greater, which would have increased the cost of production and reduced the profitability compared with the SPR farmlet.

7.3.3 On-farm biophysical and economic data recording

There was only one milk vat on the research farm at the commencement of the experiment which meant that milk from both farmlets was pooled during L1 and daily tanker pick-up milk quantities could not be used in the results. Instead, monthly herd test data for individual cows were used to calculate MS production per cow, which were then combined to calculate farmlet production. This calculation slightly overestimated farmlet MS production compared with the daily tanker pick-up data because the calculation assumed 100% of the production from the cow, from the day she calved until she was dried off, was sold at the farmgate. There was no reliable way to account for colostrum, calf milk, and antibiotic-tainted milk that in practice would not have been sold at the farmgate. However, both farmlets were treated the same, and thus, the amount of unsold milk would have been similar between farmlets. Thus, relevant differences between farmlets would not have differed significantly.

Because of the size and scale of the research farm, and that it was operated by a similar number of employees as a commercial farm, it was difficult to accurately record supplementary feed data. A major limitation was that supplementary feed offered prior to 1 October 2017 was not recorded. Instead, as all animals were receiving the same amount during this period (both farmlets operated equally prior to 1 October 2017), these data had to be estimated. In addition, methods of recording harvested supplementary feed varied from year to year as the farm team changed, and there was no stock-take data for supplementary feed inventories at the beginning and end of each year.

Due to the research farm operating as a commercial entity, not all expenses were able to be allocated to an individual farmlet. An economically valid approach, which included other relevant variables, was used to estimate and apportion these expenses. Although this method was cross-validated, further research is required to assess the suitability of this approach in the context of other systems research.

Quantification of differences in labour and machinery use between farmlets would have provided additional information to calculate expenses from. It is recommended that in the future, an approach similar to that used at the Northland Dairy Research Farm is implemented. In Northland, where there are three research farmlets operating, at least one day a week, staff record hours spent on tasks over and above common farm operations on the different farmlets, and tractor engine hours. This would enable more accurate apportioning of labour and machinery costs to each farmlet (McCahon, 2019).

7.4 Recommendations for future research

The current experiment investigated the impact of changing calving season, which occurred during the initial years of a multi-year research project at Kavanagh farm. It is recommended that, where possible, limitations from the current experiment are corrected, and biophysical and economic data continue to be recorded as the experiment continues until May 2023. Data obtained in the coming years, and appropriate interpretation of these, will enable the steady-state performance of the AUT farmlet to be determined.

Extending the CI, and undertaking an extended lactation, is one of three predominant approaches farmers can implement to change their herd's calving season. The current experiment provided useful information on the system-level performance of this approach. Further research that quantifies systems-level impacts from the two other approaches would provide valuable information for the dairy industry. Unfortunately, the ability to compare these three different approaches in a farmlet context is limited due to scale and resource, therefore, a modelling study could be undertaken to model these different approaches at a commercial farm level.

Prior research has identified the impact of regional differences in pasture growth on the suitability for autumn calving (Chikazhe et al., 2017). Variations in weather, and in turn pasture growth profiles, during the experimental period affected the results of the current experiment. It would be beneficial to analyse the biophysical and economic performance, within different NZ regions, of commercial farms that have changed calving season. By assessing a farm's monthly MS production, farms that have changed calving season could be identified from a database, and paired with a farm that remained spring calving, to identify key performance indicators of success for farms that have changed calving season.

As with the current experiment, and other experiments that have investigated extended lactations in pasture-based dairy systems, cows were predominantly HF (Auldist et al., 2007; Kolver et al., 2007; Grainger et al., 2009; Butler et al., 2010). There are differences in lactational performance between HF and Jersey cows (Coffey et al., 2016), and it is predicted that Jersey cows would be less suitable to extended lactations due to their lower MS production capacity and propensity to partition energy to body condition instead of MS production. Considering that 48% and 9% of NZ dairy cows are either HF x Jersey crossbreds or pure-bred Jersey, respectively (DairyNZ, 2018), it would be useful for further research to investigate extended lactation performance of Jersey and Jersey-dominant crossbreds to provide more information for dairy farmers with Jersey herds who are considering changing their herd's calving season.

As discussed in section 6.5.2.2, a detailed analysis of the environmental impact of changing calving season was out of scope for this current experiment, but there may have been valid differences in both N leaching and GHG emissions between farmlets that may have influenced the results. To date, no literature has compared environmental outcomes between spring- and autumn-calving systems. Because environmental policy will continue to affect dairy system decisions and management, further research is required to understand any differences in negative environmental outcomes between calving systems. One approach may be to measure actual N leaching with ceramic cups, or alternatively, use OVERSEER® to model N leaching and GHG emissions in the different farmlets.

7.5 Conclusion

Changing calving season from spring to autumn represents a significant systems-level change to a farm, which impacts on its' biophysical and economic performance, both during the period of change and once the system has returned to a steady state. It also represents an investment that has short-term net costs that must be offset by potential long-term net gains. Farmers considering extending their herd's CI and utilising an extended lactation to change calving season must understand how the transition period will impact on their farm business in both the short and long term, what factors, benefits, and challenges they need to be aware of, and how their unique farm attributes may, or may not, influence these.

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Appendices

Appendix A

Table 7.1. Assumptions for the cost of making homemade and purchased pasture silage and hay.

	Cost per bale ($/bale)	DM per bale (kg DM/bale)	Cost per kg DM ($/kg DM)	Source
Home grown pasture silage	33	180	$0.18	DairyNZ (2010); Askin & Askin (2018)
Purchased pasture silage	100	180	$0.56	
Home grown hay	21	300	$0.07	
Purchased hay	120	300	$0.40	

Table 7.2. Assumptions for the cost of establishing the maize and turnip crops.

	Cost ($/ha)	Source
Maize establishment	$2,713.13	Askin & Askin (2018)
Turnip establishment	$438.35	

Appendix B

A paper titled “Implications of using an extended lactation to change from a spring-calving to an autumn-calving farm system in South Taranaki”, using data from this thesis, has been published in the New Zealand Journal of Animal Science and Production 2020, where I am the first author.

Jarman, J. W. M., Kay, J. K., Neal, M., Donaghy, D., & Tozer, P. (2020). Implications of using an extended lactation to change from a spring-calving to an autumn-calving farm system in South Taranaki. *New Zealand Journal of Animal Science and Production, 80, 143-149.*

Appendix C

Table 7.3. Summary of the average per cow and per ha expenses extracted from a group of biophysical and financial accounts for 113 owner-operator South Taranaki dairy farms during the 2016/17–2018/19 seasons extracted from DairyBase (Shadbolt, 2009), and the relative proportion of per cow, per ha, per days milking, per cow days milking and per ton of imported supplementary feed of those expenses to the total per ha expense; similar to the method described by Macdonald et al. (2017).

	Cost		Proportion				
Item	Per cow	Per ha	Per cow	Per ha	Per day milking	Per cow day milking	Per ton of imported supplementary feed
Labour	396	1,157	5%	10%	60%	10%	15%
Animal health	91	267	75%	10%	15%		
Breeding and herd improvement	61	180	95%	5%			
Farm dairy	28	82	10%	10%	40%	40%	
Electricity	43	124		5%	45%	50%	
Calf rearing excluding labour	26	76	100%				
Regrassing	21	62	15%	85%			
Weed and pest	14	40	10%	90%			
Vehicles	67	197	50%	30%	10%		10%
Fuel and oil	14	41	50%	30%	10%		10%
Repairs and maintenance — land	98	287	40%	40%	10%	10%	
Repairs and maintenance — plant	46	134	30%	30%	10%	10%	20%
Freight	19	57	85%	5%			10%
Administration	62	181	20%	80%			
Insurance	37	107	20%	80%			
Rates	57	170	20%	80%			
ACC	6	18	20%	80%			
Depreciation	165	480	20%	60%			20%