Cow breed, stocking rate,

and calving date

affect the profitability of pasture-based dairy farms.

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Abstract

Data from two multi-year experiments undertaken at the DairyNZ research farm, No 2. Dairy were collated and analysed. The effects of:

1) Breed (Jersey or Holstein-Friesian; **JER**, **HF**) at optimum or high comparative stocking rates (**CSR**; 80 or 100 kg body weight (**BW**)/t dry matter (**DM**) of feed available; CSR80 and CSR100, respectively); and
2) Changing the mean calving date (January, April, July, or October; **JAN**, **APR**, **JUL**, **OCT**)

on biophysical measurements (i.e., milk production, pasture growth) and farm profitability were determined.

Changing these strategic management variables affected the amount of pasture grown and consumed. For example, there was an interaction between breed and CSR in many of the measured pasture and milk production variables in experiment one; whilst, in experiment two, changes in the month of calving affected pasture dry matter intake (**DMI**) in early-mid and mid-late lactation, and annual milk production. Annual pasture production was greatly reduced at CSR100 on the HF farmlet, but not on the JER farmlet. Month of calving affected pasture DMI during early-mid lactation and mid-late lactation.

A breed x CSR interaction reduced milk production per cow at CSR100, an effect that was greater in the HF breed than in the JER. Month of calving affected milk production per cow with the JUL herd producing the highest yield, compared with the JAN, APR and OCT herds.

Other breed x CSR interactions were also detected: JER cows had the lowest mean days in milk (**DIM**) to first heat at both CSR80 and 100; furthermore, there were negative effects of an increase in CSR from 80 to 100 kg body weight/t DM feed in the HF breed on DIM to first heat. Total metabolisable energy (**ME**) requirements per cow was affected by a breed x CSR interaction. At CSR80, the HF used more ME per cow than the JER, whilst at CSR100, both breeds used less total ME per cow than at CSR80, but the HF again used more than the JER.

From a profitability perspective, HF cows had a greater operating profit per hectare than JER at CSR80; however, JER cows were more profitable at CSR100. The JUL herd had the most profitable farm system, in both the base economic model and stochastic model. Results of the stochastic modelling with no premium included in the milk payment (NZ$/kg fat and protein) variable revealed the operating profit per hectare was greatest for the JUL herd, compared with the JAN, APR, and OCT herds. Inclusion of a premium for milk supplied during 16 May to 15 July in the milk payment (NZ$/ kg fat and protein) variable as well as a downward adjustment in milk price for JUL calving cows because of the high milk production peak in spring did not overcome this difference in profitability. Therefore, the JUL calving scenario was most profitable. The APR seasonal calving strategy resulted in a 10% reduction in operating profit per hectare, compared with the JUL herd, while the JAN and OCT strategy had the lowest operating profit per hectare.

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This thesis is dedicated to my wonderful father- Michael Spaans- who worked so hard to give us the world. I strive every day to reach the heights you did.

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List of abbreviations

AI	Artificial insemination
APR	April calving date herd
BCS	Body condition score
BrW	Breeding Worth
BW	Body weight
$BW^{0.75}$	Metabolic body weight
CDF	Cumulative density function
CSR	Comparative stocking rate
DE	Digestible energy
DIM	Days in milk
DMI	Dry matter intake
FCE	Feed conversion efficiency
FCM	Fat corrected milk
GE	Gross energy
GIT	Gastrointestinal tract
HF	Holstein-Friesian
HFxJ	Holstein-Friesian x Jersey crossbreed
JAN	January calving date herd
JER	Jersey
JUL	July calving date herd
MDSM	Moorepark dairy systems model
ME	Metabolisable energy

MS	Milksolids (kg fat and protein)
NSC	Non structural carbohydrates
NZ	New Zealand
NZD	New Zealand Dollars
OCT	October calving date herd
PSC	Planned start of calving
PSM	Planned start of mating
SCC	Somatic cell count
SCM	Solids corrected milk
TDMI	Total dry matter intake
WFM	Whole farm model

1. Literature review

1.1 Agriculture in New Zealand

New Zealand is a specialist exporter of primary products such as milk powder, sheep meat, beef, wool, kiwifruit, apples, wine, and seafood (Te Ara: The Encyclopaedia of New Zealand, 2016). Contributions to the agriculture industry of NZ gross domestic product are presented in Figure 1.1, with dairy farming as the largest sector since late 2006. The dairy industry is a vital sector in New Zealand's (**NZ**) economy as the largest export earner, with meat and milk sales contributing to 38% of total merchandise export values in the year ending September 2015, and dairy produce earning NZ$11.5 billion during the same year out of NZ$51.5 billion total export receipts (New Zealand Treasury, 2016). NZ has a reputation as one of the world's most efficient agricultural economies, with expert pastoral farming practices, high quality food production systems and world-leading innovation.

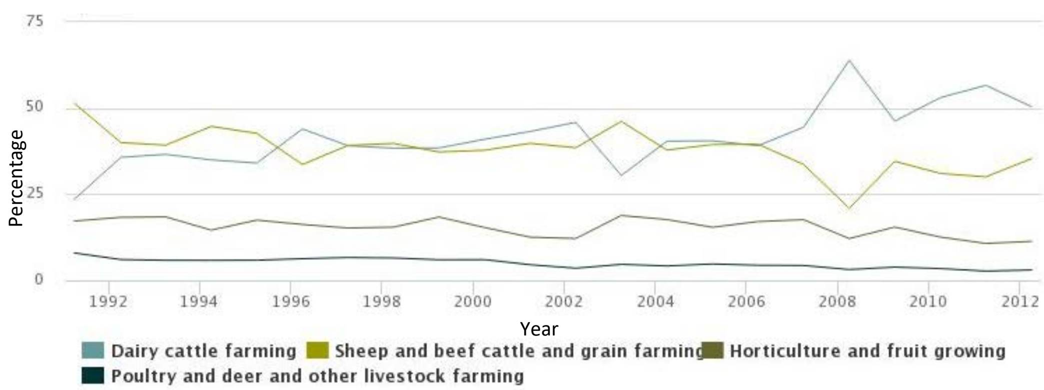

Figure 1.1 Contributions by percentage to the agriculture gross domestic product of New Zealand. Source: Statistics New Zealand (2015).

In the 1990's a new system of payment for milk fat and protein content, known collectively by the colloquial term, milksolids (**MS**), was introduced, with farmers to be paid per kilogram of the MS component of the supplied raw milk (Fonterra, 2014). Since then, there has been a focus on selecting dairy cows with superior MS production in order to maximise on-farm profit. The benefit of this focus is evident in Figure 1.2, as the MS production per cow and per hectare has risen consistently over the last 25 years, reaching an average of 381 kg MS/cow in 2016/2017 and a peak of 1,081 kg/ha in 2014/2015.

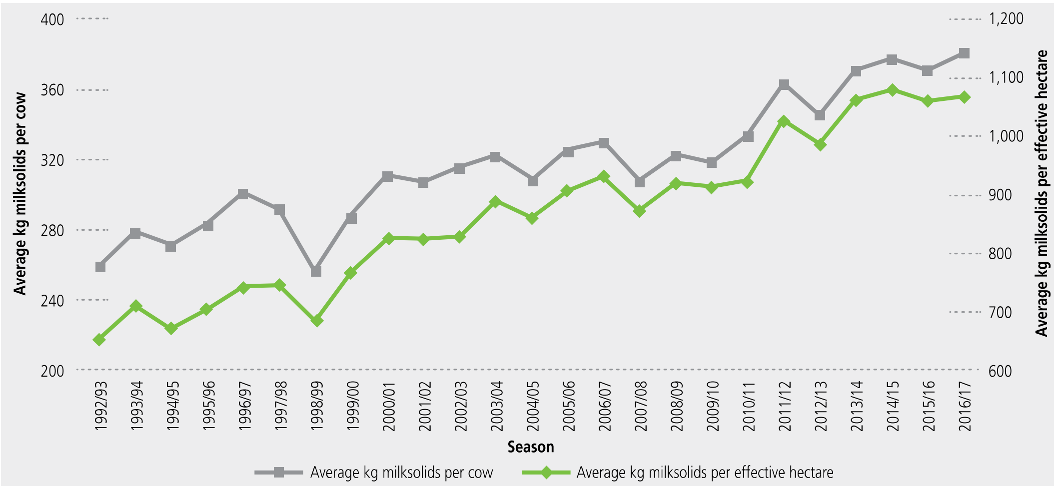

Figure 1.2 Average milksolids (kg per cow) and average milksolids (kg per effective ha) from 1992/93 to 2016/17. Source: DairyNZ & LIC (2017).

Nationally, dairy production research has focused on genetic gain in both pastures and animals to drive efficiency and on-farm profit, through maximising MS production in comparison to feed requirements (DairyNZ, 2017a). Genetic gain has been consistently positive in the animal sector, averaging 1.38% per year over the last five years, and the same trend is expected in pasture genetics following recent developments; these will provide the opportunity for further increases in on-farm profit (DairyNZ, 2017b). The value of genetic gain in dairy herds accumulates over time, as genetically superior heifers enter the milking herd and add value through increases in production and passing on their genes to their progeny. DairyNZ (2017b) estimated that, on average, genetic gain will contribute $NZD11 per cow per year profit over the next 10 years; based on the average herd size of 419 cows, these profits will accumulate to approximately $500 million.

1.2 Dairy farming in New Zealand

In NZ, herds are predominantly pasture-fed, kept outdoors, calve seasonally, and milked twice daily; with the average herd size increasing over the last 30 years from 147 to 419 cows, whilst the number of herds has decreased over the same time period from around 15,500 to 12,000 herds, respectively, as presented in Figure 1.3 (DairyNZ & LIC, 2017). The majority (60%) of dairy farming in New Zealand is located in the North Island, and the largest dairy region is the Waikato, at 23% of national milk production (see Figure 1.4). New Zealand dairy companies processed nearly 21 billion litres of milk and 1.85 billion kg MS in the 2016/2017 season, compared with 35 years ago when 5 billion litres of milk and 491 million kg MS was processed (DairyNZ & LIC, 2017).

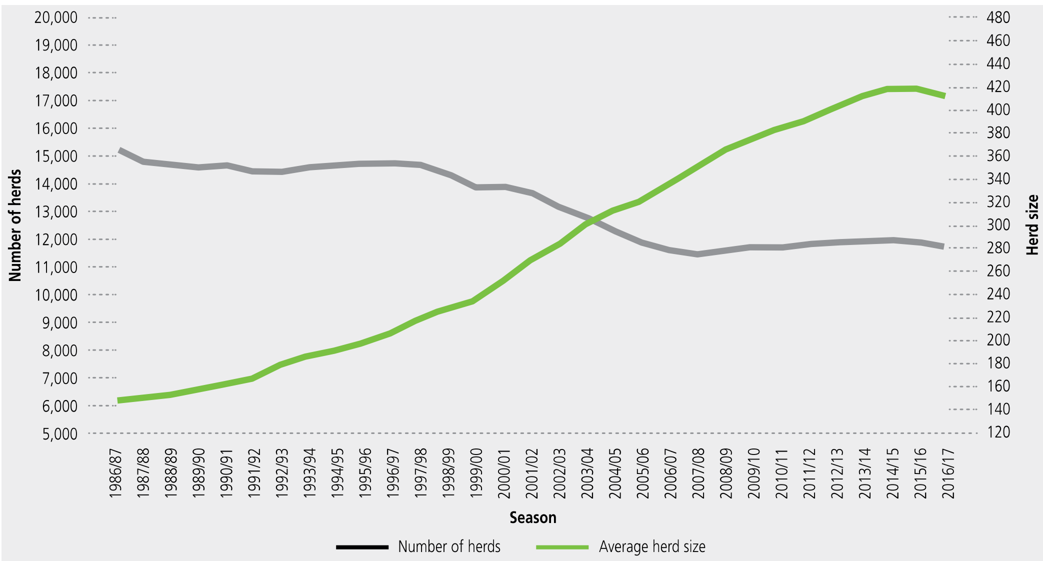

Figure 1.3 Number of herds and herd size from 1986/87 to 2016/17. Source: DairyNZ & LIC (2017).

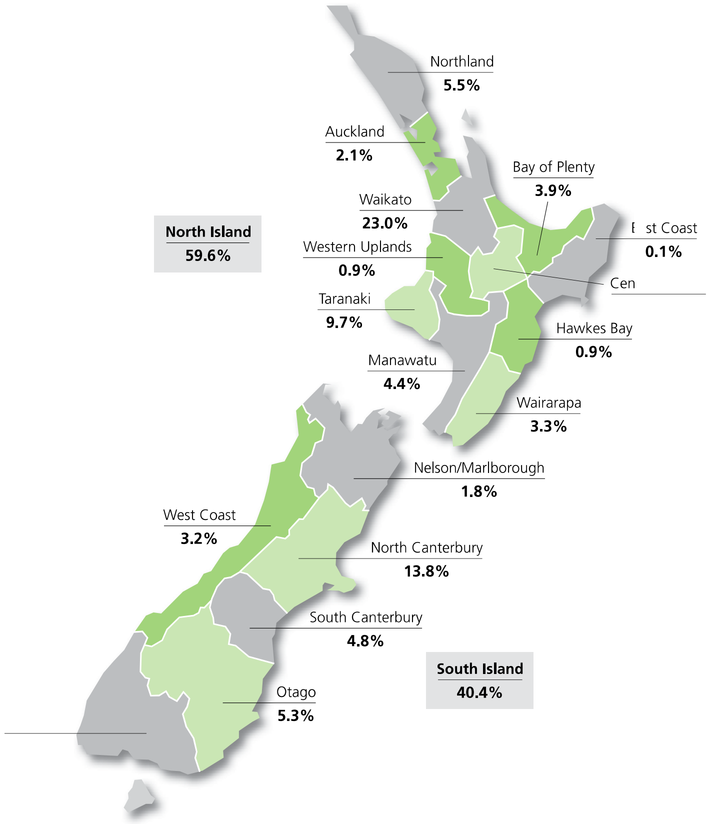

Figure 1.4 Map of New Zealand with the percentage of dairy produced by each region. Source: DairyNZ & LIC (2017).

1.2.1 Pasture-based systems

One of the primary goals of pasture-based dairy systems is maximising the profitability of grazing land per hectare by optimal pasture production and utilisation (B. McCarthy, Delaby, Pierce, Journot, & Horan, 2010). Since the 1960's it has been recognised that the amount of pasture utilised, rather than the amount of pasture grown, and the amount of MS produced per hectare is the major limiting factor of dairy farm profit (Macdonald & Penno, 1998).

Various aspects of pasture and herd management are vital for a successful farm operation, each of which are usually closely linked with other system components. Pasture yield characteristics often cannot be changed, but quality and utilisation can be manipulated or exploited to achieve management goals. The availability of pasture to meet a herd's requirements is one of the most important targets to meet on a weekly, monthly, and annual basis. Herd management goals are more varied, involving reproduction, milk production, and animal condition.

To achieve a lactation every year, the cows must be mated, usually in October in New Zealand, and calve the following winter (Figure 1.5), after a gestation period of around 282 days (Macdonald, Glassey, & Rawnsley, 2010). Mating should begin within 83 days of parturition, known as the planned start of mating (**PSM**), with at least 95% of the herd inseminated, either by artificial insemination (**AI**) or natural breeding, within 21 days of the PSM to enable a calving period of less than 12 weeks (Macdonald et al., 2010). A compact calving period is desired to match the peak grass growth and quality in spring (August, September in NZ) with the peak energy requirements of the herd in early lactation (Figure 1.5) to, thereby, maximise profitability (P. Dillon et al., 2007; K. A. Macdonald et al., 2010; B. McCarthy, Pierce, Delaby, Brennan, & Horan, 2012; Roche, Washburn, Berry, Donaghy, & Horan, 2017).

As a result, in seasonal dairy systems, submission during the first 21 days of the breeding period is an important measure of reproductive success to ascertain the likelihood of a compact calving period (Roche, Macdonald, Burke, Lee, & Berry, 2007a). Reproductive performance of dairy cattle is economically important as it affects milk yield per cow per day for the duration of their life in the herd, and the number of progeny produced per cow as either herd replacements or income (Fonseca, Britt, McDaniel, Wilk, & Rakes, 1983).

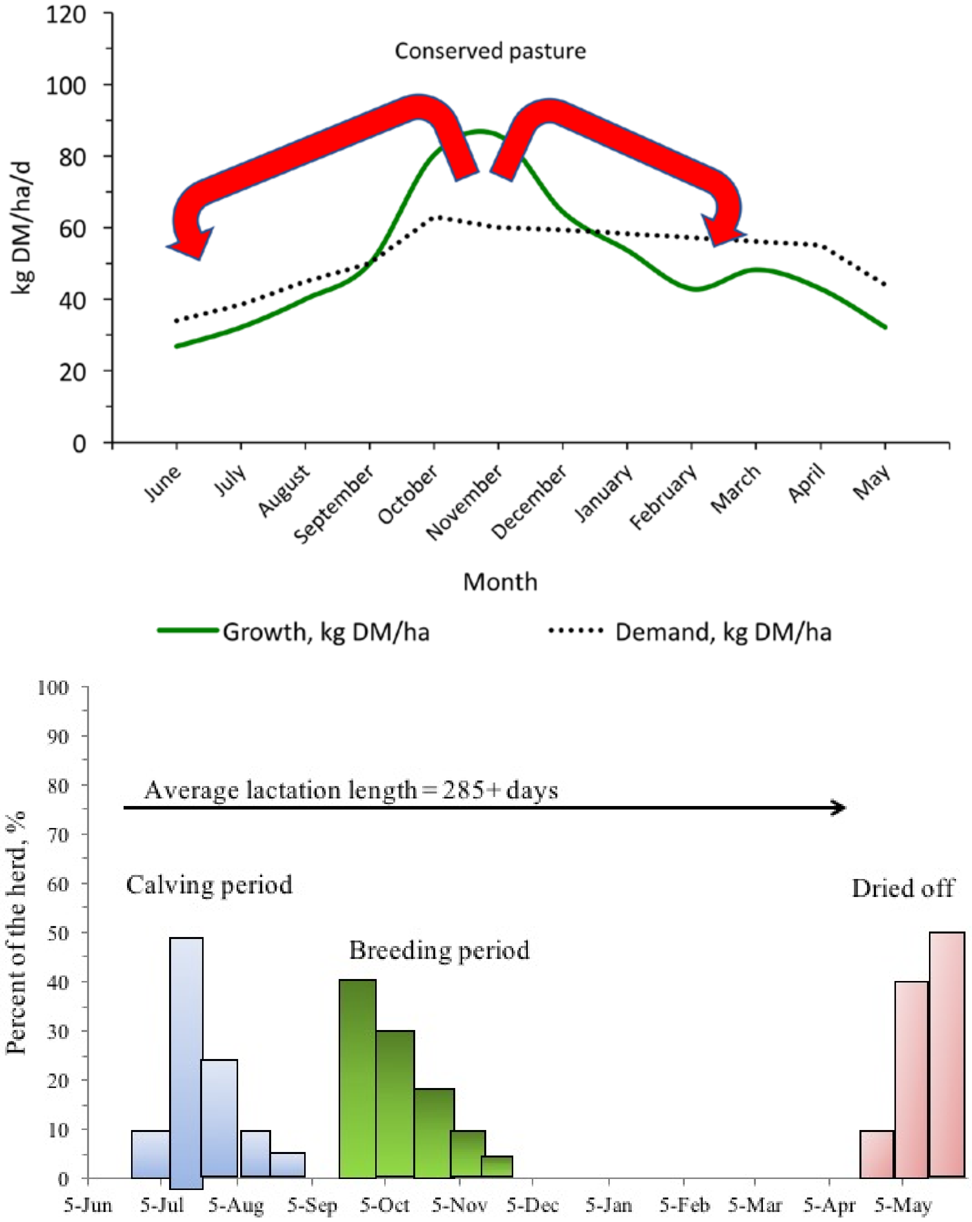

Figure 1.5 Top: Pasture growth and herd demand (kg/ha/day) from June to May. Bottom: Percentage of the herd in the calving period, breeding period and dried off by fortnight from June to May. Adapted from Roche et al. (2017).

1.3 Grazing management

The profitability of pasture-based systems is closely related to the amount of pasture dry matter consumed per hectare per year (Macdonald et al., 2010). Therefore, the key focus for effectively managing a pasture-based system is cost-efficient pasture production and utilisation by carefully balancing feed supply and demand; this balance is critical for preventing underfeeding of the herd or wasting surplus feed (see Figure 1.5; B. McCarthy et al., 2010). If pasture production does not meet the requirements of the herd, then altering the supply of the pasture through grazing management should be considered, along with manipulation of the environment by application of fertiliser or irrigation, or feeding supplement (Lee, Donaghy, & Roche, 2008).

1.3.1 Pasture allocation

Rotational grazing patterns where cows are offered a defined pasture area daily, after which that pasture is rested, is key for efficient pasture utilisation, which is important for maximum MS production and farm profitability. Dry matter intake is primarily controlled by altering pasture allocation, and is the main determinant of milk production (Macdonald, Penno, Lancaster, & Roche, 2008a). Managing pasture allocation is important for managing the energy requirements of the herd, whilst optimising future pasture quality through meeting target grazing residuals of 40 - 60 mm (Lee et al., 2008; Macdonald et al., 2010). The ability of a pasture to regrow following grazing is essential for maintaining productivity and persistence of the cultivar (Lee, Sathish, Donaghy, & Roche, 2011).

Maximum annual MS production is achieved by offering a pasture allowance that meets approximately 90% of potential pasture intake (Macdonald et al., 2010). For a cow at peak lactation on a pasture only diet, this equates to 30 - 40 kg DM/cow/day. Sufficient pre-grazing mass is also important, as low pasture height reduces DMI by reducing bite size and cows cannot compensate sufficiently by increasing bite numbers per day (Macdonald et al., 2010).

1.3.2 Post-grazing residual

Whilst the climatic variables influencing regrowth of pasture are outside farmer control, one decision the farmer commonly makes (either consciously or sub-consciously) is the desired height of the post-grazing residual and this has been reported to have a substantial impact on rates of regrowth (Lee et al., 2008; Lee, Donaghy, Sathish, & Roche, 2009; Lee et al., 2011).

Ganche, Delaby, O'Donovan, Boland, and Kennedy (2013) reported that a low post-grazing pasture height of 27 mm during the first ten weeks of lactation was physically restrictive for the herd and prevented sufficient DMI, as milk yield was reduced by 11% and significant BW losses were observed compared with cows grazing to 35 mm. Despite no carryover effect of restricted DMI during early lactation observed on subsequent milk yield, the cumulative MS yields did not recover from the deficit in early lactation.

It would appear, therefore, that cows restricted to a post-grazing residual height of 27 mm in the first two grazing rotations of their lactation will recover milk yield but not MS production when grass supply becomes more plentiful later in spring. These results are particularly important in a system of milk payment that is based on milk components, such as in NZ. Ganche et al. (2013) suggested a post-grazing residual height of 35 mm during the first two rotations of early spring to effectively balance herd production and pasture utilisation. To provide sufficient DMI for expression of the herd milk production potential, it was suggested that from mid-spring, the post-grazing residual be extended to 45 mm (Ganche et al., 2013).

Once the pasture growth exceeds herd requirements, the surplus must be removed as silage to achieve an appropriate post-grazing pasture mass; this promotes future pasture quality and greater MS production as a result (Macdonald et al., 2010). Lax grazing (i.e., leaving too high a residual) can result in reduced photosynthesis long term through various effects such as an increased proportion of aged leaves in the pasture, or increased stem development causing less light penetration to the base of the plant where new leaves emerge (Lee et al., 2008). Surplus pasture is identified and harvested according to a calculation of expected future pasture growth and the number of days between the current grazing and next scheduled grazing to give an indication of the pasture area to be allocated for conservation.

A visual representation of the ideal post-grazing pasture mass is presented in Figure 1.6, where there is a linear decrease in the amount of pasture mass in each paddock in co-ordinance with the area least recently grazed to the area most

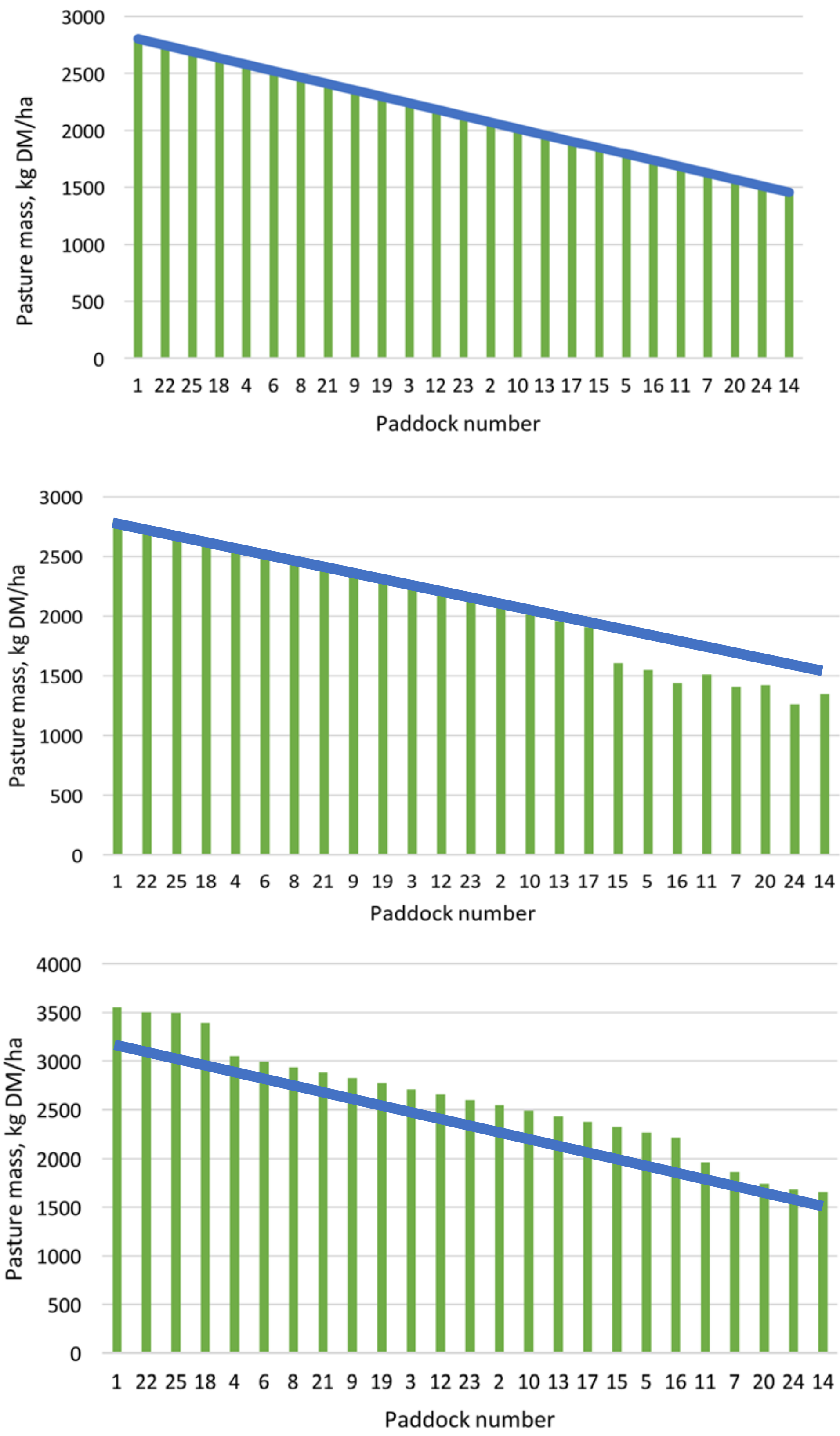

Figure 1.6 Top: Ideal pasture wedge showing a linear decrease (blue line) in the amount of pasture mass (kg DM/ha); Middle: Deficit pasture wedge showing a deficit of pasture mass (kg DM/ha) in the last paddocks, below the ideal linear decrease (blue line); Bottom Surplus pasture wedge showing a surplus in pasture mass (kg DM/ha) above the ideal linear decrease (blue line).

recently grazed. If the post-grazing residual is allowed to become too low, (i.e., towards 20 mm), then a pasture deficit will occur, presented in Figure 1.6, and the reduced pasture regrowth may have a long-term effect on pasture mass.

Supplementary feed should be added (Figure 1.5) to fill the deficit, with rotation length extended to allow the pasture to recover. A post-grazing residual that is too high (i.e., towards 60 mm), presented in Figure 1.6, is an indication of a pasture allowance which is too high. The post-grazing residuals should be reduced by removing surplus pasture to avoid poor pasture quality in future.

1.3.3 Seasonal management of pasture

Pasture growth fluctuates throughout the year, with each season presenting its own challenges to balance feed availability and demand (Lee et al., 2008; Macdonald et al., 2010). Lee et al. (2008) presented seasonal differences of post-grazing residual heights on the regrowth ability of pasture, and therefore, the amount of feed available. Between the beginning of spring and mid-autumn (August-April), a post-grazing residual of 40 - 60 mm maximises the production and nutritive value of a predominantly ryegrass pasture (Lee et al., 2008), presented in Figure 1.7. During winter a post-grazing residual of 20 - 40 mm promotes pasture accumulation; however, low post-grazing residuals during early spring, (i.e., towards 20 mm), affect pasture mass negatively (Figure 1.7).

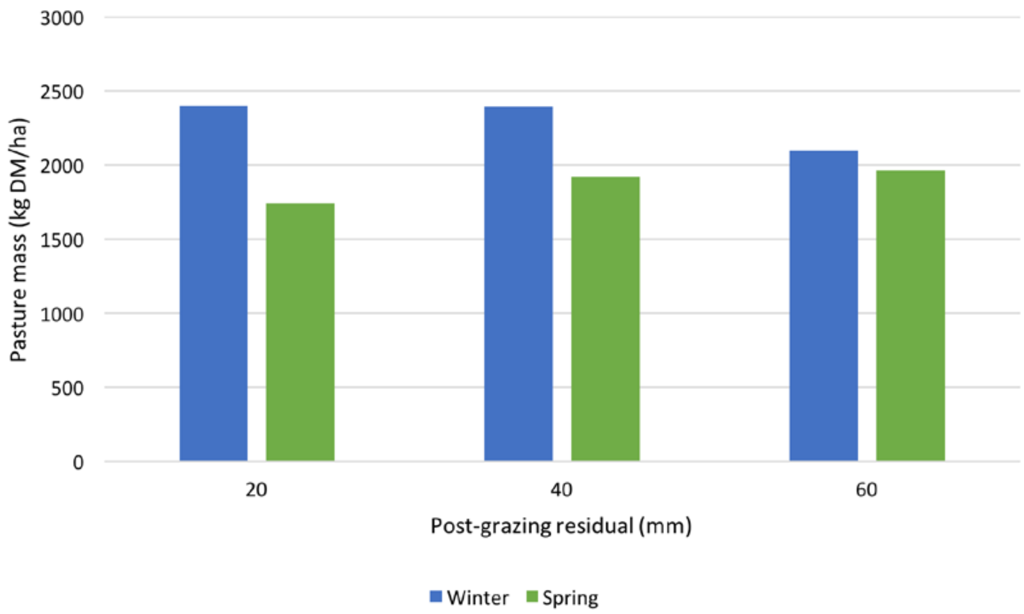

Figure 1.7 Effect of post-grazing residual (mm) on pasture mass accumulation (kg DM/ha) during Winter (June) and Spring (August-October). Data from Lee et al., (2008; 2011).

1.3.3.1 Autumn and winter management

One of the main objectives of autumn (March to May in New Zealand) pasture management is to increase the mean pasture cover at the onset of winter, whilst achieving the optimum body condition score (**BCS**) for calving by 1 June (Macdonald, 2014). Use of the autumn rotation planner (Figure 1.8) between April and June allows the mean pasture mass to increase in anticipation of calving requirements (Macdonald et al., 2010).

An ideal rotation length of 80 - 100 days should be reached by early June and this rotation should be maintained until planned start of calving (**PSC**). To avoid decreasing the pasture cover, herd pasture intake should be restricted to winter growth rates and the remainder of the total intake be filled by supplementary feed, if necessary (Figure 1.5). Damage to the pasture during wet periods from pugging should be avoided by increasing the allocated area temporarily or using stand-off areas to maintain a longer rotation and protect the integrity of the soil. Planned rotation length may be faster with a low SR or high pasture growth rates, or may be even slower with a high SR.

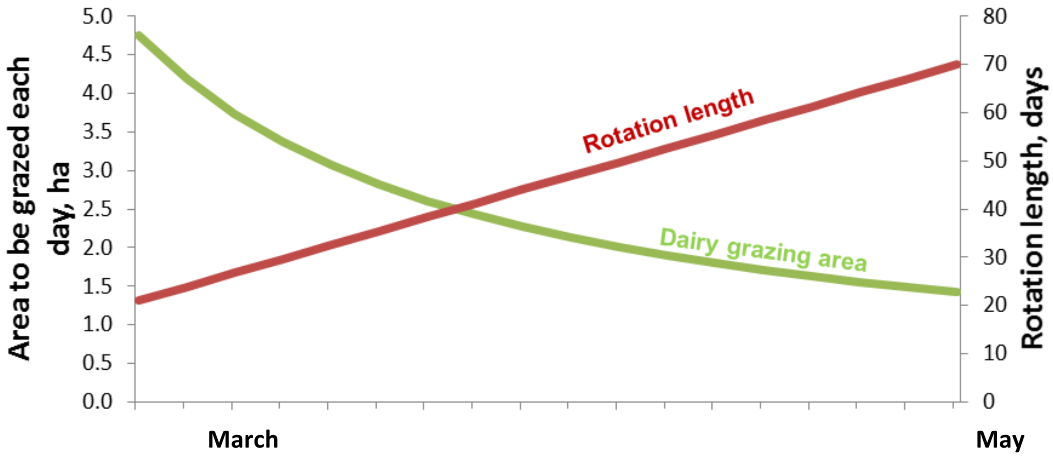

Figure 1.8 Visual representation of the autumn rotation planner. Source: J. R. Roche (pers comm.).

1.3.3.2 Spring management

It has been suggested that achieving cow condition and mean pasture mass targets are most important in spring (August-October in NZ), as it prepares the herd for the remainder of the season; underfeeding during this time can impair both immediate and future herd performance (Macdonald et al., 2010; Macdonald & Penno, 1998). Cover at planned start of calving (**PSC**) should be approximately 2200 – 2400 kg DM/ha for a moderate SR of 2.8 – 3.3 cows/ha (Macdonald et al., 2010). Cover at PSC needs to be sufficient to meet herd demand at balance date, which occurs when the pasture growth rate matches the herd demand (Figure 1.9; DairyNZ, 2017b).

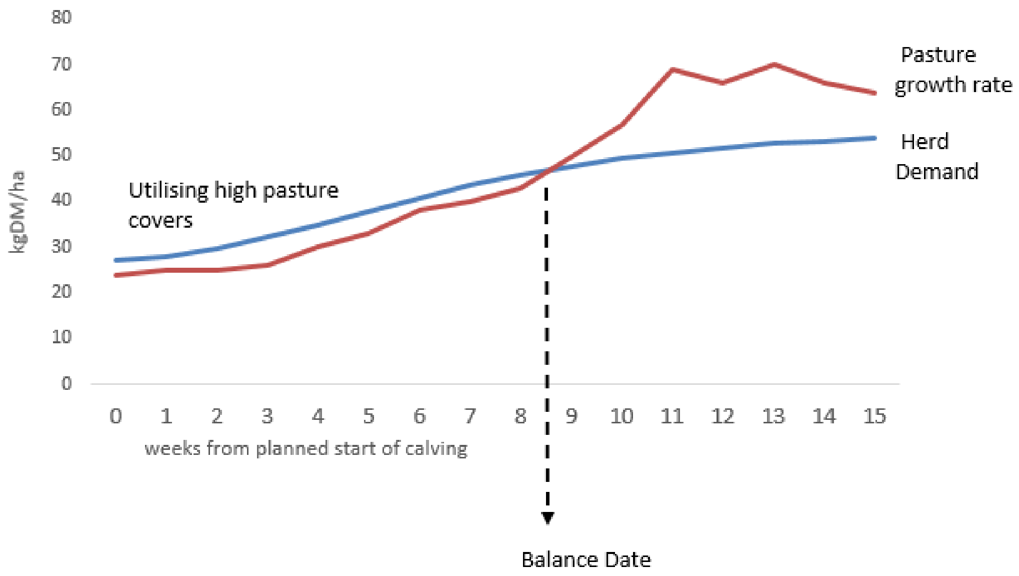

Figure 1.9 Pasture growth rate (kg DM/ha) and herd demand (kg DM/ha) over 15 weeks from the planned start of calving with balance date around 8.5 weeks. Source: (DairyNZ, 2017a).

Although pasture growth is slower than the high energy requirement of the herd in early lactation, it is critical that the pasture allocated to the herd is tightly controlled by ensuring that there is a linear increase in pasture allowance from approximately 1.25% of the total farm area at PSC to approximately 5% at the date when growth is expected to surpass herd demand (Figure 1.9). Following these recommendations, commonly known as the spring rotation planner (Figure 1.10), ensures control of feed supply whilst reducing the risk of introducing too fast a rotation length, negatively affecting quality and regrowth of the pasture for the remainder of the season (Macdonald et al., 2010). A visual representation of the spring rotation planner is presented in Figure 1.10, where the rotation length deceases linearly from July to September, whilst simultaneously the daily grazing area increases exponentially.

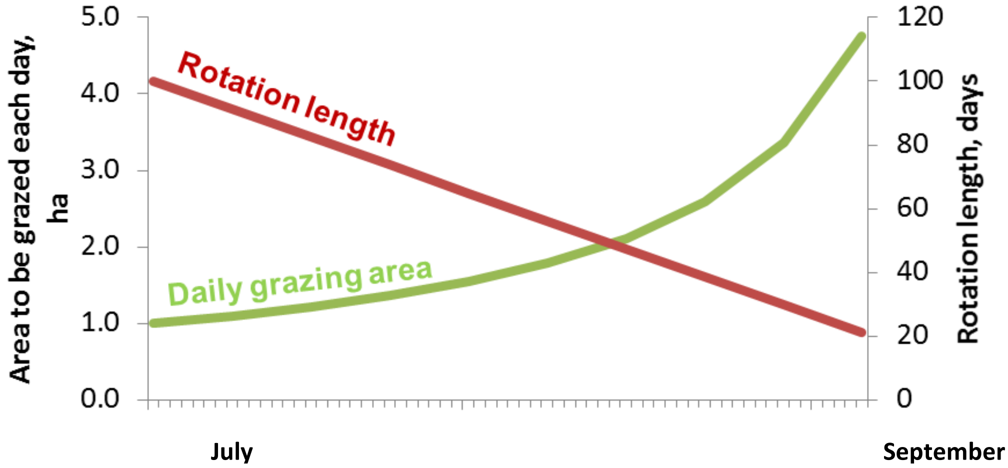

Figure 1.10 Visual representation of the spring rotation planner. Source: J. R. Roche (pers. comm).

1.3.3.3 Summer management

Mean pasture mass is usually high during early summer (November in NZ), due to the excess of pasture relative to herd requirements from the previous months. However, pasture growth rates can decline gradually due to lower soil water availability as summer progresses. Furthermore, extending the rotation length, as recommended from 20 to 30 days, reduces herbage allowance; therefore, the herd is more likely to achieve the desired post-grazing residuals (Macdonald et al., 2010).

If the pasture allowance is less than herd demand from the increase in rotation length, supplementary feed can be offered to make up the total herd intake (Figure 1.5; Macdonald et al., 2010). Other strategies to reduce herd demand and increase feed allowance per cow include the removal of poorly performing or non-pregnant cows from the milking herd early, at an average rate of 20% of the herd, or drying off a portion of the herd early to spread the available pasture further (Macdonald et al., 2010).

1.3.4 Conclusions

Managing pasture growth and feed demand of the herd is a careful balance that can be achieved by monitoring post-grazing residuals and varying rotation lengths. Seasonal variations in pasture growth drive the need for changes in rotation length to promote future pasture growth; therefore, the spring and autumn rotation planners are vital tools in seasonal pasture management. Post-grazing residual length can affect subsequent amounts of pasture mass; therefore, pasture allocation and removal of surplus pasture should be considered carefully to ensure optimal future pasture growth and quality. Additionally, restricted post-grazing residuals affect herd milk production in early lactation; therefore, to balance future pasture quality and herd production, a post-grazing residual of 35 mm in early spring is most appropriate, followed, possibly by extension to 45 mm in mid-spring to maximise milk production, although this has only been verified under experimental conditions in Ireland, and has not been investigated in NZ, thus far.

1.4 Animal management

Cow BCS is an important component of animal management as it is related to milk production and reproductive outcomes (Berry, Macdonald, Penno, & Roche, 2006; Roche, Berry, Lee, Macdonald, & Boston, 2007b; Roche et al., 2009a). Interactions between BCS and reproduction are particularly important in seasonal-calving systems due to the short period between calving and PSM. Increasing BCS has been reported to be positively associated with production over the duration of lactation, with an increase of one body condition score at calving, equivalent to 25 to 32 kg BW, reported to increase production by 12 to 18 kg MS/cow in the following lactation (Roche et al., 2007b).

During periods when the feed requirements of the herd are greater than the amount of pasture available, supplement can be used to fill the deficit. Supplements can be used within reason to maximise herd production, although it is important to consider the profitability of the system when importing feed.

1.4.1 Body Condition Score

Body condition scoring involves a visual inspection of the cow's fat cover over the backbone, hips, ribs, base of the tail, and pin bones, with low scores reflecting an emaciated animal and 10 a grossly obese animal (Roche, Dillon, Stockdale, Baumgard, & van Baale, 2004). A 10-point scale is used in New Zealand; however, there are different scales used internationally, with Australia using 8 points, and the United States and Ireland using 5 points. Research discussed will be converted to a 10-point scale according to Roche et al. (2004). Essentially, the

BCS gives an approximate measure of the amount of energy stored as body fat (Macdonald et al., 2010; Macdonald & Penno, 1998).

In grazing systems, BCS is used to decide when cows should be dried off, thereby influencing lactation length. Thin cows with low BCS can be dried off early to enable them to achieve adequate BCS for their next parturition (Macdonald et al., 2008). In New Zealand, the target condition score for calving is 5.0 for mature cows and 5.5 for heifers (Roche, et al., 2009a).

1.4.2 Supplement

Offering purchased feed must not compromise the objectives of grazing management (i.e. rotation length, residuals), regardless of the season, which should continue as if there were no additional feed available (Macdonald, 2014). Grazing rotations should progress according to guidelines (Macdonald et al., 2010), with the supplementary feed used to assist in slowing the rotation length, maintaining post-grazing residuals, or ensuring the herd is adequately fed. The limiting nutrient in the system, nutritional composition, cost, likely production response, and practicalities of feeding should be considered when evaluating the use of supplement (Macdonald et al., 2010).

The greatest feed deficit is usually experienced in the autumn and early winter, when pasture growth rates decline, rotation lengths are extended to meet mean pasture cover targets at calving, and the potential maximum lactation length of the herd is yet to be met. High or low levels of supplementary feed can be used, depending on the SR, to assist in meeting the daily nutritional requirements of the herd when pasture quality is low, or to maintain an optimal rotation length and post-grazing residual (Macdonald et al., 2017).

1.4.2.1 Response to supplement

The largest response to supplementation was achieved in the autumn, resulting in a longer lactation (Macdonald, 2014). Responses and carry-over effects from feeding pasture silage to dairy cows during different seasons of the year were reported by Clark (1993 in Macdonald, 2014), which revealed a 66 g MS/kg DM immediate response in autumn, twice that of the immediate responses measured in spring and summer (26 and 16 g MS/kg DM, respectively). Lactation was extended seven days by feeding pasture silage in the autumn in this trial.

Carry-over responses were measured between the end of the spring and summer silage feeding periods and the end of the season, culminating in an additional 46 and 45 g MS/kg DM for spring and summer periods respectively. The feed deficits under high SR were filled by the supplemented pasture silage, which enabled improvements in cow condition and utilisation of pasture that resulted in small MS production and/or lactation length increases (Macdonald, 2014).

1.4.2.2 Economics of feeding supplement

Ramsbottom, Horan, Berry, and Roche (2015) reported the decrease in pasture harvested (t DM/ha) when increasing amounts of supplement (t/ha) are used. Four systems were used, where system 1, 2, 3, and 4 refer to <10%, 11-20%, 21-30%, and 31-40% of annual feed requirements were derived from purchased feeds (i.e., non-pasture), respectively.

Milk yield increase in response to increased supplement was 0.67 L/kg DM purchased. Although more milk and MS were produced from an increase in supplement to the diet, multivariate-regression analysis revealed a decrease in profit per hectare and per litre of milk produced with increasing amounts of supplement bought, presented in Figure 1.11.

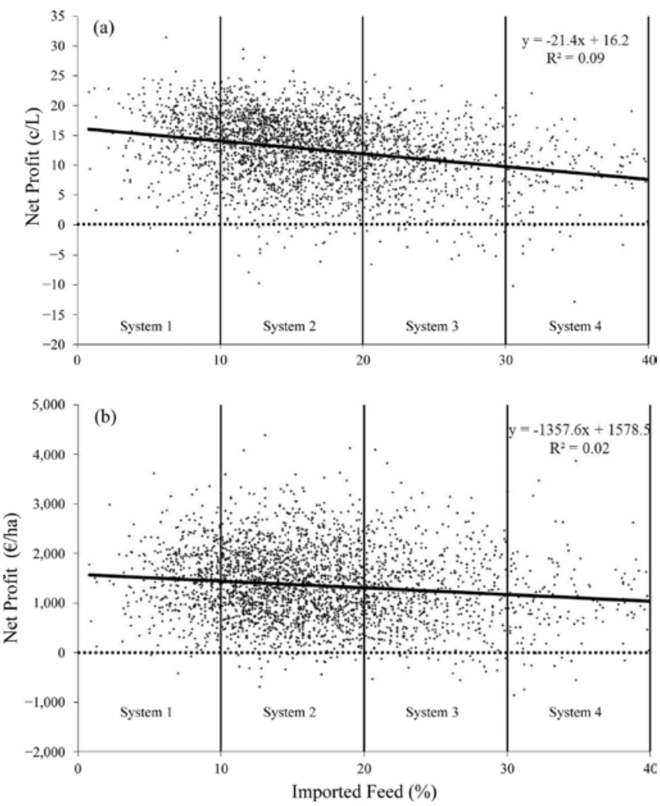

Figure 1.11 Correlations of net profit (c/L; €/ha) with increasing imported feed (%) for system 1, 2, 3, and 4, corresponding to <10%, 11-20%, 21-30%, and 31-40%, respectively. Source: Ramsbottom et al. (2015).

The reported effect was due to the variable and fixed cost increases with feed use over the cost of the feed (Ramsbottom et al., 2015). Total costs increased on average €1.53 for every €1 spent on supplementary feed, therefore, NZD$1[1] spent on supplementary feed increases total costs by NZ$2.24, on average. The decline in profitability with increasing use of purchased feeds reported by Ramsbottom et al. (2015) is consistent with the effect of proportion of grazed pasture in the herd diet on net farm profit per hectare previously reported by Dillon, Hennessy, Shalloo, Thorne, and Horan (2008). Additionally, Roche and Horan (2013) reported the greatest operating expense of the farm business is purchased feed, which heavily exposes businesses that rely on large amount of imported feed to fluctuations in commodity prices (i.e., oil and grain prices). A breakeven cost of purchased feed, assuming an on-farm milk production response to supplement of 55 g MS/kg DM, is 3.5% of the milk price (Figure 1.12; Roche & Horan, 2013), in a payment system based on milk components. Therefore, the majority of supplement used to fill unexpected deficits must be sourced at less than 3.5% of the milk price to avoid detrimental effects on the operating profit of the farm business (Roche & Horan, 2013).

Response to supplements, g MS/kg DM	Breakeven price for supplements, % milk price
80	5.0%
60	4.0%
55	3.5%
40	2.5%
20	1.5%

Figure 1.12 Response to supplement and breakeven price for purchased supplements (% of milk price) in a payment system based on milk components. Source: Roche and Horan (2013).

[1] At the time of writing, €1 equals NZ$1.71.

1.4.3 Conclusions

Monitoring BCS on a regular basis is important to ensure an approximate balance of pasture allowance and herd nutrition requirements is achieved. A low BCS for the herd on average can be an indication of a nutritional deficit, whereas a high average BCS for the herd can be an indication of a nutritional surplus. A deficit can be filled by supplementary feed, whether purchased or conserved pasture silage from a previous surplus period. However, it is important to consider the effect on operating expenses, and therefore, operating profit when purchasing feed, to ensure a viable farm business.

1.5 System management

Management of the dairy herd, regardless of breed, is vital to the success of the farming operation, with key areas of manipulation including calving date and stocking rate. These topics have been extensively researched over the last several decades in the quest to optimise dairy herd performance for milk production, with the global intensification of farming practices provoking further investigation.

1.5.1 Calving date

There is limited literature available on the effect of changing month of calving on farm system characteristics. Dillon, Crosse, Stakelum, & Flynn (1995) compared early (January) and late (March) spring-calving herds, whilst B. McCarthy et al. (2013) compared two herds which calved two weeks apart in mid-February and late-February. B. McCarthy et al. (2013) suggested that by altering the mean calving date of the herd, the reliance of pasture-based system on purchased supplement may be reduced by improved alignment between feed supply and demand. However, few studies have analysed the effect of changing the month of calving from a commonly favoured spring calving date to a calving date in autumn.

It has been suggested that changes in the season of calving from spring (July in New Zealand) that is more common, to autumn (April in New Zealand) implies a mismatch between the herd feed requirements and pasture availability, impacting cow BW, milk yield (García et al., 2000; García & Holmes, 1999, 2001, 2005) and potentially profitability.

However, the published effects of autumn calving are inconsistent. García and Holmes (1999) reviewed comparisons of spring and autumn calving systems, concluding autumn calving cows require more supplement during early lactation in winter, yet commonly have lower daily milk yields at peak lactation. Despite the lower daily yields, autumn calving cows produced higher annual yields of both milk and MS per cow, evident due to longer lactation lengths and higher daily milk yields achieved during late lactation. In contrast, however, García et al. (2000) reported similar yields of MS per hectare between autumn and spring calving herds in New Zealand experiments, suggesting that changing the season of calving may not affect the production of the herd, despite an apparent mismatch of pasture demand and growth.

The lactation curves of herds calving during either autumn or spring in New Zealand were compared by García and Holmes (2001); autumn calving resulted in a different lactation profile, with greater total yields of milk and MS per cow for the autumn calving herd. The lactation curve of the spring calving herd was a typical shape, peaking shortly after calving and declining slowly thereafter. However, the shape of the curve for the autumn calving herd was flatter and longer, due to the lower yield at peak lactation and the longer lactation: 291 days compared with 241 days for the spring calving herd. It was, therefore, suggested that it may not be as important in pasture-based systems to maximise the peak yield in early lactation, as it is for other production systems.

Pasture accumulation rate, as an indicator of pasture production, has been reported to be similar between autumn and spring calving herds on a monthly basis in a New Zealand experiment (García & Holmes, 2005). Despite the same grazing management decision rules being applied to both herds, during summer of the first year of the trial, the spring calving herd had a higher pasture accumulation than the autumn calving herd, which had a higher accumulation rate the following summer. The difference was hypothesised as being related to the proportion of farmlet closed for silage. Over the three years of the trial, the farmlet for the autumn calving herd had a higher proportion of pasture conserved as silage than the spring calving farmlet. Pasture DMI varied seasonally between herds, but this effect was independent of whether the herd calved in autumn or spring. Consequently, the authors suggested that applying the same grazing management decisions to systems with opposite calving dates would result in small seasonal differences in pasture accumulation, but no annual effects would arise (García & Holmes, 2005).

The above literature indicates that there is no effect of changing the month of calving on pasture growth or MS production, between autumn and spring calving herds. The profitability of the change in calving date has not been analysed in any available literature to date. In addition, the other seasons of the year (i.e., summer and winter) have not been assessed, and could potentially provide a viable alternative to spring calving. Therefore, the common assumption of a spring calving date being the most viable option in terms of production and profitability could be challenged by further research and analysis.

1.5.2 Stocking rate

Stocking rate, defined as the number of animals allocated to an area of land (i.e., cows/ha), has been acknowledged as the primary driver of milk productivity in pasture-based systems, with several research studies examining its effect on pasture and animal production characteristics (Macdonald et al., 2008a; B. McCarthy et al., 2012).

Predictions of the optimum SR for maximum production and economic performance in both HF and JER cows were made by calculating response curves from regression equations of SR on cow production (Ahlborn & A. M. Bryant, 1992). The optimum SR predicted for the JER breed was 3.7 cows/ha, compared with 3.0 cows/ha for the HF breed, based on the maximum net income achieved using 1990/91 costs and prices; JER returned 5% higher net income. As SR increased, production per hectare decreased at a slower rate in JER cows, compared with the HF. The predictions made by this study were based on only one year of data and with only two SR trialled for each breed, giving only two data points for each regression equation of the breeds; therefore, these results should be interpreted within the context of the study.

1.5.2.1 Pasture response

A more recent study was undertaken, comparing the pasture and milk production, and reproduction of seasonally calving HF cows at five different stocking rates of 2.2, 2.7, 3.1, 3.7, and 4.3 cows/ha (Macdonald et al., 2008a). As SR increased, both the amount grown and quality of pasture, particularly organic matter digestibility, increased. This additional pasture per hectare appeared to relieve some of the effect of the reduced pasture allowance per cow. This effect is likely due to the lower post-grazing residual pasture mass of the higher SR, allowing less shading of tiller bases and renewal of photosynthetic efficiency; both factors which stimulate pasture growth (Lee et al., 2008). An essential element in managing an increase in SR was increasing the interval between grazing events, which also allows additional pasture grown to be utilised by the greater number of cows. The effect of SR on pasture growth rate and DMI is presented in Figure 1.13.

Macdonald et al. (2008a) introduced the concept of CSR, which offers a more comparable measure of SR, and includes in its calculation the carrying capacity of the farm, in terms of the BW of the cows, potential pasture growth, and amount of supplement purchased to give a measured unit of kg BW/t DM available. This unit of measure allows more direct comparisons to be made between farms, regions, and countries, and between research and commercial farm data, and between different farm systems.

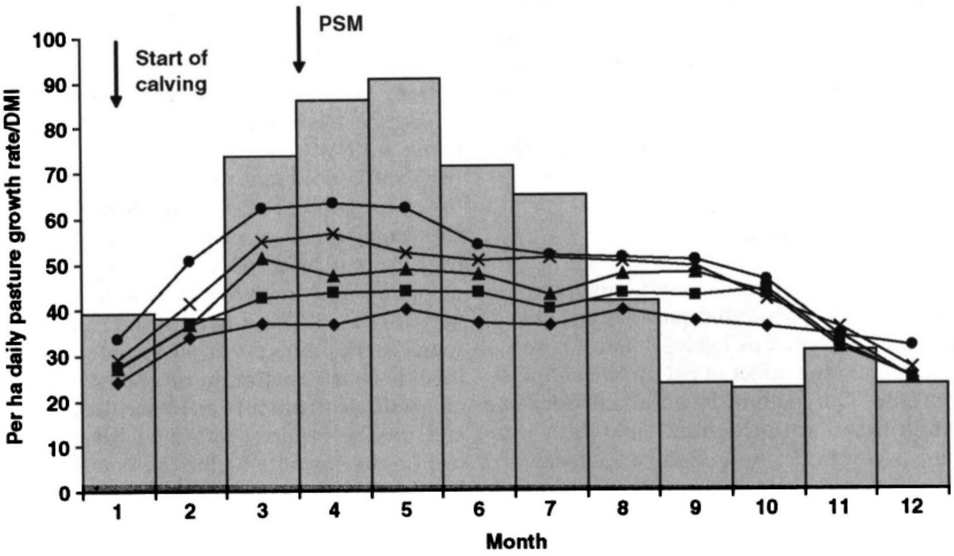

Figure 1.13 Pasture growth rate (vertical bars; kg DM/ha/d) and pasture intake (kg DM/ha/d) of cows at stocking rate 2.2 (♦), 2.7 (■), 3.1 (▲), 3.7 (x), and 4.3 (•) cows per hectare. Months 1 to 12 refer to the southern hemisphere pasture growth season (July to June). PSM = Planned Start of Mating. Source: Macdonald et al. (2008a).

1.5.2.2 Milk production response

Macdonald et al. (2008a) reported milk production per cow declined linearly as SR increased, primarily due to a lower peak milk yield and a shorter lactation length at higher SR. However, production per hectare increased linearly with an increase in SR. There was a small decline in the conversion efficiency of 3 - 5% for each additional cow per hectare, offset by the 5.5% increase in pasture DM availability with increasing SR.

A meta-analysis of published research papers allowed quantification of the milk production response per cow and per hectare as SR increases incrementally (B. McCarthy et al., 2010). A database was compiled containing 109 experiments from 44 papers, which involved a comparison of at least two SR under the same experimental conditions and provided experimental length, and milk production results per cow and per hectare. A summary of the production per cow and per hectare changes with SR for experiments of common length is presented in Table 1.1.

Table 1.1 Changes in production per cow and per hectare with increasing stocking rate of one cow per hectare of common length experiments (n = 99) in a meta-analysis by B. McCarthy et al. (2010).

	Number of data	Base SR[1]	Actual change (kg)	Proportional change (%)
Production per cow				
Milk yield (kg)	99	18.1	-1.228 *	-7.42 *
Fat yield (kg)	83	0.71	-0.040 *	-6.32 *
Protein yield (kg)	70	0.62	-0.046 *	-8.21 *
Lactose yield (kg)	43	0.93	-0.063 *	-6.81 *
Fat content (g/kg)	83	40.2	0.434 **	1.23 **
Protein content (g/kg)	70	32.9	-0.507 *	-1.53 *
Lactose content (g/kg)	43	46.6	-0.234 **	-0.50 **
Production per hectare				
Milk yield (kg)	99	8,868	1,657 *	20.1 *
Fat yield (kg)	83	348	69 *	21.0 *
Protein yield (kg)	70	317	47 *	16.9 *
Lactose yield (kg)	43	527	77 *	16.2 *

[1]Base SR: the result for the lowest stocking rate in each experiment.
*Statistically significant ($P < 0.001$)
**Statistically significant ($P < 0.01$)

For milk, fat, protein, lactose, and MS yields, a one cow/ha increase in SR resulted in a decline of 7.4, 6.3, 8.2, 6.8 and 7.0% per cow, respectively; whilst an increase was evident in yield per hectare of 20.1, 21.0, 16.9, 16.2 and 18.5%, respectively. With a one cow per hectare increase in SR, milk fat content was increased by 1.2%; however, the protein and lactose content were reduced by 1.5% and 0.5%, respectively.

It has been suggested the favourable effects of increasing SR on milk production per hectare may be due to a combination of less pasture wastage and improved pasture growth and quality in association with an increase in the severity of grazing (Macdonald et al., 2008a). In contrast, the reduced production per cow as a result of increasing SR is a consequence of a lower annual pasture allowance, along with a reduction in lactation length. The results of the meta-analysis reported the net energetic consequences of an increase of one cow/ha in SR is comparable to 1 kg less in daily pasture allowance per cow (B. McCarthy et al., 2010).

1.5.2.3 Body condition score response

Stocking rate was reported to have an effect on BCS and BW, when comparing HF cows in three herds of low, medium, and high stocking rates at 2.5, 2.9, and 3.3 cows/ha, respectively (B. McCarthy et al., 2012). The amount of concentrate supplement fed per cow was similar for all SR. The low SR treatment was designed to allow the herd to express its potential, with little limitation in feed supply, whilst the medium and high SR treatments were designed to investigate the potential of an increase in herd productivity per hectare with an increase in SR and herbage utilisation by grazing to lower post-grazing residual height.

The authors did not publish the length of lactation, so there may have been differences in the length of lactation between the SR treatment groups which affected BCS and BW parameters, as decisions on when to cease lactation should involve appropriate BCS targets and management (Macdonald et al., 2010). The differences in daily herbage and total feed allowance between the treatments, where the low SR group had a higher allowance than the medium and high SR groups which were similar (B. McCarthy et al., 2012), may have affected BCS and BW trends, however the authors failed to address this potential interaction.

Irrespective of these limitations, B. McCarthy et al. (2012) reported differences in BW or BCS are not always reflected in differences in SR.

1.5.2.4 Economic response

Macdonald, Beca, Penno, Lancaster, & Roche (2011) modelled the effect of altering SR and CSR on the economics of pasture-based systems, using data on pasture production and utilisation, milk production per cow and per hectare, reproduction, and cow health previously published in Macdonald et al. (2008a). The effect of increasing CSR and system of milk payment (i.e., fluid milk or milk component payment systems) on the operating profit (NZD) per cow and per hectare is presented in Figure 1.12.

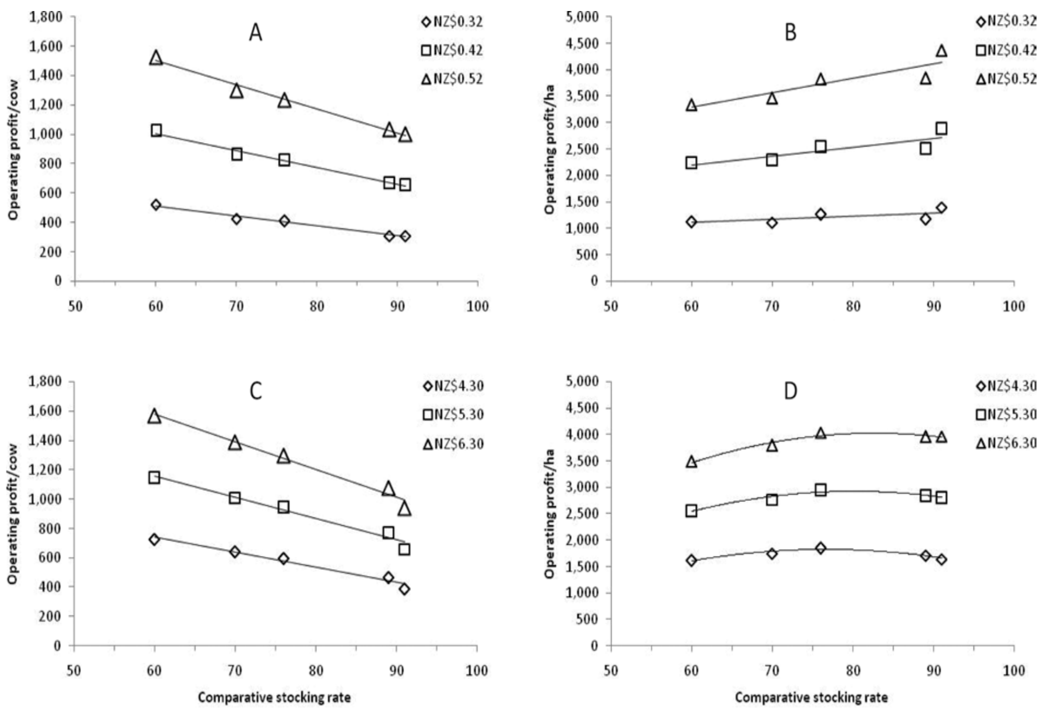

Figure 1.14 Operating profit (NZ$/cow) and (NZ$/ha) with increasing comparative stocking rate. A and B: fluid milk payment systems. C and D: milk component payment systems. Source: Macdonald et al. (2011).

Macdonald et al. (2011) reported that gross revenue (NZD), operating expenses (NZD), and operating profit (NZD) per cow, along with the milk production per cow, declined as the SR and CSR increased; gross revenue (NZD) per cow declined by more than operating expenses (NZD). However, on a per hectare basis, the gross revenue (NZD) and operating expenses (NZD) increased at higher SR and CSR, along with milk production per hectare. Interestingly, operating profit (NZD) per hectare increased with SR from 2.2 to 3.1 cows/ha and, thereafter, declined as SR continued to increase from 3.1 to 4.3 cows/ha (Macdonald et al., 2011).

1.5.3 Breed comparisons

The most common species of dairy cow in New Zealand is *Bos taurus,* which belongs to the subfamily Bovinae. Various breeds are favoured in different countries, regions and by different farmers; the most common in New Zealand are the Holstein-Friesian x Jersey crossbred (**HFxJ**), HF, and JER (DairyNZ & LIC, 2017).

1.5.3.1 Effect of breed on feed conversion efficiency

In a comparison of production characteristics between JER and HF cows, it was reported that at a common SR of 3.7 cows/ha the HF cows produced 7, 15, and 13% more milk fat, protein and solids corrected milk (**SCM**) per hectare than the JER cows (A. M. Bryant, Cook, & Macdonald, 1985). Similarly, the annual gross feed conversion efficiency (**FCE**; g milk constituent/kg DM) was estimated to be

10% higher for milk fat and 18% higher for MS in the HF, compared with the JER cows. Due to differences in BW of the JER and HF breeds, a SR of 4.2 cows/ha was calculated for a JER herd to achieve the same BW per hectare (1487 kg/ha) as the HF herd at a SR of 3.7 cows/ha. When comparing the production of the herds at an equivalent BW per hectare, the HF still outperformed the JER herd by 3, 13, and 10% for milk fat, protein, and SCM per hectare, respectively. Feed conversion efficiency was 15% and 25% higher in the HF, compared with the JER herd.

Another NZ experiment compared the performance, FCE, and energy metabolism of pasture fed, seasonal-calving JER and HF cows during early-mid lactation (L'Huillier, Parr, & A. M. Bryant, 1988). The pasture allowance (kg DM/cow/day) was varied in the experiment, with either 10, 20, 30, or 40 kg DM offered to the respective trial group, with JER and HF breed separated, resulting in eight trial groups.

On average, the pasture utilisation, a measure of the amount of pasture offered that was consumed by the herd, was lower for the JER cows than the HF, with a mean of 46% and 50%, respectively. Additionally, the HF grazed the pasture lower and more evenly compared with the JER cows; which culminated in a 13% higher DMI in the HF. It was reported that the HF cows produced 26% more milk, 6% more milk fat, 13% more protein, and 24% more lactose per cow than the JER, when averaged over the different feeding levels. However, at the lowest allowance, the HF produced more milk but less milk fat and protein than the JER cows. Consequently, the HF cows had, on average, a lower FCE of 61 g milk fat/kg DM than the JER cows with 67 g milk fat/kg DM. This finding is in contrast to that of A. M. Bryant et al. (1985), who concluded the higher production of the HF was due to their superior FCE over the JER cows.

The study by L'Huillier et al. (1988) was conducted over weeks 14 to 17 of lactation only, which may account for the variation in results, as at other stages of lactation the effect of breed on FCE may be different. Production parameters of the two breeds on a per hectare basis were calculated to reveal no difference in milk yield between the herds at a common BW per hectare, but less milk fat and total MS produced by the HF, particularly at high SRs, compared with the JER cows.

A regression analysis of energy partitioning was completed using the variables gross energy (**GE**), digestible energy (**DE**), ME, urine energy, methane energy, heat energy, balance energy, milk energy and tissue energy; the data for which was measured by open circuit calorimetry. The analysis indicated that only ME was affected by breed, with the HF partitioning more ME into heat than the JER cows. As a result, the efficiency of utilisation of ME for milk and tissue energy was significantly lower for HF cows than JER cows. The authors suggest that the greater FCE of the JER cows seen in their experiment may reflect the differences in energy metabolism between the breeds, and combined with higher DMI per kg BW allows the JER to achieve a higher production on a per hectare basis than the HF (L'Huillier et al., 1988).

1.5.3.2 New Zealand's herd in the 21st Century

As a result of this research and the drive for greater milk production per hectare, the composition of the national herd by the mid-1990's was 57% HF, 16%

JER, 18% HF×J crossbreed, 2% Ayrshire, and 7% other breeds, with around 96% of the HF having some North American/Dutch Holstein-Friesian ancestry (Roche et al., 2017b). Today the national herd is made up of 43% HFxJ crossbreed, 37% HF, and 12% JER cows (Figure 1.15).

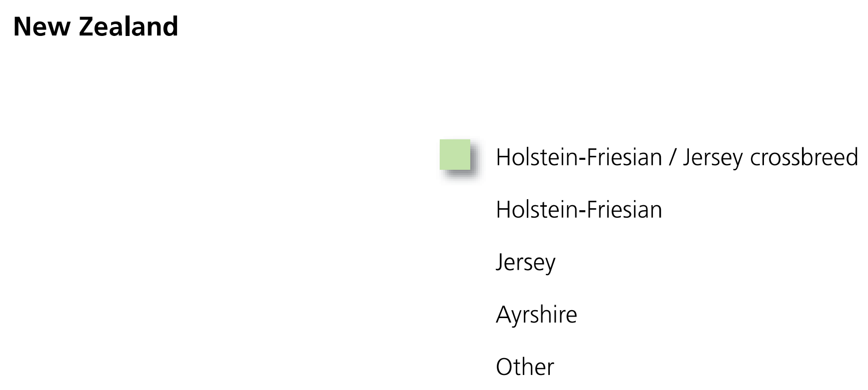

Figure 1.15 Composition of the national dairy cow herd in New Zealand in 2017. Source: DairyNZ and LIC (2017).

1.5.1.4 *Breeding worth*

Dairy cow breeds have evolved based on traits considered to be of economic importance (Dillon et al., 2007). Specifically, in NZ's Breeding Worth (**BrW**), seven profit-related traits of milkfat, protein, milk volume, body weight, somatic cell count, fertility and residual survival are included (LIC & DairyNZ, 2016). An economic index of BrW values is calculated by the sum of each product of the breeding value and the economic value for breeding replacements for each trait. Breeding worth ranks male and female animals for their genetic ability for breeding replacements; for example, a bull with a BrW of +68 would be expected to breed daughters that are NZ$34 more profitable than daughters of a 0 BrW bull, and similarly for cows. The mean breeding values and breeding worth for the bulls of HF, JER, and HFxJ breed, born in 2011 and proven in the 2015/16 season are presented in Table 1.2 below, with 75% or greater reliability (LIC & DairyNZ, 2016).

Table 1.2 Mean Breeding Value for the seven traits incorporated into Breeding Worth (BrW) and BrW of 2015/16 bulls (LIC & DairyNZ, 2016).

Breed	HF	JER	HFxJ
Number of bulls	135	68	61
Milkfat trait	23.7	14.4	22.6
Protein trait	30.1	3.3	17.9
Volume trait	841.8	-346.1	223.7
Body weight trait	39.4	-61.3	-14.5
Somatic Cell Count trait	0.0	-0.2	-0.1
Fertility trait	1.4	2.3	2.3
Residual Survival trait	1.7	-35.1	-49.4
Total BrW	144.4	184.9	186.2

1.5.3.5 Jersey and Holstein-Friesian comparisons: 21st Century

An evaluation of the production efficiencies of pasture-fed and seasonally calving JER, HF, and HFxJ crossbreed cows was undertaken in Ireland to compare the characteristics between breed (Prendiville, Pierce, & Buckley, 2009). The results showed significant effect of breed on all production parameters investigated, namely milk yield, SCM, milkfat and protein concentrations, and MS.

Milk yield was highest for the HF with a mean of 18 kg/day, a mean of 17 kg/day for the HFxJ, and lowest for the JER breed with a mean of 14 kg/day. Solids corrected milk production was similar for the HF and HFxJ, with 18 and

17 kg/day, respectively, which was higher than the mean production for the JER breed at 16 kg/day.

The content of milk fat and protein was highest for the JER at 5.3 and 4.1%, intermediate for the HFxJ at 4.8 and 3.8%, and lowest for the HF at 4.0 and 3.5%, respectively. The HFxJ produced more daily MS (with a mean of 1.4 kg/day) than the HF and JER, which produced a similar amount on average of 1.3 and 1.3 kg/day, respectively.

Despite these differences, the mean DMI was similar for the HF and HFxJ breeds (17 and 16 kg DM/day), whilst the mean for the JER was less, at 15 kg DM/day. The mean BW for the HF herd was higher than for the HFxJ and JER throughout the study. Consequently, breed had a significant effect on the production efficiency parameters of total DMI (**TDMI**) per 100 kg BW, SCM per 100 kg BW, MS per 100 kg BW, and MS per kg TDMI.

The JER was the most efficient on average for each parameter, with means of 4.0 kg TDMI, 4.3 kg SCM, and 0.4 kg MS/100 kg BW, and 0.09 kg MS/kg TDMI calculated.

The HFxJ breed had means of 3.6 kg TDMI, 4.0 kg SCM, and 0.3 kg MS/100 kg BW, and 0.09 kg MS/kg TDMI.

The HF breed had the lowest means in all parameters with 3.4 kg TDMI, 3.4 kg SCM, and 0.3 kg MS/100 kg BW, and 0.08 kg MS/kg TDMI.

The authors confirmed the superior intake per kg BW and gross production efficiency characteristics of the JER genotype, and the increased efficiencies of the HFxJ with their marginal gains in DMI capacity, production and feed efficiency over the HF (Prendiville et al., 2009).

In a comparison between the biological differences contributing to milk production efficiency variation between JER, HFxJ, and HF cows in USA, Beecher et al. (2014) reported that the gastrointestinal tract (**GIT**) size, ability to digest perennial ryegrass, and relative abundance of rumen microbial populations may be responsible factors. The JER breed had a greater daily milk fat and protein concentration, compared with the crossbreed and HF, which had a higher daily milk yield, BW, and DMI; however, there were no differences between the breeds for the daily MS yield.

The unadjusted GIT weight of the HF was heavier than the JER and HFxJ, however when expressed as a proportion of the BW, the JER and crossbreed had a heavier GIT weight than the HF. The intake capacity, expressed as kg DMI per kg BW, was greatest for the JER, intermediate for the crossbreed, and lowest for the HF; while FCE was highest for the JER genotype.

Prendiville, Lewis, Pierce, and Buckley (2010) also reported the inherent grazing and ruminating differences between the JER, HF, and HFxJ crossbreed which lead to the observed variations in intake capacity and production efficiency. Little difference in recorded measurements of grazing behaviour between the breeds was observed; however, when expressed per 100 kg BW and per kg of DMI, differences in total grazing time (min), bites per day and per minute, rate of pasture DMI (g/min) and bite size (g/bite) were apparent.

Jersey cows had a higher mean for each variable expressed per kg BW, compared with both the HF and HFxJ. When expressed per kg pasture DMI, the JER again had a higher mean, compared with the HF and HFxJ, for each variable.

Differences in rumination, defined as the regurgitation of fibrous ingesta from the rumen to the mouth, remastication, and reinsalivation, followed by swallowing and returning the material to the rumen (Welch, 1982 in Prendiville et al., 2010), were evident in the absolute measurements of some variables. Means of the variables ruminating time (min/d), ruminating bouts (n/d), ruminating bout duration (min/bout), ruminating mastications (n/d), rumination time of the bolus (min/bolus), and the total mastication time (min/d) were all greater for the HF compared with both the JER and HFxJ.

The HFxJ had a similar mean to the HF for ruminating boli (n/d), both of whom were lower than the JER breed; they had a similar mean for ruminating mastications of each bolus (n/bolus), both higher than the JER.

When expressed per 100 kg BW, the ruminating time (min) and number of ruminating mastications was higher for the JER compared with the HF and HFxJ, which had similar means for these variables. The bolus size (g/100 kg BW) was highest for the HFxJ, intermediate for the HF, and lowest for the JER. Mean ruminating time (min) and number of ruminating mastications per kg of pasture DMI was highest for the HF, intermediate for the JER, and lowest for the HFxJ genotype.

The authors concluded that the results of the study indicate a higher intake capacity, commonly reported in the JER genotype, have a greater rumen capacity per 100 kg BW; with variations in grazing behaviour of increased grazing time and rate of intake per 100 kg BW also thought to assist. Increases in production efficiency seen in the HF breed appear to be facilitated by mastication behaviour during grazing (Prendiville et al., 2010).

Beecher and colleagues (2014) also reported the JER genotype had higher digestive efficiency, expressed as digestibility of DM, organic matter, Nitrogen, neutral and acid detergent fibre, compared with the HF, with the HFxJ crossbreed intermediately ranked. Holstein-Friesian and HFxJ cows had a higher relative abundance of Ruminococcus flavefaciens, a cellulolytic bacteria important for fermenting feed into useable energy in the rumen, compared with the JER breed.

The authors conclude from these findings that the more efficient digestibility, proportionally greater GIT weight, and different rumen microbial population of the JER genotype contributes to the production efficiency differences, when compared with the HF genotype.

JER genetics appear to be well suited to pasture-based systems due to their ability to achieve high pasture intakes and efficiently convert the energy to MS, thereafter (Beecher et al., 2014). The HFxJ crossbreed generally sits intermediately in biological and production characteristics, between the JER and HF, appearing to carry beneficial characteristics of each breed.

Supporting the above findings, is a review of ten studies, by Grainger and Goddard (2004), who reported differences between HF and JER cows in both intake, expressed as kg DM and per 100 kg BW, and FCE, summarised in Table 1.3. The authors found in every experiment reviewed, the JER breed ate on average 14% more DM per 100 kg BW than HF cows.

However, the differences in DMI between the breeds were smaller in the NZ literature, with a difference of 8% compared with in the USA literature with 14% between the breeds. This is largely due to the difference in BW of the breeds,

Table 1.3 Comparison of intake (kg DM/100 kg BW) and food conversion efficiency (FCE; g MS/kg DM) between Holstein-Friesian (HF) and Jersey (JER) cows.

Reference (First author)	Intake			FCE		
	HF	JER	%difference	HF	JER	%difference
Beaulieu & Palmquist (1995)	3.3	3.84	-16.4	108	108	0
Blake et al. (1986)	3.2	3.65	-14.1	1.4[1]	1.3[1]	7.1
Gibson (1986)	2.68	3.09	-15.3	42.3	43.1	-1.9
L'Huiller et al. (1988)	2.9	3.2	-10.3	105	108	-2.9
Mackle et al. (1996)	2.55	2.66	-4.3	115	128.5	-11.7
Oldenbroek (1988)	3.29	4.05	-23.1	87.5	95.1	-8.7
Oldenbroek (1988)	3.11	3.84	-23.1	88.6	105.2	-18.7
Rastani et al. (2001)	3.34	3.59	-7.5	134	130	3.0
Thomson et al. (2001)	2.8	3.03	-8.2	99	109.8	-10.9
Tyrrell et al. (1990)	4.08	4.73	-15.9	110	125	-13.6
West et al. (1990)	3.17	3.74	-18	78	86	-10.3

[1]FCE is kg 4% fat corrected milk/kg dry matter

as in the USA literature the cows were heavier than in NZ literature with the JER weighing on average 430 kg in USA compared with 360 kg in NZ, whilst USA HF cows weigh on average 610 kg and NZ HF weigh 450 kg; resulting in a larger average difference between breeds in the USA literature, of 180 kg compared with 90 kg in NZ literature.

The other main difference contributing to the variations between countries and breeds is the diet of the cows, as the USA experiments offer ad libitum total mixed ration to the herd, whilst the NZ experiments were pasture-based on a controlled daily intake. As confirmed by Beecher et al. (2014), the higher intake capacity of JER cows, described in multiple pieces of literature since the mid-1970's, may be explained by the greater weight of the JER GIT per kg BW, compared with HF cows (Grainger & Goddard, 2004).

It would then appear that the higher DMI per kg BW would lead to a higher production of MS per kg BW, assuming no difference between genotypes in energy losses from urine, faeces, methane, and heat. As presented in Table 1.3, the JER breed produced a mean of 3.8 g MS/kg BW, compared with 3.1 g MS/kg BW for the HF, giving a 23% margin, on average. When comparing FCE between the breeds, the JER was, on average, 6% more efficient than the HF in 8 out of 11 comparisons, as presented in Table 1.3.

1.6 Economic modelling

Research into the responses of pasture and animals to variations in inputs in pasture-based dairying provides the technical foundation for whole farm systems analysis (Chapman, Malcolm, Neal, & Cullen, 2007). Prendiville et al. (2009) suggested efficient conversion of feed inputs to milk and meat products is critical to the economic profitability of a farm operation, as total feed costs have been reported to account for around 80% of the total variable costs associated with milk production. A useful tool for farm systems analysis is simulation models that describe key interactions between soil, plants, animals, the broader environment, and farm management techniques, such that the resulting level of output is computed (Chapman et al., 2007).

Simulation models do not replace well-designed field experiments conducted to answer specific questions, but allow further exploration of the research questions, experimental data, extrapolation to new spatial and/or temporal contexts, and illumination of knowledge gaps. Variability in production and price can impact farm profitability; moreover, the way that a farmer perceives risk may change the way that a farm is managed.

Risky events or outcomes are those that can be assigned a probability based on historical information or experience, whereas uncertainty involves unexpected events for which a probability cannot be assigned. The use of mathematical models is valuable to assist in decision making (mathematical programming) in the context of risk and uncertainty, given their ability to provide consistent, coherent, and flexible frameworks for describing and analysing the management of diverse systems. With regards to the inclusion of risk preferences for farm managers, the inclusion of risk aversion has been recognised as an important factor for obtaining more realistic and consistent solutions (Doole & Pannell, 2011).

1.6.1 Risk and uncertainty

A vital part of successfully managing farm systems is the acknowledgement and consideration of risk and uncertainty. It is because of uncertainty that the future financial performance of pasture-based systems can be merely estimated (Chapman et al., 2007). System risk analysis provides a framework for the evaluation of the risk associated with a system, whilst aiming to provide decision support on design and action choices (Zio, 2013).

To provide a measure of risk in farm management economics, it is common to assess the volatility over time of key farm system elements such as crop yields, prices, interest rates, rainfall, pasture growth, annual profit, and annual net cash flow. Volatility can be defined as the variability around the mean value of the elements, which can be observed in a single year or over a series of years. It is typically used as an approximation of the volatility these elements may take over the relevant planning period (Malcolm & Sinnett, 2015).

1.6.2 Risk in the farm business

Risk associated with farm systems can be classified as business risk, financial risk, and institutional risk. Business risk stems from variations in annual yields, prices, reproduction rates, pest and disease outbreaks, environmental extremes such as drought or flood, and fluctuations in inflation and interest rates (Chapman et al., 2007; Malcolm & Sinnett, 2015). The various sources of business risk can be condensed to price and production risks, which exist regardless of financial matters; however, financial risk exacerbates business risk (Chapman et al., 2007). Financial risk in farming refers to that of the proportions of debt and equity in the total capital (total assets) of a farm business and the rate of earning of the total asset base, relative to the cost of the debt (Malcolm & Sinnett, 2015).

Business and financial risk are separated as they have different consequences for the farm business, and require different forms of management by the farmer, who has different levels of control over them. Managing for yield and price volatility represents managing the business risk, as decisions and actions are made that can have consequences on the profitability of the farm business. In comparison, making initial decisions about financing the farm business and subsequent changes to financing arrangements represents some measure of control over the equity and debt structure, thereby managing the financial risk (Malcolm & Sinnett, 2015). Inclusion of meaningful estimates of stochastic input variables in the model is vital to obtain relevant Monte Carlo simulations for practical inference (Evans, Wallace, Shalloo, Garrick, & Dillon, 2006).

1.6.3 Uncertainty in the farm business

Risk can be incorporated into farm budgets by using probability distributions for key variables; in comparison, uncertainty is more difficult to assess. Estimated probability distributions of future yields and prices provide no indication, by definition, of the effect that other unknown and uncertain events may have on the future yields and prices, and therefore, the fortunes of the business. Although it may be unknown why the historical prices or yields reached extreme highs or lows, these values become a known possibility from the past and can therefore influence subjective judgements on future price and yield distributions to include in analyses (Malcolm & Sinnett, 2015).

1.6.4 Deterministic and stochastic simulation models

In deterministic models, the output of the model is fully determined by the assumed parameter values and initial conditions, whereas in stochastic models there is inherent randomness in model inputs (North Carolina State University Statistics Department, 2013). Parameter uncertainty arises from measurement and prediction errors, and can result in misleading solutions or cause the results of sensitivity analysis to be unreliable (Doole & Kingwell, 2010). Deterministic model output consistent with the use of point estimates may also be infeasible once variability is observed. Doole and Kingwell (2010) found that 40% of models were infeasible, once data input varied from the point estimates that were used in the determination of the optimal plan.

A more informative approach is stochastic programming, which involves that inclusion of probability distributions in the determination of optimal solutions (Doole & Kingwell, 2010). Typical forms of stochastic programming provide an optimal solution for each possible variation in the environment. This provides deep insight into optimal responses, but also increases model size and data needs due to the inherent curse of dimensionality imposed. The inclusion of explicit probability distributions reveals inherent variation, as well as allowing integrated insight into the impacts of risk when they are considered together in stochastic models. Yet, it does have its limitations:

1) It requires past information on the behaviour of the parameter;
2) Identification of precise information, such as a distribution which represents a variable, can be prone to measurement error;
3) Estimating future states of a parameter from historical data can be difficult to justify in some cases;
4) Defining specific correlations and/or distributions can limit the relevance of output;
5) The size of the model can be significantly increased, requiring more computing power.

An alternative to stochastic programming is robust optimisation, where uncertainty is represented through the use of uninformative probability distributions and the objective of analysis is changed to represent a precautionary approach to management. An assumption is included that each realisation of a variable parameter is as likely to occur as another; as there is insufficient reason to believe uneven probabilities in a state of uncertainty (Doole & Pannell, 2011).

Early applications were constrained by conservatism, where there was limited tolerance for infeasibility. Doole and Kingwell (2010) developed a framework for robust nonlinear programming, where only the bounded set of outcomes for uncertain parameters is known, thereby allowing exogenous control of conservatism. The robust model can be solved by standard mathematical programming software, and is no larger after transcription from its deterministic equivalent (Doole & Pannell, 2011).

The models can incorporate a measure of uncertainty aversion, which represents the degree of conservatism a decision-maker wishes to consider (Doole & Pannell, 2011; Doole & Kingwell, 2010). Different model outputs resulting from changing trade-off parameter values is presented in Figure 1.16 (Doole & Pannell, 2011).

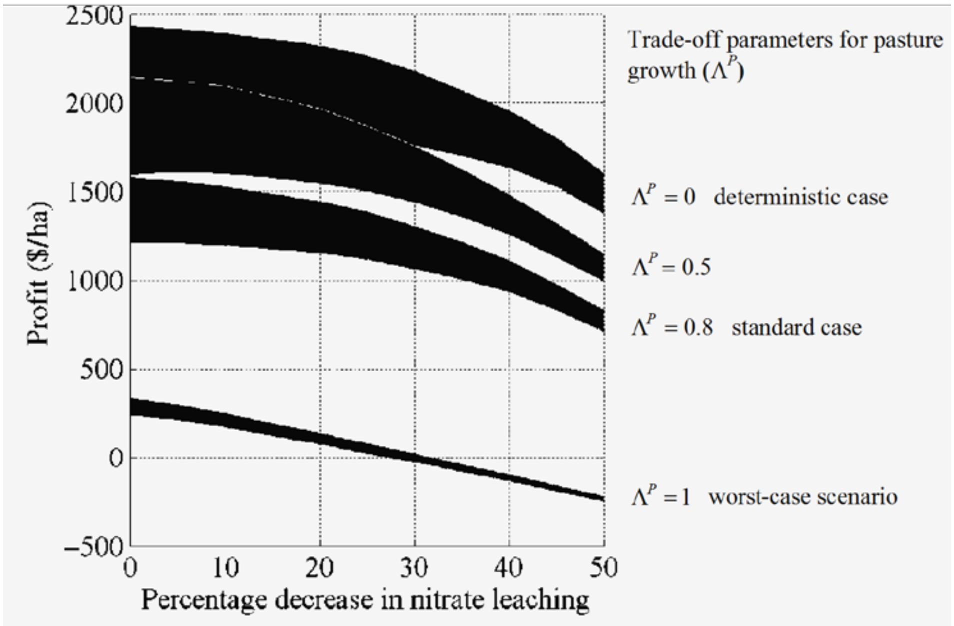

Figure 1.16 Changes in trade-off parameters for pasture growth affect the profit per hectare (NZD). Source: Doole and Pannell (2011).

1.6.5 Farm system models

The aim of effective farm management is to ensure the financial performance of the farm business will be persistently maximised, whilst being well positioned to exploit opportunities that may arise (Chapman et al., 2007). As farm systems operate under both uncertainty and risk, several models have been developed for scientific and economic research purposes, and some for commercial use to support farm management decisions (Chapman et al., 2007; Malcolm & Sinnett, 2015).

In a model that includes risk, instead of a single estimate of an output variable of interest, a distribution is instead computed for a single run of the model. A single run is described as the process of a model carrying out a series of calculations, without input from the user during the run. This typically involves multiple simulations of the farm system (as in Monte Carlo simulation) or could involve multiple runs of a Monte Carlo simulation when this information is used to guide a search process used to find superior solutions in an optimisation model. Each run of a Monte Carlo simulation involves a single draw from each of the input distributions, which is combined with point estimates defined for the non-stochastic variables to simulate one possible outcome of the simulated decision context. By including many iterations in a simulation, a distribution of the output variable is able to be estimated given the specified set of input distributions and non-stochastic parameters (Hyde & Engel, 2002).

1.6.6 Simulation models considering risk

A common approach to modelling risk in decision models is to define conservative estimates of input parameters (Doole & Pannell, 2011). Whole-farm stochastic budgeting takes into account the inherent uncertainty of decision making in dairy systems, whilst developing a model that mimics the farm business to provide financial performance projections (Evans et al., 2006).

One of the earliest dairy-related models to include estimations of risk was that of Hinman and Hutton (1971), who evaluated the potential returns and risks involved in Pennsylvania, USA dairy farms expanding at different levels of equity under different levels of management efficiency, using simulation. By allowing for the expression of variation in crop and livestock due to natural hazards and variability in product prices within upper and lower limits to give realistic outcomes, along with trends in product prices and asset values over time, the framework is more robust than one with a single point estimate for each variable. The authors modelled the variability in net worth, given a particular equity policy, defining the minimum equity ratio, and the level of efficiency through the farm production relative to a standard milk production.

For all scenarios, the average net worth increased, except for the combination of the highest equity ratio at 60%, and the lowest management efficiency at 85% which decreased over the 10 year period. As the efficiency level and equity ratio of the farm decreased, the measurement of risk as variation of cash income increased (Hinman & Hutton, 1971).

1.6.6.1 Whole Farm Models

Development of a Whole Farm Model (**WFM**) by Dexcel (now DairyNZ Inc.) was undertaken to simulate the complex and dynamic interactions between climate, management, and cow and pasture production, whilst objectively comparing different management strategies. Beukes et al. (2005) used the Dexcel WFM to explore the effect of climate and price variability on production, profit, and risk for three typical farm systems of the Taranaki region in New Zealand (Figure 1.4). The three scenarios were a:

1) Conventional farm with twice-a-day milking and 3.3 Jerseys/ha;

2) Farm with once-a-day milking after Christmas, more days in milk, and 3.5 Jerseys/ha; and

3) High-input farm with more N fertiliser, maize silage, off-farm grazing during the dry period, and 4.2 Jerseys/ha.

The WFM uses Monte Carlo simulated economic inputs, derived from Dexcel Economic Farm Survey data (Beukes et al., 2005), applied to selections of climatic data to produce an economic report with a calculated economic farm surplus (NZ$/ha) and return on assets[2]. The inclusion of past data gives distributional information of stochastic variables to influence decision outcomes (Doole & Pannell, 2011).

The economic farm surplus calculation is adjusted for differences in pasture cover, supplement stacks, and cow condition at the end of the simulation compared with the beginning values. The high-input system (scenario 3) had the highest average return on assets, however the greatest variability over the 9 seasons simulated, and a higher risk measurement due to the effect of variability in milk payment in a high MS yield system. However, the high-input system was less prone to the effects of a poor season compared with the other scenarios, with an economic farm surplus of NZ$1344/ha, NZ$939/ha, and NZ$794/ha for the high input, once-a-day, and conventional systems, respectively.

[2] Return on assets (%) = (economic farm surplus + capital gain) / assets

The high-input scenario also had the highest economic farm surplus in the best season compared with the once-a-day and conventional system scenarios, with values of NZ$2286/ha, NZ$1890/ha, and NZ$1679/ha, respectively. A higher production per cow and therefore greater efficiency of production (kg MS/t DM) was the key to higher returns for the high-input system compared with the other systems; stemming from the cheap, reliable, and abundant feed induced by higher N input, grazing off-farm during the dry season, and maize silage supplement. The authors concluded higher producing systems show greater variability in return on assets, given a variable MS price, however if high production is achieved at a low cost, the higher average return of assets compensates for the increase in risk (Beukes et al., 2005).

The Moorepark Dairy System Model (**MDSM**; Shalloo, Dillon, Rath, & Wallace, 2004) is a stochastic budgetary simulation model of a dairy farm which was developed to investigate variations of biological, technical, and physical processes on farm profitability. One application of the model involved Monte Carlo simulation to determine the effect of milk price, concentrate cost, and silage quality on farm profitability under two calving date scenarios:

1) Mean calving date January 27 (late winter);
2) Mean calving date February 24 (early spring).

The financial performance of the scenarios was compared, with scenario 1 attaining €177,152 in total farm receipts, compared with €177,987 for scenario 2 (NZ$302,444 and NZ$303,870). Under both scenarios, milk accounted for 77% of total sales. Net profit was €51,687 for scenario 1, compared with €53,547 for scenario 2 (NZ$88,243 and NZ$91,418). Therefore, at a profit and loss level, it would appear that scenario 2 (mean calving date February 24) would be the preferred choice.

A cumulative density function (**CDF**) is a powerful risk efficiency criterion, and useful in decision making contexts, as a CDF contains all the information on the output distribution of the risky potential outcomes, and by comparing the CDF, the stochastically dominant or efficient set can be determined. If one CDF lies to the right of another over the entire probability interval, then first-degree stochastic dominance of the risky outcome (on the right) over another is implied (Evans et al., 2006). A CDF representing the influence of stochastic input variables milk price, concentrate cost, and silage quality on net farm profit under the two calving date scenarios is presented in Figure 1.17 (Shalloo et al., 2004), which shows scenario 2 has stochastic dominance over scenario 1. Therefore, a mean calving date of February 24 is the preferred prospect in terms of a greater expected net farm profit, in comparison with a mean calving date of January 27.

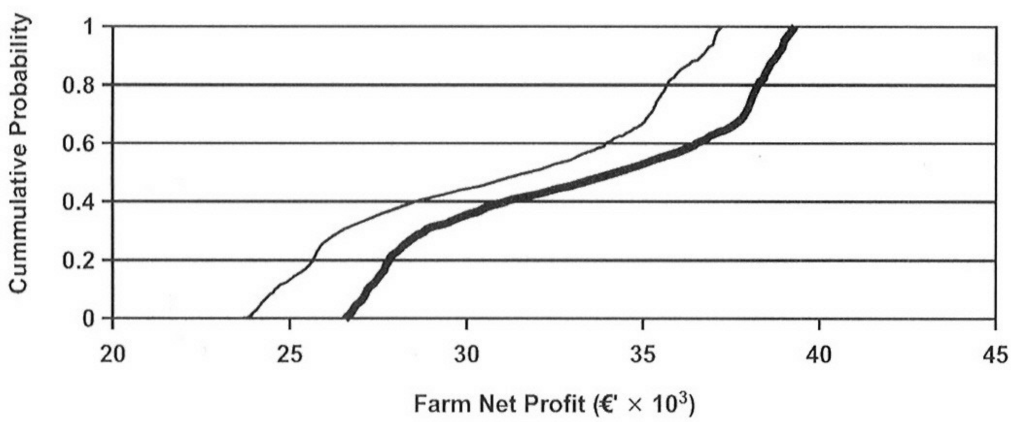

Figure 1.17 Cumulative density function of the influence of milk price, concentrate costs, and silage quality on farm net profit (€'000) for scenario 1) mean calving date January 27 (thin line); scenario 2) mean calving date February 24 (bold line). Source: Shalloo et al. (2004).

In addition, a sensitivity analysis was carried out using multiple regression on the simulation data, to quantify the relative contribution of the stochastic input variables on the output variable distribution. The analysis revealed milk price had the largest influence on the overall output variable distribution; therefore, the net profit is most sensitive to changes in milk price. As similar amount of silage was used in each scenario, the silage quality had a similar influence in each scenario; however, the cost of concentrate supplement had a much larger influence on net profit in scenario 1, as a larger amount was supplied to the herd, in comparison with scenario 2.

A mean calving date of February 24 (early spring) was reported to be more profitable than a late winter mean calving date of January 27, which was mostly due to the greater cost of concentrate supplement for the scenario of late winter calving date (Shalloo et al., 2004).

Evans et al. (2006) used the MDSM (Shalloo et al., 2004) to investigate the effect of changes in milk production and composition, calving pattern, and replacement rate on farm profit under two scenarios of EU milk quota restrictions and no quota restrictions. Stochastic variables used in the model were milk price (under two scenarios), cull-cow value, replacement heifer price, and replacement rate. These were simulated together, under three situations of:

1) Herd milk production and calving spread in 1990;
2) Herd milk production and calving spread in 2003;
3) Potential herd milk production in 2003 with the calving spread and replacement rate at 1990 levels.

Under scenario one, where there is a fixed EU quota, there was a significant linear increase in the margin per cow and per kg of milk produced (€10.80 and €0.13, or NZ$18.44 and NZ$0.22, respectively,) over the 14 year period. In addition, an increase in net farm profit over the same period was observed, at a rate of €546 per year from €28,941 in 1990 to €32,945 (NZ$49,410 to NZ$56,246). The milk price increased over the 14 years as a reflection of the change in milk composition, resulting in higher milk receipts. If the reproductive performance, calving spread, and replacement rate remained at 1990 levels, then the potential increase per year would have been €22.10/cow and €0.31/kg of milk in margin, and €1,341 in farm profit (NZ$37.73/cow, NZ$0.53/kg milk, NZ$2289 in profit).

Scenario two used the same production information, but with no quota restrictions. A similar linear increase in the margin per kg of milk to scenario one was observed, of €0.14, along with a linear increase of €11.30/cow margin (NZ$0.24/kg milk, NZ$19.29/cow). The net farm profit increased over the 14 year period by €1,089 (NZ$1859), which was a result of an increase in milk sales. The potential increase per year in margin would have been €22.80/cow and €0.32/kg of milk, and in farm profit €2,183 (NZ$38.93/cow, NZ$0.55/kg milk, NZ$3,727 profit), if the reproductive performance, calving spread, and replacement rate were maintained at the levels of 1990.

Therefore, the increase in farm profit per year with scenario one was only half of that of scenario two. The mean calving date of the herd used in this analysis remained relatively static, with a small shift of about 2 weeks, from February 15 in 1990 to March 4 in 2003.

After calculations of a CDF for each scenario (Figure 1.18), Evans et al. (2006) reported that situation 3 (i.e., potential herd production in 2003, had the calving spread and replacement rate remained at 1990 levels) was stochastically dominant over the other two situations, under both scenario one (quota restrictions) and two (no quota restrictions). Therefore, under either scenario, situation 3 is classified as the preferred prospect in comparison with the other two situations, and the expected farm profit of situation 3 will be greater than the expected value of farm profit under either of the other two situations.

Sensitivity analysis indicated milk price had the largest influence on farm profit, and replacement heifer cost had a larger influence on farm profit in 2003 than 1990 due to the rise in replacement rate during that period.

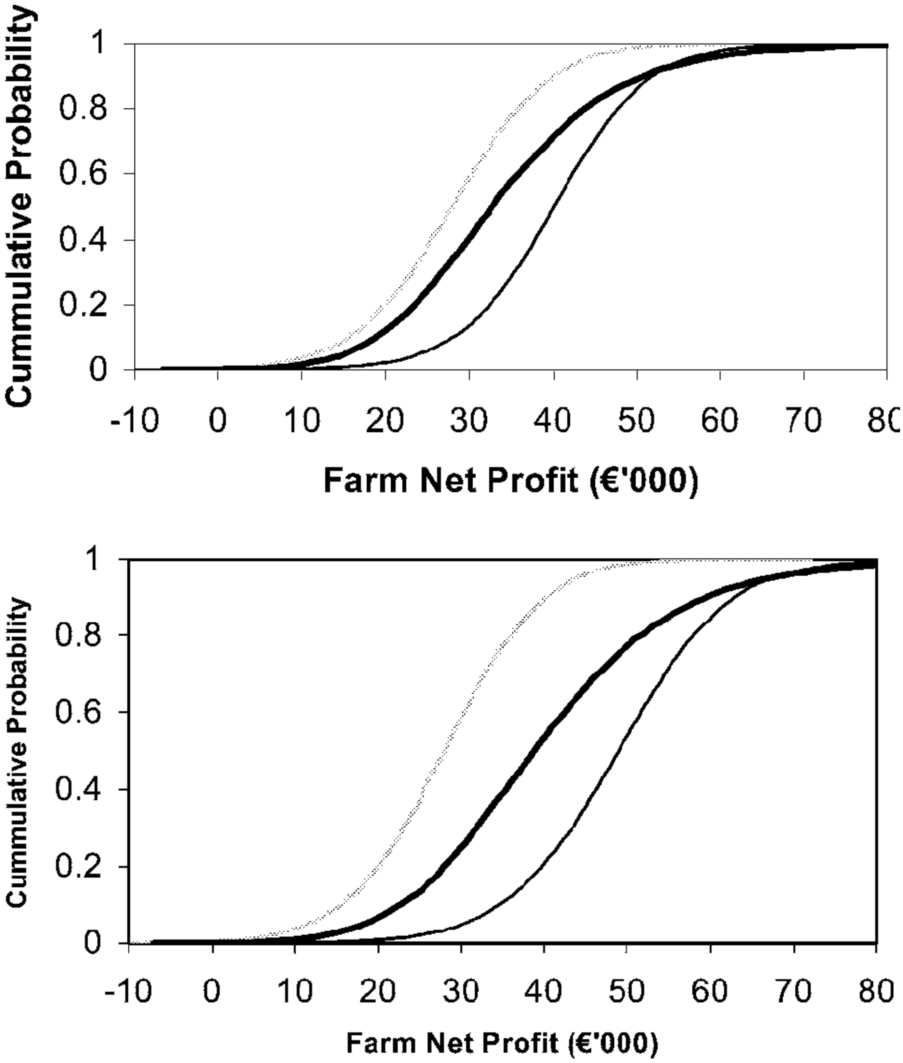

Figure 1.18 Cumulative density functions showing the influence in variation in milk price, cull cow price, replacement heifer price, and replacement rate on net farm profit (€'000) under EU quota restrictions (top) and no quota restrictions (bottom) using three situations 1) the production, calving spread, and replacement rate in 1990 (- - - -); 2) the production, calving spread, and replacement rate in 2003 (bold —); 3) the production of 2003, had the calving spread and replacement rate remained at 1990 levels (—). Source: Evans et al. (2006).

1.6.7 Conclusions

A more robust approach to deterministic analysis involves the inclusion of constraints which protect the model outcomes from infeasible solutions. Risk and uncertainty have been included in farm system model analysis for decades, with development of robust programming methods to increase the feasibility of model outputs. By defining conservative distributions or including limits for input variables prone to uncertainty, a more robust framework is created to give an output which can be applied to practical situations.

Development of whole farm models has allowed the effect of changes in aspects of farm management on farm profit and subsequent decision making to be modelled without the need for lengthy and costly experiments in the field.

1.7 Conclusion

Cow breed, stocking rate, and calving date comparisons are amongst the wide range of extensively researched topics in the field of pasture-based farm system-level science. Decades of research have reported different breed characteristics for milk production, where the Jersey produces a high milk fat and protein content, whilst the Holstein-Friesian produces superior milk yields. With an increase in SR milk production per cow decreases; however, on a per hectare basis milk production increases. The interaction of breed and stocking rate on the milk and pasture production, on either a per cow and per hectare basis, has not been addressed thus far.

Changing the month of calving is reported to cause autumn (April) calving herds to rely more on supplement more than their spring (July) calving herd counterpart. Additionally, it has been reported MS yield per hectare is similar between the autumn and spring calving herds, however, a significant difference between the shapes of the lactation curves is observed.

Pasture growth patterns and analysis of post-grazing residuals on pasture regrowth and herd milk production have been examined in systems with a spring calving date, however the effect of changing the calving date on milk and pasture production has not been extensively researched.

The effect of mean calving date (late winter and early spring) on net farm profit has been researched; with an early spring calving date reported to be more profitable than a late winter calving date, due to the greater cost of supplement for the late winter calving scenario. However, the effect of changing the mean calving date to the seasons of summer, autumn, winter and spring on the profitability of the farm business has not yet been analysed.

Opportunities within the current system of farm management are explored in this thesis, examining the interactions between breed, SR, and changing the month of calving on milk and pasture production aspects. Economic analyses of the effect of breed, SR, and calving date on the profitability of farm systems will also be undertaken. Additionally, risk and uncertainty of the business strategy will be evaluated using Monte Carlo techniques for the four month-of-calving scenarios:

1) Mean calving date in January;
2) Mean calving date in April;
3) Mean calving date in July;
4) Mean calving date in October.

2. Dairy cow breed interacts with stocking rate in temperate pasture-based dairy production systems.

2.1 Abstract

Economic optimum stocking rates for grazing dairy systems have been defined by accounting for the pasture production potential of the farm (t DM/ha), the amount of feed imported from outside the farm (t DM/ha), and the size of the cow (kg). These variables were combined into the CSR (kg BW/t feed DM available) measure. However, CSR assumes no effect of cow genetics beyond BW and there is increasing evidence of within breed differences in residual feed intake and between breed differences in the gross efficiency with which cows use metabolisable energy for milk production. A multi-year, production system experiment was established to determine whether JER and HF breeds performed similarly at the same CSR. Fifty-nine JER cows and 51 HF cows were randomly allocated to one of two CSR in a 2 x 2 factorial arrangement; systems were designed to have a CSR of either 80 or 100 kg BW/t feed DM (JER-CSR80, JER-CSR100, HF-CSR80, and HF-CSR100 treatment groups). Data were analysed for consistency of farmlet response over years using analysis of variance procedures, with year and farmlet as fixed effects and the interaction of farmlet with year as a random effect. The collated biological data and financial data extracted from a national economic database were used to model the financial performance for the

different breed and CSR treatments. On average, annual and individual season pasture DM production was greater for the JER farmlets and was less in the CSR100 treatment; however, the effect of CSR was primarily driven by a large decline in pasture DM production in the HF-CSR100 treatment (breed x CSR interaction; $P < 0.05$). This interaction in feed availability resulted in a breed x CSR interaction for the per cow and per hectare milk production variables, with HF cows producing more milk and milk components per cow in the CSR80 treatment, but the same amount as the JER cows at the CSR100. On a per hectare basis, HF cows produced the same amount of 4% fat corrected milk (**FCM**) and lactose as JER in the CSR80 treatment, but less fat; at CSR100, JER cows produced more 4% FCM, fat, and protein per ha than HF cows. Our results support a greater gross efficiency for use of ME by the JER cow; 11% less total metabolisable energy was required to produce 1 kg fat and protein at a system level. Economic modelling indicated that profitability of both breeds was less at CSR100, but the decline in profitability with increasing stocking rate was much greater in the HF breed. Holstein-Friesian cows were more profitable at the CSR80, but were less profitable at the CSR100.

2.2 Introduction

There is irrefutable evidence that animal agriculture has increased in resource-use efficiency over the last 75 years (Capper, Cady, & Bauman, 2009; Macdonald et al., 2008b; Roche et al., 2017b). Nevertheless, requirement for food is predicted to increase by a further 75 to 100% over the next 35 years (FAO, 2009; Godfray et al., 2010); this will increase the pressure on food production systems to become even more efficient. A significant portion of the historical increase in efficiency was a result of genetic selection for production-related traits. For example, Capper et al. (2009) reported that only 21% of cows are required today compared with 1944 to produce the same volume of milk. Similarly, Macdonald et al., (2008b) reported that genetic improvements within the HF breed had resulted in a 16% increase in milk yield, a 21% increase in milk fat production, and a 26% increase in milk protein between 1970 and 2000, with only a 2% increase in maintenance requirements. This improvement in production efficiency is particularly important in grazing systems, as cow DMI is limited by time to graze and not the physical capacity of the cow (Sheahan, Kolver, & Roche, 2011).

Cow breed has also been reported to affect FCE in grazing systems. For example, Prendiville et al. (2009) reported that JER cows required 7-8% less total feed for every kg of milk fat and protein produced in a pasture-based dairy production system when compared with HF cows. This is consistent with the reported differences in the mass of the gastrointestinal tract (i.e., 24% lighter in JER cows; Beecher et al., 2014), a 2-3% greater digestibility of DM and neutral detergent fibre by JER cows (Beecher et al., 2014), and the greater use of consumed ME for productive purposes by the JER cow (L'Huillier et al., 1988) when compared with HF cows. The improvement in the efficiency of ME use, however, was only apparent in a grazing environment with restricted DMI, where JER cows produced 20% more milk/kg DMI (L'Huillier et al., 1988); under ad libitum feeding this ME conversion gain disappeared. This genetics x environment interaction was also reported by J. R. Bryant, López-Villalobos, Pryce, Holmes, & Johnson (2006), when they identified that the milk production superiority of HF cows over JER cows was greater in higher milk production environments, an indicator of higher feed allowances.

Based on their superior FCE it would appear, therefore, that in grazing systems, where DMI limits production (Kolver & Muller, 1998), the JER may have a production efficiency advantage over HF due to their smaller size and less total maintenance requirement per cow. In almost all comparisons, however, the JER produced less milk. Therefore, more JER cows would be required for the equivalent per hectare milk production of the HF. As between 50 and 60% of costs in a grazing system are associated with individual cows (Macdonald et al., 2011), having more JER cows to produce the same volume of milk may negatively affect farm profitability, even if a greater proportion of consumed ME is partitioned to milk production. Nevertheless, the reported interaction between breed and FCE (L'Huillier et al., 1988) might indicate an advantage for JER cows in farming systems that limit feed allowance per cow (e.g., high SR; Macdonald et al., 2008a) and HF cows in production systems that provide a greater feed allowance per cow. To test this hypothesis, JER and HF cows were compared in pasture-based systems over multiple lactations at either moderate or high stocking rates.

2.3 Materials and methods

The experiment was conducted over three lactations at No. 2 Dairy, DairyNZ, Hamilton, New Zealand (37°47’ S, 175°19’ E, 40 m above sea level) between 1990 and 1993. However, based on recent component-study publications, it was deemed that the data were sufficiently important to present in a scientific journal (see Appendix I for Article in Press). The permanent grassland area had pastures of predominantly ryegrass (*Lolium perenne* L.) and white clover (*Trifolium repens* L.), with evenly distributed soil type, specifically a Te Rapa peaty silt loam soil; known as a Humic Aquic Haplorthod in soil taxonomy or a Humose Groundwater-Gley Podzol in the New Zealand classification. All experimental procedures were approved by the Ruakura Animal Ethics Committee, New Zealand.

2.3.1 Experimental design and treatments

Fifty-nine JER cows and 51 HF cows were randomly allocated to one of two CSR (kg BW/t feed DM allowance; Macdonald et al., 2008a) in a 2 x 2 factorial arrangement; systems were designed to have a CSR of either 80 or 100 kg BW/t feed DM. Comparative stocking rate is a more complete measure of stocking rate than feed allowance per cow, as it accounts for the number of cows per hectare (i.e., stocking rate), the BW of the cow (i.e., as a proxy for milk production potential), the pasture producing potential of the farm (t pasture DM/ha), the amount of supplement imported from off the farm (t DM/ha), and whether replacement stock are reared on the farm or on land remote from the milking platform (Macdonald et al., 2008a). From a profitability perspective, optimum CSR for grazing dairy systems with HF cows was reported to be 75-80 kg BW/t feed DM (Macdonald et al., 2011). Because of the different BW of JER and HF cows, the number of cows was greater in the JER treatment to ensure the same CSR as the HF treatment.

Historically, average pasture production on the experimental farm was 16.5 t DM/ha (Macdonald et al., 2017) and cow BW was 360 and 420 kg BW for JER and HF cows, respectively (mid-lactation BW). To create the 80 and 100 kg BW/t feed DM CSR treatments for both breeds, JER cows were managed at stocking rates of 3.6 and 4.5 cows/ha (26 and 33 cows, respectively) and HF cows were managed at 3.0 and 4.0 cows/ha (22 and 29 cows, respectively). This equated to 1,285, 1,631, 1,268, and 1,670 kg BW/ha for the JER-CSR80, JER-CSR100, HF-CSR80, and HF-CSR100 treatment groups, respectively, and an expected feed allowance of 4.6 t DM, 3.7 t DM, 5.5 t DM, and 4.1 t pasture DM per cow in each of the four treatments, respectively.

The cows were selected from the research farm herd, so that the genetic merit of the breeds was as similar as possible. Estimated breeding values and the genetic merit of the cows were re-calculated in the most recent genetic evaluation (NZ Animal Evaluation Ltd, personal communication); estimated breeding values for volume, fat, protein, BCS (10-point scale; Roche et al., 2004), fertility, residual survival, BW, somatic cell count (**SCC**), and gestation length for HF and JER cows, respectively, were +192 and -952 kg, -0.3 and -13.1 kg, -3.4 and -25.5 kg, +0.17 and +0.04 BCS units, +2.9 and +2.2, +43 and -18 d, +39 and -65 kg, -0.21 and -0.19, and

+1.9 and +2.9 d. Breeding worth (i.e., national measure of genetic merit for profit) was -$43.50 and -$2.10 for the HF and JER cows, respectively.

Seventy-two 0.405 ha paddocks were randomly allocated to one of four 7.29 ha farmlets, ensuring that paddock allocation were balanced for geographic location, soil type, distance from the milking parlor, and previous experimental treatments; as such, farmlets were evenly spread over the farm in a checker board fashion (Macdonald et al., 2008a). Each farmlet was then randomly allocated to one of the four treatments. Once farmlets were established, they were unchanged throughout the trial.

2.3.2 Trial management

2.3.2.1 Grazing and fertiliser management

Grazing management was determined by monitoring farm pasture cover on a weekly basis. Each herd was allocated fresh pasture once daily, as described by (Macdonald et al., 2008a), and only returned to the same area when a minimum of two leaves were present on the majority (>66%) of perennial ryegrass tillers. For all stocking rates, the intended post-grazing residual height was 40 mm.

For the JER-CSR80, JER-CSR100, HF-CSR80, and HF-CSR100 herds, respectively, the average number of days in their inter-grazing interval (i.e., rotation length) were: Winter: 72 ± 27.5, 74 ± 26.6, 72 ± 27.6, and 73 ± 26.6; Spring: 19 ± 2.7, 20 ± 3.6, 19 ± 2.7, and 20 ± 3.6; Summer: 19 ± 3.0, 20 ± 6.0, 19 ± 3.0, and 20 ± 6.0; Autumn: 47 ± 26.8, 58 ± 30.5, 43 ± 26.2, and 58 ± 30.5. Surplus pasture was conserved as silage when growth rate exceeded herd requirements; on average, 222 and 205 kg pasture silage DM/cow was harvested on the JER-CSR80 and HF-CSR80 farmlets, respectively; no silage was conserved on the CSR100 farmlets. Pasture was sampled for DM content before baling, with the bales weighed from each paddock to give an estimate of the amount of feed conserved. Mechanical cutting (i.e., clipping or topping) of residual pasture post-grazing was applied as deemed necessary to maintain quality. All farmlets received 54 kg of P/ha, 55 kg of S/ha (as single superphosphate), and 50 kg of K/ha as Muriate of Potash. No N fertiliser was applied. When pasture silage was harvested, an additional 50 kg of K/ha was applied to the relevant area.

2.3.2.2 Animal management

Across the farmlets, all cows were managed in a similar manner to that described previously for multi-year farm system experiments (Horan et al., 2005; Macdonald et al., 2008a). The system of milk production was seasonal, with the median calving dates across all years being within one week (26 July - 31 July); approximately 50% of cows calved within two weeks of planned start of calving (mid to late July), 40% calved in the next four weeks (August) and the remaining cows calved during week 7 and 8 (early September; Roche et al., 2017a). Cows with a calving due date later than week 8 of the calving period were induced to calve during week 7 or 8 with the 2-step use of hormones dexamethasone (Opticortenol S, Novartis Animal Health, Switzerland; Voren, Boehringer-Ingelheim, Berkshire, UK) and prostaglandin (Estrumate, Schering-Plough Coopers, New Zealand). This procedure was only performed if cows had low SCC before dry-off (<200,000 cells/mL), were in a BCS ≥ 5.0 (on a 10-point scale; Roche et al., 2004), and blood Mg (> 0.8 mmol/L) and gamma-glutamyl transferase (15 to 22 U/L plasma).

The routine mating management policy at No. 2 Dairy was to record any cows exhibiting signs of oestrus before the planned start of the seasonal breeding period. Oestrus detection was performed by twice-daily visual observation of estrous behavior with the aid of paint applied to the tail-head of the cow (i.e., 'chalking' or 'tail-painting'). Cows not detected in oestrus by the planned start of the seasonal breeding period were presented for veterinary examination. Those without a palpable corpus luteum were treated with an intravaginal controlled internal drug releasing insert (CIDR®; InterAg, Hamilton, New Zealand) as per the Genermate® programme (Cliff, Morris, Hook, & MacMillan, 1995). Artificial insemination was performed for the first six weeks of the seasonal breeding period, followed by a further six weeks of natural breeding with a Hereford bull. Pregnancy diagnosis was performed by manual palpation of uterine contents at least five weeks after the end of the 12 week breeding period.

At the end of each lactation, approximately 20% of the cows from each farmlet were culled because of reproductive failure, health, age, and genetic merit, and were replaced with primiparous cows 1 month before the planned start of calving. Age structure did not differ across farmlets for the duration of the study. Lactation length was shortened for individual cows within each season, based on individual cow BCS, level of milk production, and number of days from calving (Macdonald et al., 2008a; Macdonald & Penno, 1998).

2.3.2.3 *Animal health*

Because of low pasture Mg (<0.2% DM) and relatively high pasture K (>3.5% DM) concentrations during winter and spring, Mg supplementation was routinely practiced to prevent hypomagnesaemia and associated hypocalcemia (Roche & Berry, 2006). Magnesium oxide was top-dressed on pastures grazed by the non-lactating cows from three weeks before the planned start of calving until calving was completed. After calving, all lactating cows received 20 g Mg daily as an oral supplement of magnesium chloride ($MgCl_2.6H_20$) at the a.m. milking until late November when Mg supplementation ceased.

During periods of increased risk of frothy bloat, an anti-bloating solution (Pluronic; Ecolab, Hamilton, New Zealand) was also provided (orally) at the morning milking. Zinc sulfate (3.6 g $ZnSO_4.7H_2O$/100 kg BW) was given to the cows (orally) during periods of increased vulnerability to facial eczema, as determined by fungal (*P. chartarum*) spore counts. Water troughs were in each paddock and at the dairy, such that cows had unlimited access to clean drinking water.

2.3.3 Measurements

2.3.3.1 *Pasture measurement*

Pasture mass was estimated by two people using calibrated visual assessment of each paddock from a weekly farm walk similar to the method described by O’Donovan, Dillon, Rath, and Stakelum (2002). On each occasion, 11 calibration quadrats (each 0.3 m^2) covering a range of pasture mass were assessed before and after the farm walk. After the final assessment, the pasture within the quadrats was cut to ground level, washed, and dried in a forced draught oven at 100^{O}C until dry (approximately 48 hours). The pasture mass estimate for each paddock during the farm walk (for that week) was then adjusted using a regression of quadrat visual assessment on measured quadrat herbage mass. The net pasture accumulation was calculated each week from the increase in pasture mass on ungrazed paddocks. These data were used to estimate total pasture grown per hectare per year.

Grazing height was reverse-calculated from equations of regressions (seen in Figure 2.1) using compressed pasture height (Platemeter, Farmworks, Palmerston North, New Zealand) and DM yield, developed for each season over three years specifically from this research farm:

Equation 1	Winter:	DM yield, kg DM/ha	= 139.6 x ht + 317.5
Equation 2	Spring:	DM yield, kg DM/ha	= 124.8 x ht + 875.4
Equation 3	Summer:	DM yield, kg DM/ha	= 170.8 x ht + 1,423.6
Equation 4	Autumn:	DM yield, kg DM/ha	= 120.3 x ht + 952.8

where compressed height (ht) is measured in 0.5 cm.

In addition, to estimate pasture harvested per hectare per year, pasture mass in individual paddocks was visually assessed on 3 days each week pre- and post-grazing. Estimated pasture harvested (kg DM/cow per day) was calculated from pasture disappearance by:

Equation 5 (Pre-grazing DM mass – Post-grazing DM mass) x (area grazed/day ÷ no. of cows)

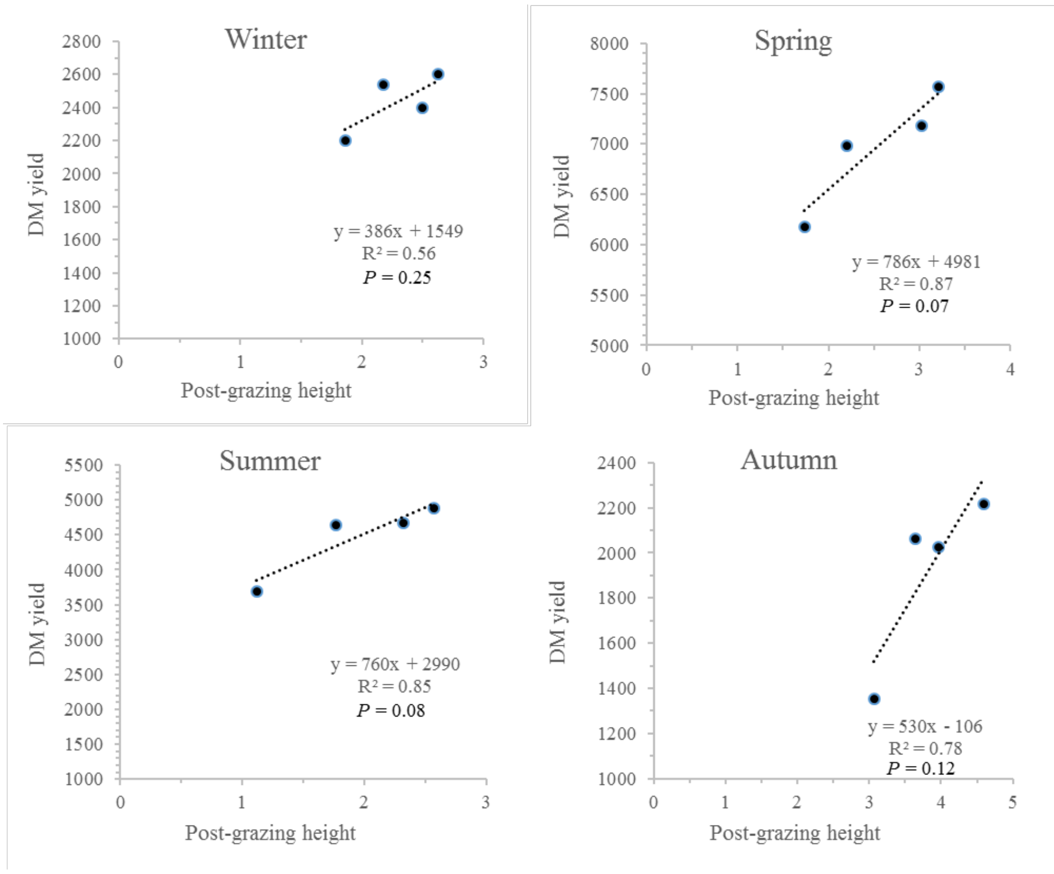

Figure 2.1 Relationship between average compressed post-grazing residual height (cm) and average DM yield/ha for the season. Winter = June to August; Spring = September to November; Summer = December to February; Autumn = March to May. Post-grazing residual heights were reverse-calculated from regression equations produced for each season on this research farm over three years.

2.3.3.2 Milk, body condition score, body weight, and energy balance estimates

Individual cow milk yields were recorded weekly (Tru-Test™ milk meter system, Palmerston North, New Zealand). Milk fat, crude protein, and lactose concentrations were determined on composite p.m. and a.m. aliquot samples by Fossomatic FT120 (Foss Electric, Denmark). Milk component data were verified by reference techniques for a subset of milk samples (milk fat: Röse-Gottlieb; Anonymous, 1987; crude protein: macro-Kjeldahl techniques; Barbano et al., 1991).

Body weight and BCS were determined weekly during the non-lactating period (at approximately 9 a.m.) and until approximately 12 weeks post-parturition and then every other week (following the a.m. milking). Body condition score was assessed on a 10-point scale, where 1 is emaciated and 10 is obese (Roche et al., 2004).

Metabolisable energy requirements for maintenance, activity, pregnancy, BCS change, and milk production per cow and per hectare were calculated using equations presented by Committee (2007; See Appendix II).

2.3.4 Statistical analyses and economic modelling

Data were analysed for consistency of farmlet response to the different treatments over three years by calculating means for each variable for each farmlet in each year and analyzing these using ANOVA procedures in GENSTAT, with year and farmlet as fixed effects, and the interaction of farmlet and year as a random effect. A *P*-value of less than 0.05 for a result was considered to be of statistical significance.

The economics of the breed and stocking rate comparisons were modelled using the same methodology described by Macdonald et al. (2011; 2017). Production data were averaged across years to provide one value per farmlet. The percentage of stock replaced each year (20%) was the same across farmlets;

therefore, the amount of stock available for sale increased with stocking rate. Gross revenue was calculated as the sum of milk and stock sales. The proportion of each expense category was classified as a per cow or a per hectare expense (Macdonald et al., 2011); the proportions are presented in Appendix III. Wherever expenses could be separated for individual farmlets (e.g., feed, silage conservation), actual data were used. Wherever data could not be separated for individual farmlets because of the structure of the research farm accounting system (administration, depreciation, electricity costs, repairs and maintenance, standing charges, vehicle expenses), equivalent expenses per cow and per hectare from similar farming systems were extracted from a commercial database used for measuring and benchmarking farm economic performance in New Zealand (DairyBase, DairyNZ, Hamilton, NZ; see Appendix IV; n = 87 farms over 3 years: 2012-15). Additional assumptions include a milk price of $0.45/kg ($4.04/kg fat and $7.35/kg protein; all figures in NZ$ unless otherwise stated), a conservation cost for pasture silage made of $250/t DM. These costs are accurate at the time of writing.

2.4 Results and discussion

The effects of stocking rate on pasture and animal production characteristics (Macdonald et al., 2011; Macdonald et al., 2008a; B. McCarthy et al., 2016), nitrate leaching (J. McCarthy et al., 2015; Roche et al., 2016), and dairy farm profitability (Macdonald et al., 2011) in temperate pasture-based production systems have been extensively reported. These studies were exclusively undertaken on HF cows and Macdonald et al. (2008a) assumed that the effects of stocking rate were the same for all breeds when they introduced the concept of CSR.

However, when compared with JER cows, many differences have been identified in production and biological characteristics of HF cows which could interact with stocking rate (Beecher et al., 2014; L'Huillier et al., 1988; Prendiville et al., 2009, 2010; Washburn, White, Green, & Benson, 2002; White et al., 2001; White, Benson, Washburn, & Green, 2002). For example, JER cows have lower maintenance requirements (Beecher et al., 2014) and were reported to require 7-8% less feed DM to produce a kg fat and protein in a pasture-based system (Prendiville et al., 2009). Such characteristics would imply a possible superiority of the JER breed's performance under a high CSR (i.e., lower feed allowance) and where lower milk yield per cow is accepted (Macdonald et al., 2008a; B. McCarthy et al., 2016). It is plausible, therefore, that the optimum CSR for HF cows is different to that of JER cows. To test the hypothesis that there is an interaction between CSR and breed, we compared HF and JER dairy cows at either the pre-defined optimum CSR (75-80 kg BW/t feed DM; CSR80; Macdonald et al., 2011) or at CSR100 (100 kg BW/t feed DM available), which is a CSR 25% greater than optimum.

2.4.1 Pasture production

Effects of breed, CSR, and the interaction of breed and CSR on annual and seasonal pasture production, average seasonal pasture cover (i.e., average mass of pasture on the farm; kg DM/ha), and on the amount of pasture conserved as silage are presented in Table 2.1. Annual pasture production was greater ($P < 0.01$) in the JER breed farmlets and in the CSR80 treatment because of treatment effects during spring ($P < 0.01$), summer ($P < 0.05$), and autumn ($P < 0.01$). Because of this, average pasture cover was also greater for the JER treatment farmlets and at the lower CSR. In previous studies (Macdonald et al., 2008a; B. McCarthy et al., 2016), pasture DM production increased with stocking rate, such that actual CSR didn't increase by as much as predicted. This is inconsistent with the results presented here. The most plausible reason for this inconsistency is that there was a negative effect of the CSR100 treatment on post-grazing residuals (Table 2.1) and that this had a negative effect on subsequent pasture production (i.e., over-grazing occurred). Lee et al. (2009) reported that repetitive severe depletion and failure to allow sufficient time for replenishment of plant non-structural carbohydrates (**NSC**) between grazing events leads to a reduction in regrowth of pasture. Post-grazing residual results presented in Table 2.1 reflect a more severe grazing severity by the HF cows and in the higher CSR farmlets; post-grazing residuals were 251 kg DM/ha less in the CSR100 farmlet paddocks than in the CSR80 farmlet

Table 2.1 Effect of dairy cow breed (Jersey; JER and Holstein-Friesian; HF) and comparative stocking rate[1] (CSR) on average pasture DM yield (kg DM/ha) during each season[2] and annually, average amount of pasture on each farmlet during each season (pasture cover; kg DM/ha), the pre- and post-grazing pasture mass during each season (kg DM/ha; height[3], cm, in parentheses), and the amount of pasture conserved as silage in each farmlet (kg DM/cow).

Breed	JER		HF			*P* - value		
Stocking Rate	CSR80	CSR100	CSR80	CSR100	SED[4]	Breed	CSR	Breed x CSR
Pasture DM yield								
Annual	17,267	16,214	16,273	13,424	533.9	<0.01	<0.01	0.05
Winter	2,599	2,536	2,396	2,200	242.4	0.17	0.48	0.71
Spring	7,569	6,982	7,183	6,179	222.7	<0.01	<0.01	0.23
Summer	4,880	4,633	4,667	3,691	283.3	<0.05	<0.05	0.12
Autumn	2,218	2,063	2,027	1,353	173.0	0.01	0.01	0.08
Pasture conserved as silage	222		205					
Pasture cover								
Winter	2,042	2,014	1,952	1,927	50.7	0.05	0.49	0.96
Spring	2,358	2,111	2,305	1,893	68.0	<0.05	<0.001	0.14
Summer	3,037	2,686	2,895	2,397	69.9	<0.01	<0.001	0.19
Autumn	2,662	2,474	2,439	2,296	25.4	<0.001	<0.001	0.26
Pre-grazing pasture mass (height[3], cm)								
Winter	3,016 (9.7)	3,000 (9.6)	2,869 (9.1)	2,741 (8.7)	80.9	<0.05	0.25	0.37
Spring	2,710 (7.3)	2,558 (6.7)	2,598 (6.9)	2,295 (5.7)	62.2	<0.01	<0.01	0.14
Summer	3,239 (5.3)	2,989 (4.6)	3,093 (4.9)	2,524 (3.2)	137.8	<0.05	<0.01	0.15
Autumn	3,115 (9.0)	2,911 (8.1)	2,893 (8.1)	2,636 (7.0)	89.9	<0.01	<0.01	0.69
Post-grazing pasture mass (height[3], cm)								
Winter	1,050 (2.6)	924 (2.2)	1,014 (2.5)	837 (1.9)	54.4	0.16	<0.01	0.53
Spring	1,676 (3.2)	1,425 (2.2)	1,631 (3.0)	1,308 (1.7)	47.7	<0.05	<0.001	0.32
Summer	2,302 (2.6)	2,028 (1.8)	2,215 (2.3)	1,806 (1.1)	69.2	<0.05	<0.001	0.22
Autumn	2,058 (4.6)	1,828 (3.6)	1,908 (4.0)	1,690 (3.1)	44.2	<0.01	<0.001	0.86

[1]Comparative stocking rate (CSR) is a more complete measure of stocking rate and, therefore, feed allowance/cow; it accounts for the number of cows/ha (i.e., stocking rate), the BW of the cow (i.e., as a proxy for milk production potential), the pasture producing potential of the farm (t pasture DM/ha), the amount of supplement imported from off the farm (t DM/ha), and whether replacement stock are reared on the farm or on land remote from the milking platform (CSR = kg BW/t feed DM allowance; Macdonald et al., 2008a).

[2] Season; Winter = June, July, August; Spring = September, October, November; Summer = December, January, February; Autumn = March, April, May.

[3]Estimated pasture compressed height, back-calculated from regression equations derived for this research farm.

[4]SE of the difference

paddocks and 100 kg DM/ha less on the HF farmlet paddocks than JER farmlet paddocks. Non-structural carbohydrates are a stored energy reserve and provide energy for regrowth of pasture when the photosynthetic centers of the plant (i.e., the leaves) have been removed following grazing.

Even if plants are allowed to recover to the three-leaf stage of regrowth before the next defoliation, successive severe defoliations (i.e., <40 mm) have been reported to impair NSC synthesis and reduce storage during the regrowth period; this results in less herbage regrowth (Lee et al., 2009). However, although the effect of CSR on pasture DM production in this experiment and the lack of consistency with previous studies is important, the interaction between breed and CSR ($P < 0.05$) in the pasture production variables measured is of particular interest. In fact, the negative effect of CSR on pasture DM production in this study was a direct result of the 17% reduction in pasture DM production in the HF-CSR100 treatment. As a result of this interaction in pasture DM production, there was a breed x CSR interaction for pasture harvested per cow and DMI per cow and for the milk production variables presented in Table 2.2. The HF cows harvested 12% more pasture per cow in the CSR80 treatment, but were unable to harvest any additional pasture DM per cow in the CSR100 farmlet. These results indicate that HF cows have a greater drive to eat than Jerseys.

The greater drive to eat due to the greater total ME requirements per cow (Table 2.4), as was evidenced in the CSR80 treatment, caused the more severe grazing defoliation in the HF-CSR100 treatment that is evident from post-grazing residuals presented in Table 2.1. This effect of breed was reported by L'Huillier et al. (1988), with HF cows grazing 0.3 cm lower than JER cows offered a similar

Table 2.2 Effect of dairy cow breed (Jersey; JER and Holstein-Friesian; HF) and comparative stocking rate[1] (CSR) on lactation length (days), annual and seasonal[2] pasture disappearance and estimated DMI (kg DM/cow), annual milk production (kg/cow and kg/ha), average milk composition (%), body weight (BW; kg) and BCS 1 month pre-calving and 1 week post-calving, and calf birth weight (kg).

Breed	JER		HF			*P* - value		
Stocking Rate	CSR80	CSR100	CSR80	CSR100	SED[3]	Breed	CSR	Breed x CSR
Lactation length	262	223	261	226	3.3	0.64	<0.001	0.38
Pasture disappearance								
Annual	4,340	3,590	4,856	3,541	88.8	<0.01	<0.001	<0.01
Winter	845	704	965	715	57.4	0.15	<0.01	0.22
Spring	1,335	1,182	1,538	1,173	24.7	<0.01	<0.001	<0.001
Summer	1,294	1,001	1,378	961	47.2	0.53	<0.001	0.11
Autumn	866	703	974	692	22.0	<0.05	<0.001	<0.01
Supplementary feed, kg	154	159	160	167	7.5	0.24	0.30	0.88
DMI								
Annual	4,494	3,749	5,016	3,708	87.9	<0.01	<0.001	<0.01
Winter	883	741	998	755	57.0	0.16	<0.01	0.26
Spring	1,335	1,182	1,538	1,173	24.7	<0.01	<0.001	<0.001
Summer	1,300	1,006	1,385	969	46.6	0.50	<0.001	0.11
Autumn	975	821	1,094	811	24.4	<0.05	<0.001	<0.01
Production, kg/cow								
Milk yield	3,224	2,673	4,574	3,352	56.2	<0.001	<0.001	<0.001
4% FCM	4,265	3,520	5,000	3,635	69.1	<0.001	<0.001	<0.001
Fat	198	163	211	153	3.2	0.60	<0.001	<0.01
Protein	136	108	161	115	2.7	<0.001	<0.001	<0.01
Lactose	156	129	216	158	2.6	<0.001	<0.001	<0.001
Production, kg/ha								
Milk yield	11,510	12,111	13,816	13,346	231.7	<0.001	0.70	<0.05
4% FCM	15,224	15,949	15,101	14,469	309.4	<0.05	0.84	<0.05
Fat	708	740	638	609	14.8	<0.001	0.90	<0.05
Protein	484	491	486	456	11.5	0.08	0.19	0.07
Lactose	557	585	651	630	12.0	<0.001	0.68	<0.05
Milk composition								
Fat	6.2	6.1	4.6	4.6	0.06	<0.001	0.30	0.89
Protein	4.2	4.1	3.5	3.4	0.03	<0.001	<0.001	0.17
Lactose	4.8	4.8	4.7	4.7	0.01	<0.001	0.87	0.43
BW pre-calving	377	368	482	456	8.1	<0.001	<0.05	0.20
BW post-calving	364	356	450	416	5.8	<0.001	<0.001	<0.05
BCS pre-calving	4.9	4.8	4.9	4.6	0.06	0.16	<0.05	0.17
BCS post-calving	5.0	4.9	5.0	4.5	0.05	0.13	<0.05	0.12
Calf birth weight	25	26	36	36	1.2	<0.001	0.95	0.72

[1]Comparative stocking rate (CSR) is a more complete measure of stocking rate and, therefore, feed allowance/cow; it accounts for the number of cows/ha (i.e., stocking rate), the BW of the cow (i.e., as a proxy for milk production potential), the pasture producing potential of the farm (t pasture DM/ha), the amount of supplement imported from off the farm (t DM/ha), and whether replacement stock are reared on the farm or on land remote from the milking platform (CSR = kg BW/t feed DM allowance; Macdonald et al., 2008a).

[2]Seasons: Winter = June, July, August; Spring = September, October, November; Summer = December, January, February; Autumn = March, April, May.

[3]SE of the difference

allowance. Estimated pasture height from reverse engineered calibration equations indicate that HF cows grazed 0.1, 0.2, 0.3, and 0.6 cm lower than JER cows in winter, spring, summer, and autumn, respectively, in the CSR80 treatment, and 0.3, 0.5, 0.7, and 0.5 cm lower in the CSR 100 treatment, respectively (Figure 2.1). So, with less feed available and already lower post-grazing residuals in the high CSR treatment, HF cows grazed even lower at the higher CSR (Table 2.1). The lower grazing residual under the same allowance would be expected to reduce the regrowth of pasture (Lee et al., 2009), particularly at the post-grazing residual height estimated (i.e., 1.1 cm in summer), and result in a cycle of more severe subsequent grazing defoliations. This interaction between breed and CSR compounded, with the lower post-grazing residual resulting in a lower pre-grazing mass in subsequent grazing events (Table 2.1), which resulted in a more severe grazing, and a lower pre-grazing mass, subsequently, reducing annual and seasonal DM production in the current study. These results confirm the effect of breed reported by L'Huillier et al. (1988) and indicate that the effect of CSR on pasture production are not consistent across breeds and that JER cows are more suitable to high stocking rates and high CSR than HF cows.

In support of this greater 'drive to eat' in HF cows in the current study, J. R. Bryant et al. (2008) suggested that nutrients are allocated to particular functions in a priority order: firstly, maintenance; then, pregnancy, lactation, growth, and fat deposition. Therefore, as proposed by Glazier (2002), when feed is scarce, body maintenance will take precedence over traits related to production, reproduction or growth. As JER cows have a lower per cow maintenance requirement to satisfy than HF, they could direct energy earlier in grazing events to milk production, maintenance of fat stores, and/or growth, reaching a point of satiation earlier. Therefore, when feed was scarce (i.e., at CSR100), grazing pressure was reduced earlier by JER cows, accommodating pasture recovery through an earlier satiation of DMI.

2.4.2 Milk production

Yields of milk, 4% FCM, and milk components per cow were less at the higher CSR for both breeds. The effect of SR on per cow milk production ($P < 0.001$) is consistent with previous studies (A. M. Bryant et al., 1985; Macdonald et al., 2008a; B. McCarthy et al., 2010). Treatment effects reflect both a reduction in DMI per cow and a reduction in lactation length with increased SR: lactation length was 39 and 35 days shorter in the CSR100 treatments for JER and HF breeds, respectively. Reducing lactation length is a standard protocol for balancing nutrient supply and demand at higher stocking rates in pasture-based systems that do not import supplementary feed (Macdonald et al., 2008a).

However, as with the pasture DM production measurements, there was a breed x CSR interaction for most of the per cow ($P < 0.01$) and per hectare ($P < 0.05$) milk production variables measured (Table 2.2). At a greater feed allowance, HF cows consumed more DM and produced more 4% FCM, fat, protein, and lactose per cow than JER cows. However, they were unable to exploit these DMI and production advantages at the higher CSR. In short-term experiments, Prendiville et al. (2010) reported that HF cows had a 14% higher pasture DMI than their JER counterparts (16.7 vs 14.6 kg/day, respectively) and L'Huillier et al. (1988) established that HF cows consumed 13% more than JER cows.

When the entire lactation was accounted for in the experiment reported here, HF cows consumed, on average, 20% more DM than JER cows at the CSR80 and produced 17% more 4% FCM. The breed effects on milk yield and yield of fat and protein at CSR80 are consistent with the predicted differences in genetic merit for these traits: HF produced 1,350 kg milk, 13 kg fat, and 25 kg protein more than JER cows at the CSR80 and the genetic predicted difference for these traits was 1,144, 13.4, and 28.9 kg respectively. In comparison, however, at CSR100, estimated cow DMI was not affected by breed (Table 2.2) and HF cows only produced 679 kg more milk, 10 kg more milkfat, and 7 kg more protein than JER cows, or 41, 25, and 76% less than the genetic predicted differences for these traits (breed x CSR interaction; $P < 0.001$). Our results highlight the effect of feed allowance on the ability of cows to achieve their genetic potential.

The interaction between breed and CSR on milk production variables are consistent with the treatment interactions on pasture production and support the previous reports of J. R. Bryant et al. (2006, 2007) and Fulkerson et al. (2008). Utilising a national genetic evaluation dataset of ~185,000 lactations, J. R. Bryant et al. (2006, 2007) identified an interaction between feed allowance and cow breed in first lactation animals. In their analysis, the milk production superiority of North American HF cows relative to New Zealand HF and JER cows increased in dairy herds with higher average milk production. Similarly, Fulkerson et al. (2008) reported that the genetic predicted difference within the HF breed was only achieved when grazing cows were offered in excess of 800 kg DM of a concentrate supplement per year in addition to their pasture allowance (i.e., lower CSR).

On a per hectare basis, the JER cows harvested more pasture (~1 t DM) and produced more milk fat at the CSR80, but the same amount of 4% FCM and milk protein. In comparison, at CSR100, the JER cows harvested >2 t DM pasture/ha more than the HF cows, produced almost 1,480 kg more 4% FCM and 131 and 35 kg more milk fat and protein/ha, respectively, than the HF-CSR100 treatment.

In summary, milk production per hectare was not affected by breed at CSR80, but per cow production was greater in the HF breed. There was a significant pasture production and milk production per hectare advantage of the JER breed in the CSR100 treatment, despite lower milk production per cow. The results indicate that:

1) The ability of a cow to achieve potential production over genetically inferior herd mates is dependent on CSR;
2) The JER is more suited than the HF to systems where feed is limited; and
3) In systems where feed is less limited, the HF cow is able to capitalise on its greater frame size and evident drive to eat (L'Huillier et al., 1988), increasing DMI per lactation and achieving the genetic predicted difference for milk production traits.

2.4.3 Body weight and body condition score

The effect of breed and CSR on BW and BCS pre- and post-calving are presented in Table 2.2. Jersey and CSR100 cows were lighter (lower BW) than HF and CSR80 cows, respectively, but cow BCS was not affected by breed; CSR100 cows had lower BCS pre- and post-calving, which is consistent with the reported profile of BCS change associated with changes in stocking rate (Roche et al., 2007).

Interestingly though, there was also an interaction between breed and CSR in post-calving BW ($P < 0.05$) and a consistent tendency ($P < 0.15$) for an interaction in pre- and post-calving BCS. This interaction reflects a failure of the HF breed to achieve calving BCS targets at high stocking rates (Roche et al., 2009a), even when managed under the same management decision rules as the JER. The 0.3 to 0.4-unit difference in BCS between HF-CSR80 and HF-CSR100 is consistent with the 0.5 BCS unit difference in BCS reported by Roche et al. (2007b) for similar differences in CSR in HF cows. In contrast, the JER cows managed to achieve the BCS targets. The reason for the interaction probably reflects differences in the BW per BCS unit (Berry et al., 2006), the previously discussed interaction between breed and CSR in annual pasture DM yield, greater maintenance requirements in HF cows, or, possibly, greater FCE of the JER described in many studies (L'Huillier et al., 1988; White et al., 2001; Prendiville et al., 2009, 2010; Beecher et al., 2014). Irrespective, it highlights an advantage of the JER in maintaining a biologically sustainable grazing system at a high CSR.

2.4.4 Reproduction variables

The effects of breed and CSR on reproduction variables are presented in Table 2.3. Even though animal numbers per treatment are small, there were noteworthy effects of breed and CSR on reproduction variables measured. The number of days in milk (**DIM**) to the first observed heat was greater (*P* < 0.001) in the HF breed and was greater in the HF-CSR100 than in the HF-CSR80; but, CSR did not affect DIM to first observed heat in the JER treatment (breed x CSR interaction; *P* < 0.05). These results are consistent with the numerical increase in the percentage of HF cows recorded as anoestrus at the planned start of the seasonal breeding period in the highest CSR treatment reported by Macdonald et al. (2008a) and it resulted in a tendency (*P* = 0.07) for a negative effect of CSR on submission rate in the current study.

Table 2.3 Effect of dairy cow breed (Jersey; JER and Holstein-Friesian; HF) and comparative stocking rate[1] (CSR) on reproduction parameters.

Breed	JER		HF			*P* – value		
Stocking Rate	CSR80	CSR100	CSR80	CSR100	SED[2]	Breed	CSR	Breed x CSR
DIM to first heat	28	28	38	56	4.4	<0.001	<0.05	<0.05
Non-cyclers[3] (%)	3	1	18	13	2.8	<0.001	0.11	0.35
Submission rate[4] (%)	97	96	98	89	3.5	0.25	0.07	0.15
Conception (%)	60	62	68	64	5.0	0.21	0.72	0.43
Services/conception	1.6	1.6	1.5	1.5	0.12	0.36	0.94	0.88
AI pregnancy rate	74	78	85	75	6.3	0.46	0.50	0.18
In Calf (%)	91	94	98	91	4.3	0.50	0.50	0.14

[1]Comparative stocking rate (CSR) is a more complete measure of stocking rate and, therefore, feed allowance/cow; it accounts for the number of cows/ha (i.e., stocking rate), the BW of the cow (i.e., as a proxy for milk production potential), the pasture producing potential of the farm (t pasture DM/ha), the amount of supplement imported from off the farm (t DM/ha), and whether replacement stock are reared on the farm or on land remote from the milking platform (CSR = kg BW/t feed DM allowance; Macdonald et al., 2008a).
[2]SE of the difference
[3]% of cows not detected in oestrus at the beginning of the seasonal breeding period
[2]% of cows submitted for AI within the first three weeks of the seasonal calving period

The effect of these two breeds on length of the post-partum anestrous period was also reported by Fonseca et al. (1983); they reported that JER cows had a shorter interval from calving to first oestrus than HF cows (37.2 ± 27.3 days and 66.9 ± 33.9 days, respectively). There were no significant effects of breed or CSR on any other reproduction variables measured.

2.4.5 Energy requirements

Estimated ME requirements for maintenance, activity, pregnancy, BCS change, and production are presented in Table 2.4. On a per cow basis, JER cows required less (P < 0.05) ME for all activities, with the exception of BCS change. In this study, JER cows had a 14% lower metabolic body weight (**$BW^{0.75}$**) compared with the HF and would be expected to have a commensurate reduction in maintenance and activity ME requirements. This assumption is consistent with recent slaughter studies undertaken by Beecher et al. (2014), who reported that for a 27% lower $BW^{0.75}$, the JER cows in their study had a 24% lighter gastrointestinal tract and liver than HF cows, all factors expected to reduce maintenance ME requirements per cow in line with $BW^{0.75}$. Similarly, the lighter calf birthweight (Table 2.2) in the JER resulted in a 30% reduction in ME requirements per cow for pregnancy.

At the CSR100, each cow required less ME per cow (P < 0.01) for maintenance, activity, change in BCS, and milk production because of the lower BW and milk production than the CSR80 treatment cows. However, in contrast, when considered on a per hectare basis, there was a greater (P < 0.01) requirement for ME (MJ/ha) for maintenance, activity, pregnancy, and BCS change in the CSR100 treatments. Per hectare, JER cows required more ME for maintenance, activity, and production because of the greater number of cows and $BW^{0.75}$ per hectare; despite this, ME requirements for pregnancy per hectare were still 20 to 25% less for JER than HF cows. Metabolisable energy required for milk production per hectare was not affected by CSR, although there was a tendency (P = 0.11) for a breed x CSR interaction for ME requirements for production

Table 2.4 Effect of dairy cow breed (Jersey; JER and Holstein-Friesian; HF) and comparative stocking rate[1] (CSR) on the Metabolisable Energy (ME) required[2] per cow and per ha for maintenance, activity, pregnancy, change in BCS, and production.

Breed	JER		HF			*P* - value		
Stocking Rate	CSR80	CSR100	CSR80	CSR100	SED[3]	Breed	CSR	Breed x CSR
ME required (MJ/cow)								
MEm	17,454	16,538	20,428	18,819	248.9	<0.001	<0.001	0.01
MEa	1,435	1,212	1,528	1,213	20.0	<0.05	<0.001	<0.05
MEpg	1,373	1,388	1,962	1,942	63.7	<0.001	0.95	0.72
BCS change	330	636	318	832	136.6	0.38	<0.01	0.32
MEp	21,694	17,756	25,073	18,139	368.8	<0.001	<0.001	<0.01
Total ME	42,636	37,530	49,308	40,946	413.4	<0.001	<0.001	<0.01
ME required (MJ/ha)								
MEm	62,834	74,420	61,283	75,278	974.1	0.63	<0.001	0.13
MEa	5,167	5,455	4,585	4,853	73.2	<0.001	<0.01	0.85
MEpg	4,944	6,245	5,885	7,767	228.0	<0.001	<0.001	0.12
BCS change	1,186	2,862	953	3,328	612.4	0.80	<0.01	0.45
MEp	78,009	79,902	75,218	72,557	1,664.0	<0.01	0.73	0.11
Total ME	152,230	168,884	147,923	163,783	1,834.4	<0.01	<0.001	0.77

[1]Comparative stocking rate (CSR) is a more complete measure of stocking rate and, therefore, feed allowance/cow; it accounts for the number of cows/ha (i.e., stocking rate), the BW of the cow (i.e., as a proxy for milk production potential), the pasture producing potential of the farm (t pasture DM/ha), the amount of supplement imported from off the farm (t DM/ha), and whether replacement stock are reared on the farm or on land remote from the milking platform (CSR = kg BW/t feed DM allowance; Macdonald et al., 2008a).
[2]Energy required was calculated using Committee (2007); See Appendix II.
[3]SE of the difference

consistent with the previously discussed interaction in 4% FCM.

Crude measures of system-level efficiency of ME use (e.g., MJ ME required to produce 1 kg 4% FCM) can be deduced from the results presented in Table 2.2 and 2.4. At CSR80, both JER and HF cows required 10 MJ ME/kg 4% FCM produced. However, JER and HF cows required 128 and 133 MJ ME/kg fat and protein produced, respectively, signifying a 4% greater efficiency in the JER cow at the low CSR for converting total ME intake to saleable product in a component pricing system. In comparison, at CSR100, HF cows required 6 and 10% more ME per kg 4% FCM and per kg fat and protein, respectively, than their JER comparison. This greater efficiency of ME use, particularly at CSR100, was also reflected at the per hectare level and these results are consistent with previous studies. For example, Prendiville et al. (2009) reported that JER cows required 11% less DMI during lactation for every kg fat and protein produced and Beecher et al. (2014) reported that DM digestibility, organic matter digestibility, N digestibility, neutral detergent fibre digestibility, and acid detergent fibre digestibility were 2.2, 2.7, 3.2, 3.0, and 5.5% greater in JER cows compared with HF cows, respectively. This equated to an 8% greater conversion of net energy intake to milk fat and protein. L'Huillier et al. (1988) also reported a breed effect in the utilisation of ME in respiratory chambers. They reported a 25% reduction in the ME lost as heat in JER cows, providing a possible reason for the breed efficiency differences estimated in the current study and in those of Prendiville et al. (2009) and Beecher et al. (2014). Irrespective of the reason, the results of a multi-year, system-level experiment presented here and recent component experiments indicate that the JER has a significant advantage in the conversion of ME to 4% FCM and milk components in grazing systems, especially when feed allowance is constrained at higher CSR.

2.4.6 Economic modelling

The modelled effects of cow breed and CSR on the revenue, expenses and operating profit of grazing dairy farms are presented in Table 2.5 and Appendix IV, all values are in NZD unless otherwise stated. Gross farm revenue was greater for the JER treatments, increased marginally with CSR in the JER breed, but declined by an equivalent amount in the HF breed between CSR80 and CSR100. Because of the greater number of cows per hectare and the assumption that labour is primarily associated with each animal (see Appendix III; Macdonald et al., 2011), labour expenses were greater in the JER compared with the HF breed and in the

CSR100 compared with the CSR80 treatment. Similarly, total stock expenses and total feed expenses were greater for the JER treatment, because of the greater number of cows per hectare at the same CSR, and were greater at CSR100 than CSR80. Other farm working expenses and overheads were also greater in the JER and CSR100 treatments, compared with the HF and CSR80 treatments, respectively, reflecting the additional costs associated with more cows per hectare. As a result, operating expenses per hectare were greater for JER and CSR100 treatments, compared with HF and CSR80 treatments, respectively.

Table 2.5 Effect of dairy cow breed (Jersey; JER and Holstein-Friesian; HF) and comparative stocking rate[1] (CSR) on gross revenue (NZ$/ha), operating expenses (NZ$/ha), operating profit[2] (NZ$/ha), and cost of production (NZ$/kg FCM and NZ$/kg fat and protein).

Breed	JER		HF	
Stocking Rate	CSR80	CSR100	CSR80	CSR100
Milk price[3]	$5.88	$5.85	$5.97	$5.96
Revenue				
Gross Farm Revenue	7,522	7,767	7,216	7,005
Expenses				
Total Labour Expenses	1,314	1,602	1,122	1,442
Total Stock Expenses	725	888	621	802
Total Feed Expenses	315	394	249	361
Total Other Working Expenses	1,151	1,256	1,081	1,197
Total Overheads	682	751	637	713
Total Dairy Operating Expenses	4,186	4,891	3,710	4,515
Dairy Operating Profit	3,336	2,876	3,505	2,490
Expenses - cost/kg FCM	0.27	0.31	0.25	0.31
Expenses - cost/kg fat and protein	3.51	3.97	3.29	4.24

[1]Comparative stocking rate (CSR) is a more complete measure of stocking rate and, therefore, feed allowance/cow; it accounts for the number of cows/ha (i.e., stocking rate), the BW of the cow (i.e., as a proxy for milk production potential), the pasture producing potential of the farm (t pasture DM/ha), the amount of supplement imported from off the farm (t DM/ha), and whether replacement stock are reared on the farm or on land remote from the milking platform (CSR = kg BW/t feed DM allowance; Macdonald et al., 2008a).

[2]Operating profit is the gross farm revenue less the operating expenses

[3] NZ$/kg fat and protein supplied. It differs for each treatment because the value of protein differs to the value of fat in component-pricing markets. Therefore, if breed or stocking rate affects protein % or fat %, it will affect milk price.

Operating profit per hectare, which was calculated as the difference between gross farm revenue per hectare and operating expenses per hectare, was less at CSR100 than CSR80, irrespective of cow breed, but there appeared to be a breed x CSR interaction; operating profit was 5% greater for the HF breed at the CSR80 ($3,505 compared with $3,336), but was 15% less at the CSR100 ($2,490 vs $2,875). The effect of CSR on operating profit is consistent with the previous economic assessment of stocking rate and CSR by Macdonald et al. (2011). They reported that operating profit per hectare declined by 11% for an equivalent increase in CSR in HF cows. In the HF and JER breeds in the current study, operating profit per hectare was 29% and 14% lower, respectively, in the CSR100 treatment compared with CSR80. The economic modelling confirms that increasing CSR from 80 to 100 reduces operating profit per hectare in a pasture-based system not importing feed from off-farm; however, the effect is much greater in HF cows than JER.

2.5 Conclusions

There was an interaction between breed and CSR in pasture and animal production variables measured. At the higher CSR, the HF treatment farmlet produced less pasture, probably because of persistent over-grazing, and as a result, produced less milk and milk components per hectare. This resulted in an interaction in the modelled operating profit per hectare, with the HF breed marginally more profitable than the JER at the CSR80, but less profitable at the CSR100. The results confirm the superior efficiency of use of ME consumed for milk production in the JER cow, particularly at the high CSR.

3. Altering month of calving affects biological production parameters and profitability of temperate pasture-based dairy systems.

3.1 Abstract

Changes in the season of calving imply a misalignment of pasture growth, the peak of which occurs in spring, and peak herd energy requirements in early lactation. A traditional spring calving date, therefore, effectively matches the flush of spring growth; with early lactation following parturition in July and, as a result, should be the most economic system to produce and utilise pasture, with minimal supplementary feed required. A multi-year, production system experiment was established to determine the effect of changing the season of calving from the traditional date of July to January, April, or October on pasture and animal production, and profitability. Eighty Holstein-Friesian cows were randomly allocated to one of four herds, each of which had a different treatment, i.e., mean calving date 10th January (JAN), 10th April (APR), 10th July (JUL), or 10th October (OCT). Data were analysed for consistency of farmlet response over years using analysis of variance procedures, with year and herd as fixed effects and the interaction of herd with year as a random effect. Collated biological data and financial data extracted from a national economic database were used as fixed variables to model the financial performance for the different month of calving treatments. An additional risk analysis was undertaken, where past data were

used to estimate the probability distributions for stochastic input variables. Furthermore, the gross farm revenue and operating profit per hectare were modelled with two scenarios, where the milk payment variable did not include a premium for milk supplied during a period in winter of 16 May - 15 July; and where the milk payment variable did include this premium. The pasture growth (kg DM/ha) and pasture DMI (kg DM/cow/d) profiles of the JUL herd best matched the lactation profile. In comparison, profiles of JAN, APR, and OCT calving herds had periods of surplus and deficit, due to the time of calving and herd demand relative to the peak pasture growth. Therefore, the JUL herd produced the greatest milk, 4% FCM, fat, protein, and lactose yields (kg/cow; $P < 0.1$). With the base scenario of no premium included in the milk payment, the JUL herd earned the most in milk revenue per hectare out of the four herds and, therefore, had the highest gross farm revenue per hectare and operating profit per hectare. The APR herd had the lowest operating expenses, with the JUL having a slightly higher total, due to the small differences in cost to conserve pasture between the herds. The operating expenses per hectare did not change with either scenario (no premium or premium included). After inclusion of a premium for milk supplied in winter in the milk price variable, the JUL herd earned less total milk revenue than in the first scenario, but still more than the APR herd in milk sales, gross farm revenue, and operating expenses per hectare. Therefore, a premium payment for milk supplied during the winter was not enough to offset the losses in production for the APR herd, compared with the JUL herd.

3.2 Introduction

In a temperate climate, pasture growth rate varies throughout the year, with peak growth during spring (Roche et al., 2009b). As highlighted by Funston, Grings, Roberts, and Tibbitts (2016), the relationship between the nutritional requirements of the herd, and the quality and quantity of available feed should be the focus of the calving system, regardless of the planned calving period. The chosen calving system should, therefore, overlap the high nutrient demand at parturition and peak lactation with optimal weather conditions and, consequent, seasonal peaks in pasture yield and quality in spring, and lowest nutrient demand with lowest pasture yield in winter. In pasture-based systems, a compact calving period in late winter is optimal in matching peak feed supply with herd demand (B. McCarthy et al., 2012).

Changes in the calving season can result in a mismatch between the herd feed requirements and pasture availability throughout the year (García & Holmes, 2005), thereby introducing the potential for nutritional deficits at key times, pasture surplus to requirements at others, and a greater need for conservation (i.e., silage or hay), and/or and increased requirement for supplementary feed (Funston et al., 2016). A farm system with a mean calving date in autumn in temperate regions is perceived as one that has lower pasture utilisation and a greater requirement for supplementary feed; therefore, in general, expected profitability would be lower than for a system with a mean calving date in spring (García et al., 2000).

For a planned calving date outside of the recommended calving date of late winter, that matches supply of and demand for quality pasture, to be preferred from a financial perspective, the higher feed cost would need to be more than offset by a greater milk price. Consideration of management strategies to ensure the economic viability of systems with herds calving at times other than those that match pasture supply and demand is also needed (Roche et al., 2017a).

The aim of the current study was to determine whether the traditional winter calving date is optimal for matching pasture growth and demand and is, therefore, the most profitable compared with calving during the other seasons of the year. Additionally, a Monte Carlo simulation using @Risk software (Palisade, 2017) was completed to assess the relative risks associated with price and production inputs and their effects on the farm operating expenses per hectare, farm revenue per hectare, and farm operating profit per hectare for each farm system calving date; with the base scenario of no premium for milk supplied during winter, and the alternative scenario of a premium for milk supplied during winter added to the milk payment ($/kg fat and protein).

3.3 Materials and methods

This trial was conducted as previously outlined in Chapter 2.3, over two lactations at No. 2 Dairy, DairyNZ, Hamilton, New Zealand, between 1999 and 2001.

3.3.1 Experimental design and treatments

Eighty HF cows were divided into four herds of twenty cows each, which were randomly assigned to one of four treatments: January calving (**JAN**), April calving (**APR**), July calving (**JUL**), or October calving (**OCT**). Planned start of calving was on the 10^{th} of the month of calving for each group. Four farmlets of 6.48 ha each were divided into 16 paddocks of 0.405 ha; these were, then, assigned to one of the four treatment herds and the farmlets and stocking rate remained unchanged.

3.3.2 Trial management

3.3.2.1 Grazing and fertiliser management

Grazing management was determined by monitoring farm pasture cover on a weekly basis. Each herd was allocated fresh pasture once daily and, as described in Macdonald et al. (2008a), only returned to the same area when a minimum of two leaves were present on the majority (>66%) of perennial ryegrass tillers; this duration determined the rotation lengths of the farmlets. For the JAN, APR, JUL, and OCT herds, respectively the average number of days in the rotation length are: Winter 56 ± 2.7, 62 ± 13.4, 77 ± 12.7, and 56 ± 7.2; Spring 22 ± 5.0, 23 ± 5.0, 22 ± 5.6, and 41 ± 16.3; Summer 47 ± 20.3, 24 ± 5.0, 24 ± 2.0, and 26 ± 5.1; and Autumn 38 ± 7.6, 50 ± 9.3, 34 ± 9.9, and 33 ± 9.3. Surplus pasture was conserved as silage when growth rate exceeded cow intake, with an annual average of 1,965, 1,158, 1,247 and 2,029 ± 216.8 kg DM/ha for the JAN, APR, JUL and OCT herds, respectively.

Pasture was sampled for DM content before being conserved as silage in bales, with the bales weighed from each paddock to give an estimate of the amount of feed conserved. Mechanical cutting (topping) of residual pasture post-grazing was applied as deemed necessary to maintain quality. All farmlets received 'maintenance' top-dressings of 54 kg of P/ha, 55 kg of S/ha (as single superphosphate), and 50 kg of P/ha (as Muriate of Potash) annually, as well as 150 kg of N/ha to enhance pasture growth. If silage was made, an additional 50 kg of K/ha was applied to the area post-harvesting.

3.3.2.2 Animal management

Each farmlet was managed individually according to the stage of lactation of the herd, as the mean calving date of the herds was at different times of the year; however, each lactation stage was managed similarly across the herds.

Cows with a calving due date later than week 8 of the calving period were induced to calve during week 7 or 8 with the 2-step use of hormones dexamethasone (Opticortenol S, Novartis Animal Health, Switzerland; Voren, Boehringer-Ingelheim, Berkshire, UK) and prostaglandin (Estrumate, Schering-

Plough Coopers, New Zealand). This procedure was performed on the condition that the cow had low SCC (<200,000cells/mL) before dry-off, a BCS ≥ 5.0 on the 10-point scale (Roche et al., 2004), blood Mg concentration of > 0.8 mmol/L and γ-glutamyl transferase of 15-22 U/L plasma in the week before induction.

At No. 2 Dairy, the mating management policy was to identify cows exhibiting signs of oestrus behaviour before PSM by twice-daily observation and positive identification marked by tail paint. Planned start of mating for the JAN herd was 1st April, for the APR herd was 1st July, for the JUL herd was 1st October, and for the OCT herd was 1st January. By PSM, those cows that were not displaying signs of oestrus underwent a veterinary examination and, if lacking a palpable corpus luteum, were treated with an intravaginal controlled internal drug releasing insert (InterAg, Hamilton, New Zealand) following the Genermate program (Cliff et al., 1995). Artificial insemination was performed for the first six weeks from PSM, with a further five weeks of natural breeding to follow. Manual palpation of the uterine contents diagnosed positive pregnancy, which occurred at least five weeks after the end of the mating period.

Cows to be culled were removed at a rate of 20% each lactation, based on reproductive failure, age, health, or genetic merit and were replaced with primiparous cows before the planned start of calving. As described by Macdonald & Penno (1998), seasonal lactation of individual cows was curtailed based on BCS, production yields, and number of days to next calving.

3.3.2.3 Animal health

Refer to Chapter 2.3.2.3 for animal health management methods.

3.3.3 Measurements

3.3.3.1 Pasture measurement

Refer to Chapter 2.3.3.1 for pasture measurement methods.

3.3.3.2 Dry matter intake

Refer to Chapter 2.3.3.2 for DMI measurement methods.

3.3.3.3 Milk, body condition score and body weight

Refer to Chapter 2.3.3.3 for milk, BCS and BW measurement methods.

3.3.4 Statistical analyses and economic modelling

Data were analysed for consistency of herd response to the different treatments over two years by calculating means for each variable for each herd in each year and analyzing these using ANOVA procedures in GENSTAT, with year and herd as fixed effects, and the interaction of herd and year as a random effect. A *P*-value less than 0.05 was considered to be statistically significant. For the purposes of statistical analysis, the data from each treatment group were divided into early, early-mid, mid-late and late lactation to compare lactation profiles of the herds regardless of month of the year.

The economics of the calving date treatments were modelled using the same methodology described by Macdonald et al. (2011; 2017), presented in Appendix V. All prices presented in Chapter 3 are in NZD unless otherwise stated. Production data were averaged across years to provide one value per farmlet. The percentage of stock replaced each year (20%) was the same across farmlets. Gross revenue was calculated as the sum of milk and stock sales; with the milk sales calculations including premium values according to milk fat and protein production of the herd, and month of year for premium or no premium, presented in Appendix VI. The lactation of each herd was separated into peak months of September, October, November, and December, and non-peak months as the rest of the year. Milk fat and protein earned \$4.05 and \$8.10 per kg, respectively, for both the peak and non-peak months.

A year volume adjustment (equation 6) was calculated at a rate of \$0.0298 per L of milk supplied relative to a threshold, to give a penalty or bonus, using the peak months MS production followed by the non-peak months MS production. The $\text{year}_{\text{peak}}$ difference (equation 7) was calculated for each herd using the Fonterra average MS percentage for the year and the MS production of the peak months. The $\text{year}_{\text{non-peak}}$ difference (equation 8) used the Fonterra average MS percentage for the year and the MS production during the non-peak months.

Equation 6 Volume adjustment (\$) =
(Volume difference, $\text{year}_{\text{peak}}$ (L) x \$0.0298) +
(Volume difference, $\text{year}_{\text{non-peak}}$ (L) x \$0.0298)

Equation 7 Volume difference, $year_{peak}$ (L) =
(Farm peak total MS (kg) / Fonterra Year MS (%)) –
(Farm peak total MS (kg) / Farm Year MS (%))

Equation 8 Volume difference, $year_{non\text{-}peak}$ (L) =
(Farm non-peak total MS (kg) / Fonterra Year MS (%))–
(Farm non-peak total MS (kg) / Farm Year MS (%))

Peak volume adjustment (equation 9) was calculated at a rate of $0.0141 per L of milk supplied relative to the peak months threshold. The peak months difference (equation 10) was calculated using the Fonterra average MS percentage for the peak months and the peak months MS production.

Equation 9 Peak volume adjustment ($) =
Volume difference, peak (L) x $0.0141

Equation 10 Volume difference, peak (L) =
(Farm peak MS (kg) / Fonterra peak months MS (%)) –
(Farm peak MS (kg) / Farm peak months MS (%))

No volume adjustment ($) was made for the non-peak months; instead, a capacity adjustment (equation 11) was calculated for the non-peak months at a rate of $0.51 per kg MS produced during the non-peak months.

Equation 11 Capacity adjustment ($) =

non-peak months total MS (kg) x $0.51

Winter premiums were calculated at a rate of $2.85/kg MS produced during 16 - 31 May, $3.50/kg MS produced during 1 - 15 June, $3.50/kg MS produced during 16 - 30 June, and 2.85/kg MS during 1 - 15 July. A transport charge is calculated for milk at a rate of $0.025 per 10km distance from the factory.

The proportion of each expense category was classified as a per cow or a per hectare expense (Macdonald et al., 2011); the proportions are presented in Appendix V. Wherever expenses could be separated for individual farmlets (e.g., feed, silage conservation), actual data were used. Wherever data could not be separated for individual farmlets because of the structure of the research farm accounting system (administration, depreciation, electricity costs, repairs and maintenance, standing charges, vehicle expenses), equivalent expenses per cow and per hectare from similar farming systems were extracted from a commercial database used for measuring and benchmarking farm economic performance in New Zealand (DairyBase, DairyNZ, Hamilton, NZ; see Appendix IV; n = 87 farms over 3 years: 2012-15).

The base economic model (see Appendix V) was then used to assess the risk of the alternative calving date treatments in the current experiment, using @Risk software (Palisade, 2017), a Microsoft Excel plug-in. @Risk (Palisade, 2017) allows a distribution for input variables to be specified to perform a Monte Carlo simulation analysis of an output variable (Hardaker, Lien, Anderson, & Huirne, 2015). Single estimates of the variables of interest, specifically the mean values for milk price, silage cost, urea price, meat price, and annual pasture yield were replaced with distributions for each variable, presented in Figure 3.1.

The distribution fitted to the milk price dataset of mean annual milk price for the last 15 years, was an extended value distribution with mean \$6.16/kg MS ± \$1.54/kg MS. The variable silage cost, determined from national data for similar supplements, was fitted with a Weibull distribution, mean \$290/t DM ± \$47/t DM. The distribution for the urea price variable was taken from Neal & Cooper (2016), who fitted an extended value distribution, mean \$711/t ± \$91/t. The dataset for meat payment was the last 10 years of payment for kg of carcass weight, obtained from Beef and Lamb NZ (personal communication, 12 July 2017). The data had an extended value distribution fitted, mean \$3.09/kg ± \$0.15/kg. The dataset for the annual pasture growth variable was the annual pasture growth for No. 2 Dairy and Scott farm (DairyNZ research farms) for the last 20 years, which had a beta general distribution fitted, mean 16.5 t ± 2.0 t. Correlations between variables were also included in the analysis, sourced from Neal and Cooper (2016) at 0.1 for milk price and urea price, -0.3 for annual pasture yield and milk price, and 0.1 for urea price and annual pasture yield.

Using @Risk (Palisade, 2017) Monte Carlo simulations were then performed with 10,000 iterations[3] to generate, for each herd, probability distributions for the outputs dairy operating expenses, gross farm revenue, and dairy operating profit, under both the base and alterative scenarios of no premium and including premium.

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[3] 10,000 iterations give a stable estimate without requiring excessive computing power.

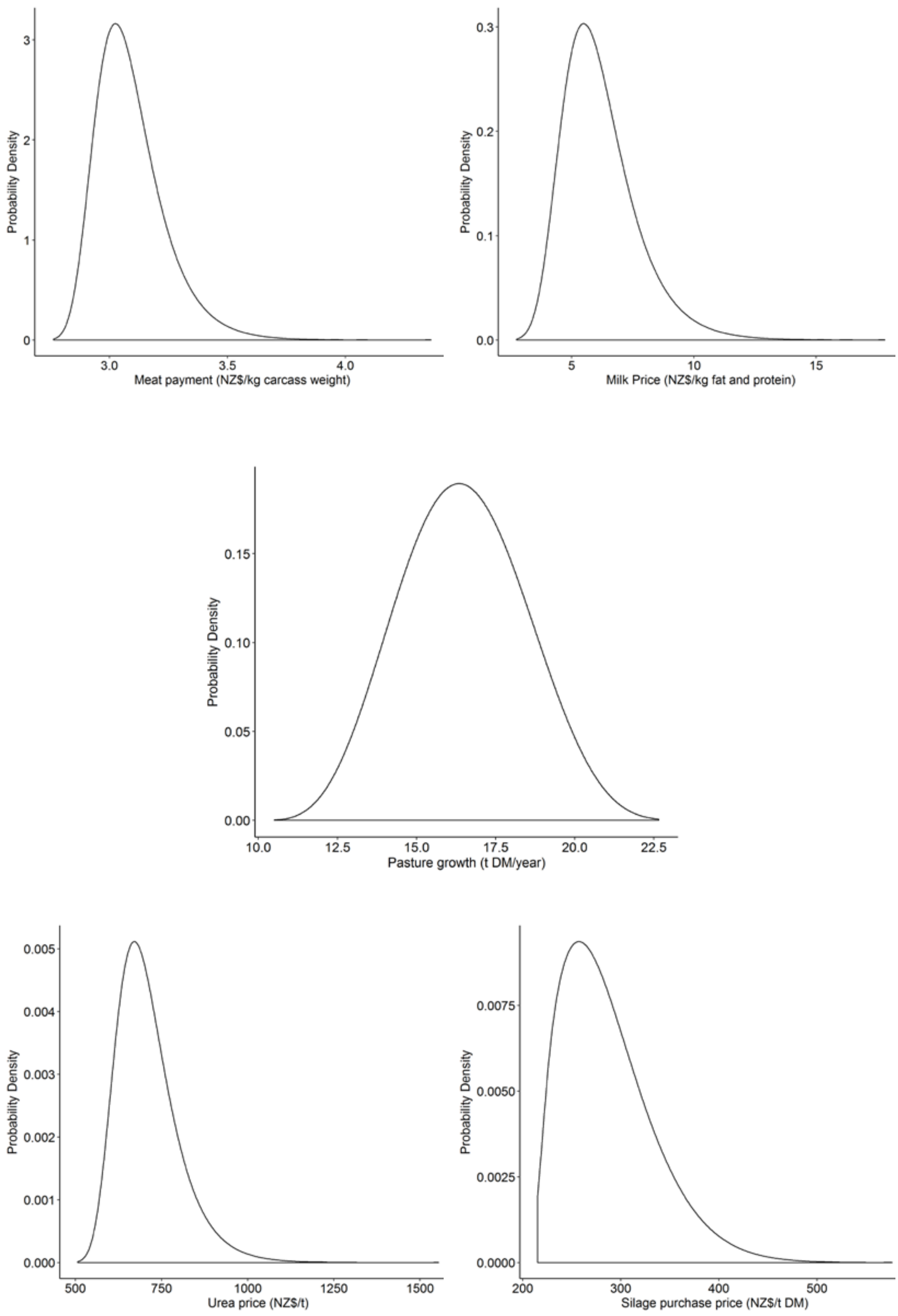

Figure 3.1 Probability density distributions for input variables: milk price (distribution mean NZ$6.16/kg fat and protein ± $1.54); silage purchase cost (distribution mean: NZ$286.69/t DM ± $46.84); urea price (distribution mean: NZ$711.01/t ± $91.09), meat price (distribution mean: NZ$3.09/kg carcass weight ± $0.15), and annual pasture growth (distribution mean: 16.5 t DM/year ± 2.0 t) calculated by @Risk software (Palisade, 2017) and graphed using R software (R Core Team, 2017).

3.4 Results and discussion

3.4.1 Pasture growth and intake

The effects of month of calving on pasture growth, the amount of pasture conserved as silage, and pasture, supplement, and total DMI are presented in Table 3.1. Whilst the annual pasture growth was not significantly affected by season of calving, the pasture growth at equivalent stages of lactation was affected because of the seasonal nature of pasture growth. September to November (Spring) is the period of peak pasture growth, therefore, the stage of lactation that coincided with spring had the highest pasture growth, however, a treatment effect was still noticeable:

- In early lactation in the OCT farmlet ($P < 0.01$) at 6,818 kg DM/ha;
- In early-mid lactation in the JUL farmlet ($P < 0.05$) at 7,894 kg DM/ha;
- In mid-late lactation in the APR farmlet ($P < 0.05$) at 8,254 kg DM/ha; and
- In late lactation in the JAN farmlet ($P < 0.05$) at 7,873 kg DM/ha.

García and Holmes (2005) suggested that similar levels of pasture production and utilisation can be achieved in contrasting pasture-based calving systems if common grazing, conservation, and feeding management criteria are applied to all systems. In other words, they concluded that overall pasture utilisation is independent of the month of calving when pasture management was optimal. The results presented in Table 3.1 are consistent with their conclusion, in that annual pasture DM yield per hectare and annual pasture DMI per cow were not significantly affected by season of calving ($P = 0.46$ and $P = 0.28$, respectively); however, the pasture intake per cow during early-mid and mid-late lactation was

Table 3.1 Effect of change in herd mean calving date treatment[1] (JAN; APR; JUL; OCT) on pasture growth (kg DM/ha); pasture, supplement and total DMI (kg DM/cow/day), and pasture conserved as silage (kg DM/ha).

Treatment	JAN	APR	JUL	OCT	SED[2]	*P* - value
Pasture growth						
Early lactation	4,357	1,238	3,311	6,818	574.4	<0.01
Early-Mid lactation	1,325	3,500	7,894	4,870	765.2	<0.05
Mid-Late lactation	3,834	8,254	5,583	1,661	870.9	<0.05
Late lactation	7,873	4,774	2,538	3,392	973.0	<0.05
Annual growth	17,389	17,767	19,327	16,741	1,463.1	0.46
Pasture DMI						
Early lactation[3]	11	9	10	11	1.1	0.31
Early-Mid lactation[4]	9	10	15	14	0.7	<0.01
Mid-Late lactation[5]	10	15	15	10	1.2	<0.05
Late lactation[6]	14	14	11	12	1.4	0.17
Annual intake (kg DM/cow)	4,073	4,306	4,679	4,205	256.6	0.28
Supplement						
Early lactation	0	1	0	0	0.2	0.09
Early-Mid lactation	4	3	0	1	1.3	0.16
Mid-Late lactation	4	0	0	5	1.6	0.12
Late lactation	0	0	3	2	1.3	0.19
Annual intake (kg DM/cow)	699	371	348	700	121.5	0.10
Annual conservation (kg DM/ha)	1,965	1,158	1,247	2,029	216.8	0.05
Total DMI						
Early lactation	11	10	10	11	1.1	0.53
Early-Mid lactation	13	13	15	15	0.8	0.12
Mid-Late lactation	14	15	15	15	0.9	0.63
Late lactation	14	14	14	13	0.8	0.64
Annual intake (kg DM/cow)	4,772	4,677	5,026	4,905	160.4	0.32

[1]JAN = planned calving date of herd 10th January; APR = planned calving date of herd 10th April; JUL = planned calving date 10th July; OCT = planned calving date 10th October.
[2]SE of the difference.
[3]Early: JAN = December, January, February; APR = March, April, May; JUL = June, July, August; OCT = September, October, November.
[4]Early-Mid: JAN = March, April, May; APR = June, July, August; JUL = September, October, November; OCT = December, January, February.
[5]Mid-Late: JAN = June, July, August; APR = September, October, November; JUL = December, January, February; OCT = March, April, May.
[6]Late: JAN = September, October, November; APR = December, January, February; JUL = March, April, May; OCT = June, July, August.

affected by treatment ($P < 0.05$). This difference in profile is evident in the very large difference in silage conservation (58 to 75% more in the JAN and OCT calving treatments).

Despite the stage of lactation being compared directly for statistical purposes, these stages occur during different months of the year for each herd; therefore, the biological demands of the herds are not equal during the same periods. For example, the profiles of pasture growth (DM/ha) and pasture DMI (kg DM/cow/d) in the JUL calving treatment best mimic the shape of the lactation curve and, therefore, cow demand for milk production; however, the profile in the other calving date treatments results in periods of deficits and surplus relative to demand throughout the year. In the period of early-mid lactation pasture DMI was greatest for the JUL herd, with the OCT herd next highest (15.2 and 14.1 kg DM/cow, respectively). In comparison, the pasture DMI in the JAN and APR calving treatments in early-mid lactation lower ($P < 0.01$) by about a third.

The reason for this effect of calving season is merely the pattern of the pasture growth profile of temperate pastures in a temperate climate. Early-mid lactation for the JUL herd occurred between September and November, whilst for the OCT herd it coincides with December to February, the next highest period of pasture growth providing rainfall is not limiting. The JUL herd also had the greatest pasture DMI in mid-late lactation, with the APR herd having a similarly high DMI during this period, in comparison with the other herds ($P < 0.05$; 15.2 and 14.6 kg DM/cow). For the JUL herd, mid-late lactation occurs during December to February, whilst for the APR herd it is September to November.

As presented in Figure 3.2, the peak of the pasture growth occurs during

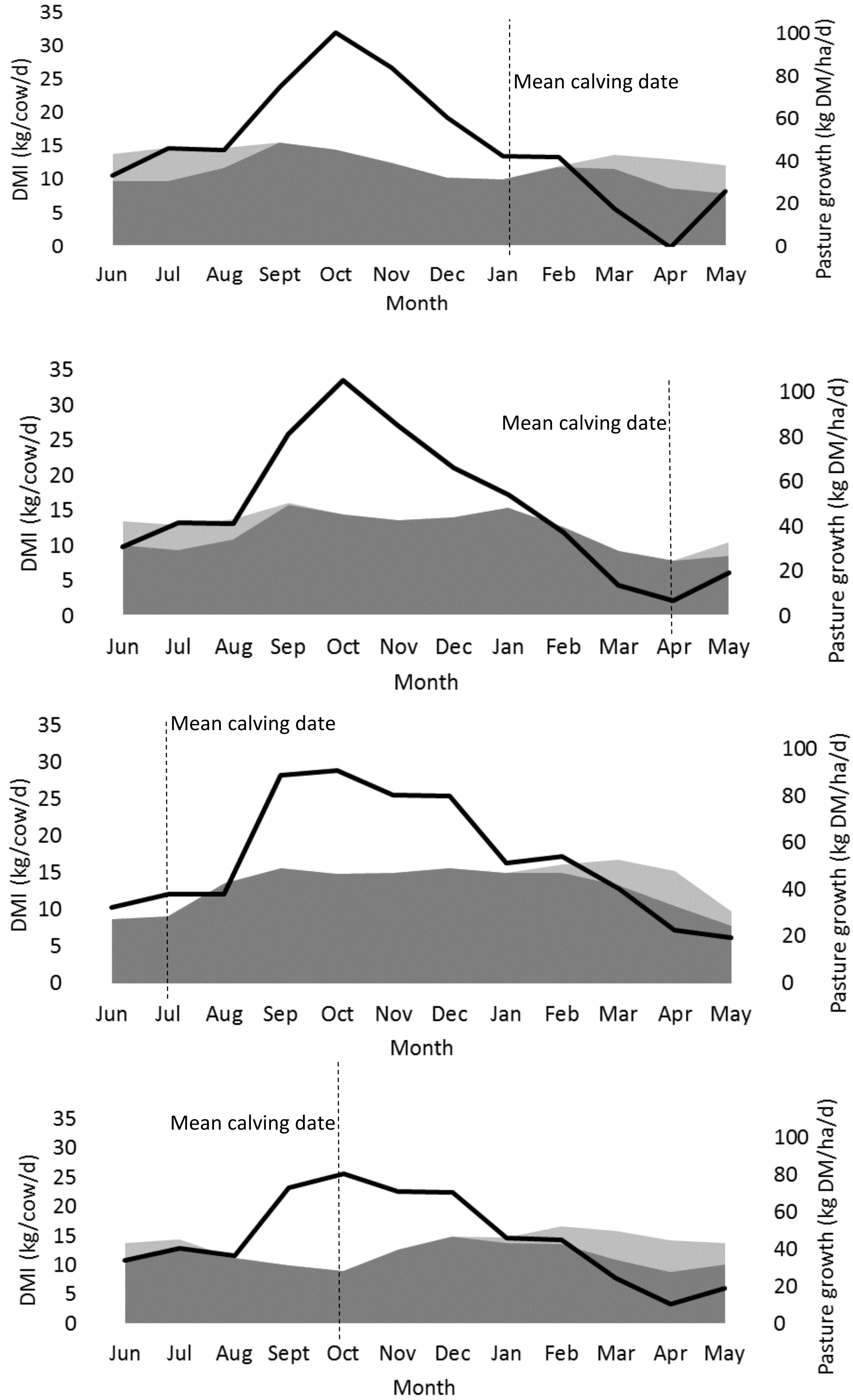

Figure 3.2 Effect of change in mean calving date treatment (top to bottom: JAN; APR; JUL; OCT) on pasture (dark grey area) and supplement (light grey area) DMI to give a total DMI (total grey area; kg DM/cow/day) and pasture growth (black line; kg DM/ha/day) Dashed lines denote mean calving date for each treatment.

the months of September to December for the JUL and OCT herds, with the mean growth during this period fluctuating around 85 kg DM/ha/d for the JUL herd, and 70 kg DM/ha/d for the OCT herd. The JAN and APR herds both have a sharp pasture growth peak during October of around 105 kg DM/ha/d in both systems, which rapidly declines in the months following.

The between farmlet differences in the pasture growth profiles as a result of changes in the month of calving are due to shifts in the peak nutritional demands of the herd. During early lactation, lactogenesis requires a dramatic increase in metabolic demand, resulting in the mobilisation of body reserves and an increase in feed requirements (Chagas et al., 2007; Contreras & Sordillo, 2011). A calving date in late winter allows an overlap of the peak pasture growth period with the peak nutritional demands of the herd post-calving. By changing the month of calving of the herd, the peak pasture growth period remains the same; however, the peak nutritional demand of the herd which occurs post-calving is shifted, thereby misaligning the supply and demand peaks.

For the OCT herd there is a decrease in pasture DMI from July to nadir in October, and for the JAN herd a decline from September to nadir in January as the nutritional demand of the herd in mid-late and late lactation declines; however, during this period the pasture growth is at its peak, as presented in Figure 3.2. The extra pasture is conserved as silage to be used to fill deficits in pasture supply and demand, with the OCT herd having the most conservation at 2,029 kg DM/ha, closely followed by the JAN herd at 1,965 kg DM/ha; both the APR and JUL herds have significantly less pasture available for conservation ($P < 0.05$). Pasture conserved from each farmlet is not shared between farmlets, so any silage made is used only to supplement the herd on the farmlet it was harvested from. Supplement fed to the herds (Table 3.1), was not significantly different between herds for any stage of lactation or for the total amount fed. Extra silage from a farmlet was sold, whilst if in a deficit in both pasture available and silage conserved occurs, extra pasture silage was bought. The greater amount of pasture conserved is an indication of the misalignment of the supply and demand, as presented in Figure 3.2 when the pasture growth is above the pasture DMI.

3.4.2 Milk production

Lactation length, annual milk production, and milk composition are presented in Table 3.2. For the JUL herd, milk production parameters, including total milk, 4% FCM, and fat, protein, and lactose yield (kg per cow) have a tendency ($P < 0.1$) to be greater, compared with the other herds. In contrast to these data, García et al. (2000) report a greater yield of MS per cow in autumn calving cows (APR herd equivalent), as a result of longer lactations, on average, compared with the spring calving cows (JUL herd equivalent) of 291 and 241 days, respectively. In the present study, the lactation length of the APR and JUL calving herds were 287 and 261 days, respectively. The herds in the experiment of García et al. (2000) were managed at a lower SR (2.0 cows/ha and 2.4 cows/ha for autumn and spring calving herds, respectively) than the APR and JUL herds (both 3.1 cows/ha), and also purchased maize silage as supplementary feed, which may have extended the lactation length beyond that of the present study.

Table 3.2 Effect of change in herd mean calving date treatment[1] (JAN; APR; JUL; OCT) on lactation length (days); mean annual milk, fat, protein, and lactose production (kg/cow); average fat, protein, and lactose composition (%); body weight (BW; kg) and BCS 1 month pre-calving and 1 week post-calving; and calf birth weight (kg).

Treatment	JAN	APR	JUL	OCT	SED[2]	*P* - value
Lactation length	292	287	261	262	12.3	0.17
Annual production, kg/cow						
Milk yield	3,726	3,843	4,445	3,681	188.2	0.07
4% FCM	4,057	4,236	4,878	4,002	218.9	0.08
Fat	171	180	207	169	9.7	0.08
Protein	128	134	154	123	6.5	0.06
Lactose	179	186	215	177	10.5	0.09
Milk composition, %						
Fat	4.6	4.7	4.7	4.6	0.07	0.40
Protein	3.5	3.5	3.5	3.3	0.06	0.27
Lactose	4.8	4.9	4.9	4.8	0.04	0.60
Pre-Calving BW	522	477	513	537	10.2	<0.05
Post-Calving BW	465	406	449	481	8.3	<0.01
Pre-Calving BCS	5.4	5.1	4.9	5.6	0.41	0.47
Post-Calving BCS	4.6	3.9	4.4	5.1	0.20	<0.05
Calf birth weight	38	37	37	39	0.8	0.18

[1]JAN = planned calving date of herd 10th January; APR = planned calving date of herd 10th April; JUL = planned calving date 10th July; OCT = planned calving date 10th October.
[2]SE of the difference.

There was no significant difference between the mean milk composition (%) of the herds, in terms of fat, protein, and lactose. This finding is in agreement with García et al. (2000), who also reported there was no difference between the milk composition (fat and protein %) of herds that calved in autumn or spring.

3.4.3 Body weight and body condition score

The pre-, and post-calving BW, BCS, and calf birth weights for each herd are also presented in Table 3.2. Changing the month of calving affects the mean of both pre- and post-calving BW, with the APR herd having the lowest BW preand post-calving ($P < 0.05$; $P < 0.01$). The APR herd also lost the most condition on average, 1.23 units between pre- and post-calving, and had the lowest BCS post-calving ($P < 0.05$). The loss of BW and condition suggests that the APR herd did not have sufficient nutrition in early lactation (Autumn; 1 March – 31 May) which overlapped with the lowest growth rate of pasture and the period of 'autumn ill thrift', wherein an unspecified feature of autumn pasture results in below expected pasture growth rates in growing ruminants and BCS gain in cows (Mandok et al., 2014). An increase of one body condition score at calving, equivalent to 30 kg BW, has been reported to increase production by 15 kg MS/cow in the following lactation (Roche et al., 2007b). Therefore, in the case of the APR herd which lost over one BCS unit, a common management decision would be to feed supplement, in the form of conserved pasture silage or other purchased feed to prevent the loss of condition. However, it is important that the economic ramifications also be considered. Ramsbottom et al. (2015) report the cost of supplementary feed cannot be higher than 3.5% of the milk payment; otherwise, any marginal gains in milk supply from maintaining condition will be lost by the increase in expenses. Therefore, a change in mean calving date to April, or autumn, will impact BCS during calving, and may not be economic to feed supplementary DM to mitigate this effect.

In contrast, the OCT herd had the highest BW both pre- and post-calving, along with the highest BCS pre- and post-calving, decreasing 0.5 units from 5.6 to 5.1. A mean calving date of October is late spring, which aligns with the peak of pasture growth (Figure 3.2). Therefore, the herd had more than sufficient pasture available during late gestation and early lactation, as indicated by the mean BW and BCS of the herd.

Although the JUL herd has the lowest pre-calving BCS, they lost the least amount of body condition, on average 0.5 BCS units from 4.9 to 4.4, a similar profile of loss to the OCT herd. This indicates that the herd had sufficient nutrition in the form of pasture during late gestation and early lactation to meet metabolic demand.

3.4.4 Economic modelling

The milk price, gross revenue, operating expenses, operating profit, and cost of production calculated as part of the base economic model are presented in Table 3.3 and Appendix V. All values are in NZD unless otherwise stated. Milk price is calculated individually for each herd, as under a component-pricing market the values per kg of fat and protein are different, and a premium for milk supplied during the winter period of 16 May to 15 July is also included (calculations in Appendix VI). The milk price presented is the mean revenue from milk sales, including the premium earned in winter, divided by the mean annual amount of MS produced by the herd. Changes in the month of calving also change the lactation period and volume of milk supplied during the winter months; therefore, the amount of premium earned by each herd varies. Milk payments calculated for the JAN, APR, JUL, and OCT herds are \$6.60, \$6.60, \$5.97, and \$6.54, respectively. Fixed values for the input variables are \$250/t DM to purchase silage, \$150/t DM to sell silage, \$100/t DM to make silage, and \$500/t of urea are used, along with the aforementioned milk payment. Carcass weight payment ($/kg) varied by month of sale January $2.92, February $2.96, March $2.98, April $2.94, May $2.96, June $3.14, July $3.25, August $3.34, September $3.35, October $3.19, November $3.08, and December $3.03.

Table 3.3 Effect of change in mean calving date treatment[1] (JAN; APR; JUL; OCT) and using fixed values[2] for input variables milk payment[3], meat payment, silage cost to buy, sell, and make, and urea price on the calculation of gross revenue (NZ$), operating expenses (NZ$), and operating profit (NZ$) per hectare, and cost of production (NZ$).

Treatment	JAN	APR	JUL	OCT
Milk payment	$6.60	$6.60	$5.97	$6.54
Milksolids (kg/ha)	928	972	1,118	905
Revenue				
Gross Farm Revenue	6,546	6,813	7,088	6,258
Expenses				
Total Labour Expenses	1,165	1,158	1,164	1,162
Total Stock Expenses	651	648	633	633
Total Feed Expenses	344	215	224	332
Total Other Working Expenses	1,365	1,358	1,358	1,365
Total Overheads	660	662	644	647
Total Dairy Operating Expenses	4,171	4,053	3,953	4,073
Dairy Operating Profit[4]	2,344	2,774	3,140	2,157
Expenses - cost/kg FCM	0.36	0.34	0.29	0.36
Expenses - cost/kg fat and protein	4.50	4.17	3.54	4.50

[1]JAN = planned calving date of herd 10th January; APR = planned calving date of herd 10th April; JUL = planned calving date 10th July; OCT = planned calving date 10th October.
[2]Fixed values for the input variables are $3.00/kg of carcass weight for meat payment; $250/t DM to purchase silage; $150/t DM to sell silage; $100/t DM to make silage; $500/t of urea.
[3]NZ$/kg fat and protein supplied. It differs for each treatment because the value of protein differs to the value of fat in component-pricing markets. Therefore, if the change in planned calving date affects protein % or fat %, it will affect milk price.
[4]Operating profit is the gross farm revenue less the operating expenses.

Output variables for the model are dairy operating expenses ($/ha), gross farm revenue ($/ha) and operating profit ($/ha). The farmlets were managed individually in terms of silage made, sold, and bought, so that silage made on one farmlet could only be sold or fed back to the herd on the same farmlet.

Total dairy operating expenses for the base economic model are the lowest for the JUL herd at $4,022/ha, which also has the highest dairy operating profit of $3,066/ha. Dairy operating profit is calculated by the gross farm revenue less the operating expenses. The APR herd had second lowest dairy operating expenses at $4,041/ha and second highest dairy operating profit of $2,771/ha. Dairy operating expenses for the OCT herd were approximately $100 more than the JUL and APR calving herds, at $4,138/ha; however, the lowest dairy operating profit of $2,120/ha was earned, due to the herd producing the lowest amount of MS per hectare, compared with the other herds. The JAN herd had the highest dairy operating expenses (i.e., $4,184/ha) and a dairy operating profit of $2,362/ha.

Inclusion of risk assessment through the use of @Risk software (Palisade, 2017) was undertaken to provide insight into how variation in key input parameters affects profitability metrics. This method yields a distribution for each model output, conditional on the joint distribution of all input data. The change in input variable values by using the mean of the fitted distribution (Figure 3.1) instead of a fixed value are presented in Table 3.4; whilst distributions of the output variables of the model Monte Carlo simulation using @Risk (Palisade, 2017) are presented in Figure 3.3. The output variables were calculated with a base scenario of no premium included in the milk payment variable, and an alternative scenario of a premium for milk supplied during winter (16 May - 15 July) included in the milk payment variable.

Gross farm revenue per hectare calculated using a milk payment of $6.16/kg MS (base scenario) was $6,153, $6,421, $7,424, and $5,932 on average for the JAN, APR, JUL, and OCT calving herds, respectively (Figure 3.3). When

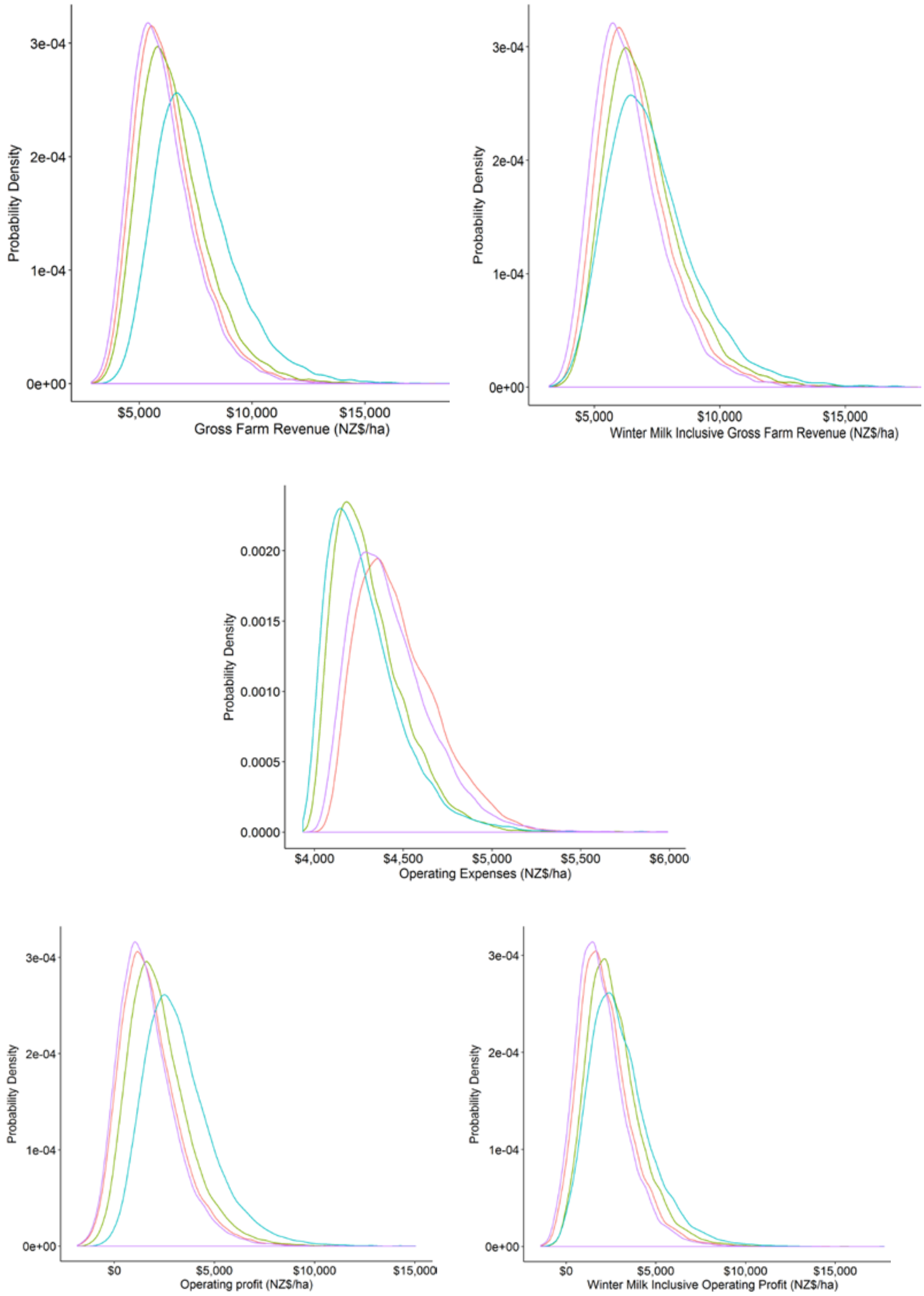

Figure 3.3 Probability distributions of model output variables operating expenses (NZ$/ha), gross farm revenue (NZ$/ha) and operating profit (NZ$/ha) for January (Red), April (Green), July (Blue), and October (Purple) month-of-calving scenarios.

Table 3.4 Effect of month of calving treatment[1] (JAN, APR, JUL, and OCT) and stochastic input variable[2], on revenue items, expense items, and output variables gross farm revenue (NZ$/ha), operating expenses (NZ$/ha), and operating profit (NZ$/ha), modelled under two scenarios[3] of a) no premium included; and b) with premium included in the milk payment variable using @Risk software (Palisade, 2017).

Treatment	Scenario	JAN	APR	JUL	OCT
Revenue					
Net milk sales/ha	a	5,718	5,990	6,889	5,578
	b	6,126	6,418	6,677	5,922
Net stock income	N/A	436	408	398	350
Surplus silage sales[4]	N/A	0	23	136	5
Expenses					
Supplements purchased[4]	N/A	132	0	0	0
Silage conservation[4]	N/A	233	174	245	297
Nitrogen	N/A	244	244	244	244
Gross farm revenue	a	6,153	6,421	7,424	5,932
	b	6,562	6,849	7,211	6,276
	±	1,479	1,564	1,804	1,459
Operating Expenses	N/A	4,304	4,099	4,142	4,202
	±	224	199	211	223
Operating Profit	a	1,850	2,322	3,282	1,730
	b	2,258	2,749	3,069	2,079
	±	1,501	1,556	1,769	1,458

[1]JAN = planned calving date of herd 10th January; APR = planned calving date of herd 10th April; JUL = planned calving date 10th July; OCT = planned calving date 10th October.
[2]Fitted distribution means (presented in Figure 3.1): Meat price = NZ3.09cents/kg; urea price = NZ$711/t; silage purchase = NZ$287/t DM; silage sale = NZ$187/t DM; make silage = NZ$137/t DM
[3]Scenario a) no premium included in milk payment variable (NZ$6.16/kg fat and protein for JAN, APR, JUL, and OCT herds); scenario b) premium for milk supplied during 16 May - 15 July included in milk payment variable (NZ$6.60, NZ$6.60, NZ$5.97, and NZ$6.54/kg fat and protein for JAN, APR, JUL, and OCT herds, respectively).
[4]Amount of silage purchased, sold and made based on modelled amount of pasture growth due to annual growth variation during trial.

calculated using a milk price that includes the distribution of the milk price variable as well as an adjustment for any premium earned for 'winter milk' produced (i.e., the alternative scenario; calculations in Appendix VI), the mean gross farm revenue per hectare was $6,562, $6,849, $7,211, and $6,276 for the JAN, APR, JUL, and OCT herds, respectively (Figure 3.3). Therefore, the adjustment for winter milk premium earned an extra $409, $428, and $344 per hectare on average for the JAN, APR, and OCT herds, respectively; however, the JUL herd declined by $213/ha under the adjusted payment system, which accounted for the proportion of milk produced at peak; compared with the greater milk fat and protein payment received by the other three treatments, the JUL calving treatment received the lower average milk price of $5.97/kg MS.

Mean operating expenses per hectare for the JAN, APR, JUL, and OCT herds after Monte Carlo simulation of input variable distributions using @Risk (Palisade, 2017) were $4,304, $4,099, $4,142, and $4,202, respectively, presented in Table 3.4. The APR and JUL herd expenses were close, with the small differences stemming from the small cost to make supplement ($174 and $245 for the APR and JUL herd, respectively; see Appendix VI). Similarly, Shalloo et al. (2004) reported differences in net farm profit between late winter and early spring calving date scenarios; where the farm system with the early spring calving date had a higher profit, due to a greater amount of supplement purchased in the farm system with late winter calving. Operating expenses per hectare do not vary under the alternative scenario.

Operating profit per hectare with the base scenario is, on average, $1,850, $2,322, $3,282, and $1,730 for the JAN, APR, JUL, and OCT herds, respectively (Figure 3.3). When the winter milk premium adjustment is made, the mean operating profit per hectare for the JAN, APR, JUL, and OCT herds, respectively, is $2,258, $2,749, $3,069, and 2,074 (Figure 3.3). Without the premium for winter milk and an average milk price of $6.16/kg MS for all four herds, the APR herd earned $960/ha less in operating profit, compared with the JUL calving herd. Even with the inclusion of a premium for milk produced during the winter period, which generated more milk revenue per hectare and having lower operating expenses per hectare, the APR calving herd earned ~10% less ($320/ha) in operating profit, compared with the JUL calving herd.

A CDF (Figure 3.4) is a powerful risk efficiency criterion, and useful in decision making contexts, as a CDF contains all the information on the output distribution of the potential outcomes and by comparing the CDF, the stochastically dominant or efficient set can be determined. If one CDF lies to the right of another over the entire probability interval, then first-degree stochastic dominance of the risk outcome (on the right) over another is implied (Hardaker et al., 2015). A CDF of the effect of change in the month of calving on the operating profit of the farm business is presented in Figure 3.4, without (base scenario) and with (alternative scenario) inclusion of the premium for supplied winter milk in the milk payment per kg MS input variable.

Stochastic dominance is observed (Figure 3.4) for the JUL herd over the other treatments without winter milk premium; therefore, the decision to calve in July is considered to be less risky in terms of operating profit per hectare compared with calving in January, April, or October. In addition, the APR herd is stochastically dominant over the JAN and OCT herds, without inclusion of winter milk premium; therefore, calving in April is less risky than calving in January or October for the outcome of operating profit per hectare.

With the inclusion of winter milk premium in the milk payment per kg MS, the JUL herd remains stochastically dominant over the other three treatments (Figure 3.4), whilst the APR treatment remains stochastically dominant over the JAN and OCT treatments. Therefore, even with inclusion of the winter milk premium in the milk payment input variable, the decision to calve in July is less risky than the other three options, for the outcome of operating profit per hectare.

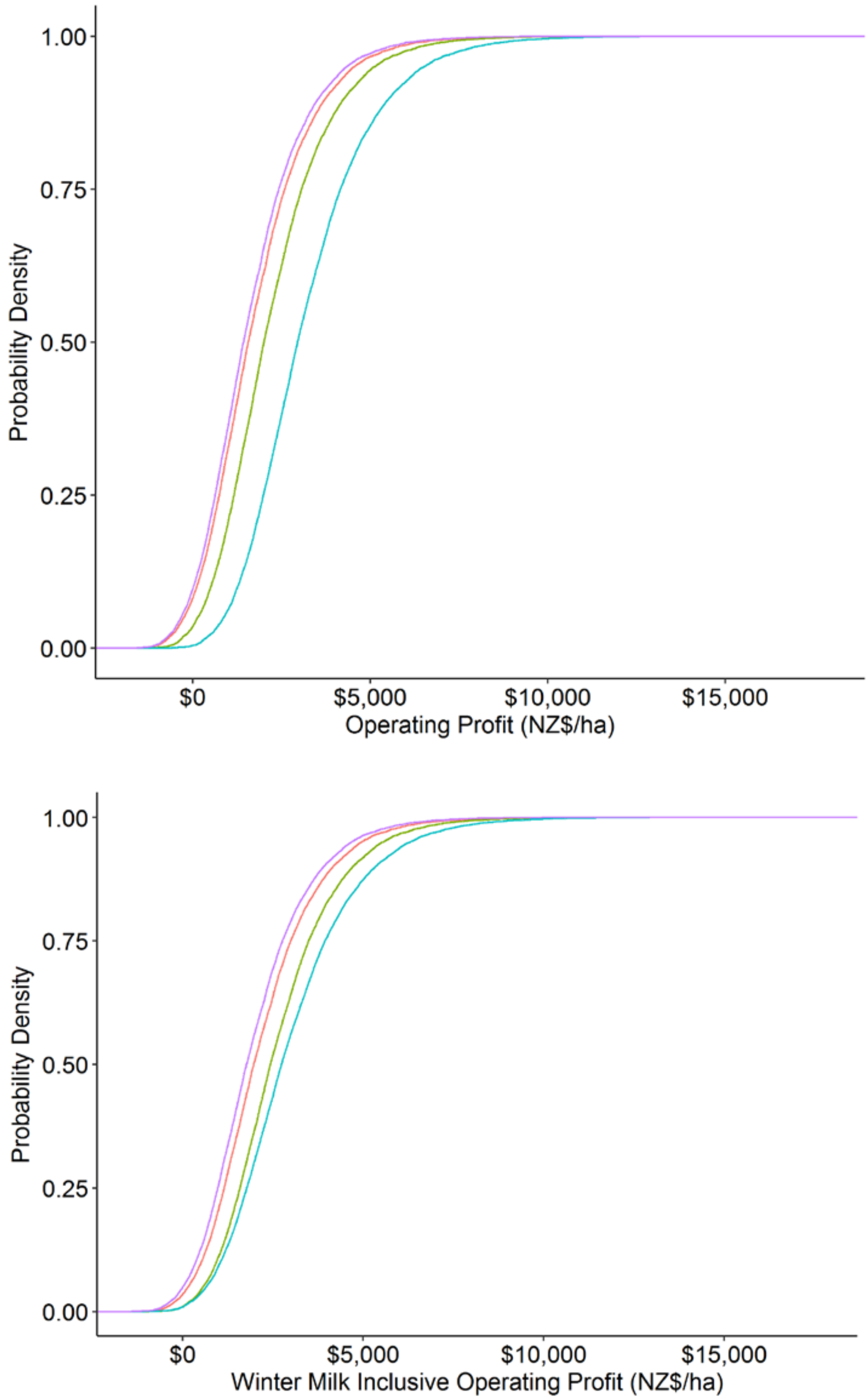

Figure 3.4 Cumulative density function of the effect of month-of-calving scenarios January (Red), April (Green), July (Blue), and October (Purple), on the operating profit (NZ$/ha) without premium payment for winter milk supplied (Left) and with premium payment (Right).

3.5 Conclusions

A mean calving date of July, has a positive effect on pasture DMI during early-mid and mid-late lactation, milk production (kg/cow), BCS, and farm operating profit per hectare. The JUL herd had a greater pasture DMI during early-mid and mid-late lactation (September to February), compared with the other herds, and was subsequently able to convert this extra pasture intake to milk production per cow. The JUL herd produced more milk, fat, protein and lactose (kg/cow), compared with the JAN, APR, and OCT mean calving date herds.

The best fit for pasture growth and herd demand was the JUL herd, whilst the JAN and APR herds had opposite calving dates to the peak pasture growth. The nutritional deficit during the calving period resulted in the lowest mean pre- and post-calving BCS for the APR calving herd, which also lost the most condition during the calving period, compared with the other herds. As a result, more supplementary feed is required by the APR herd, which was realised in the operating expenses per hectare in both the base economic model and economic risk model.

Despite the potential for autumn (April) calving to be more profitable than Spring (July) calving, because of the premium paid for milk produced between May and July, the results of the present study indicate this is not the case. Without inclusion of a premium for the supply of milk during the period 16 May to 15 July in the milk payment variable, gross farm revenue is highest for the JUL herd. When the premium is applied to the milk payment variable, despite a narrowing in the difference, the JUL herd still had the highest gross farm revenue, compared with the other herds, although the APR herd earned the highest milk revenue sales per hectare with the premium included.

The APR herd had the lowest farm operating expenses per hectare, whilst the JUL herd expenses were slightly higher due to small differences in the cost to conserve silage. However, the JUL herd had the highest operating profit per hectare, compared with the APR herd, at the second highest, and JAN and OCT herds.

4. General discussion

In pasture-based dairy systems, one of the primary goals is maximising the profitability of grazing land per hectare by optimising pasture production and utilisation (B. McCarthy et al., 2010). Therefore, strategic decisions regarding pasture and herd management, such as choosing a SR and mean calving date, can materially impact profitability of the farm business by affecting the alignment of peak pasture growth and quality with herd demand (Chapter 3). In Chapter 2, I identified a hitherto unknown interaction between cow breed and CSR, which must also be considered in deciding the strategy. For example, at CSR80, the HF was around $200/ha more profitable than the JER breed, whilst at CSR100, the JER was more profitable than the HF by around $400/ha. As Arnold Bryant, the former science leader for dairy production systems at Ruakura, is reputed to have quipped *"If you are short of land, milk Jerseys and if you are short of labour, milk Friesian."*

The profitability of pasture-based systems is closely related to the amount of pasture DM consumed per hectare per year (Macdonald et al., 2010; Ramsbottom et al., 2015). This was evident in Chapter 3, as the APR and JUL herds had 92 and 93%, respectively, of their total DMI as pasture, whereas 85 and 86% of total DMI for the JAN and OCT herds, respectively, was pasture. As a result, the APR and JUL calving herds had a greater operating profit per hectare than either the JAN or OCT calving herds.

Since pasture growth rate varies throughout the year in a sinusoidal pattern, peaking in October to November (Figure 4.1; Roche et al., 2009b), each season presents its own challenges to balance feed availability and demand (Lee et al., 2008; Macdonald et al., 2010).

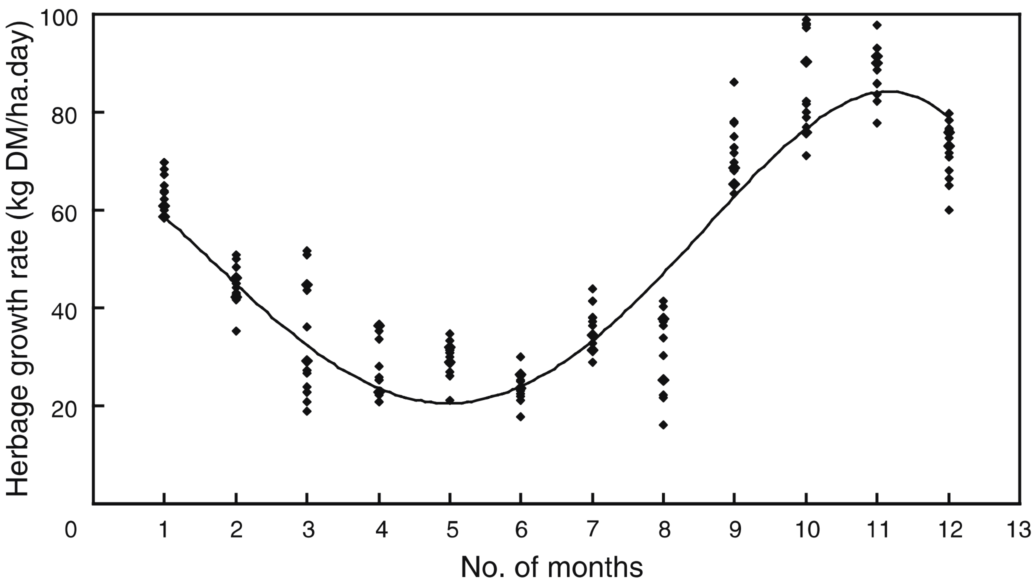

Figure 4.1 Sinusoidal pattern of pasture growth rate (kg DM/ha/d) over the 12 months of the year. Source: Roche et al. (2009b).

In Chapter 3, my results indicate that changing the season of calving from spring, which is most common in New Zealand, to autumn resulted in a mismatch between the herd feed requirements and pasture availability, and this affected cow milk yield (Chapter 3; García et al., 2000; García & Holmes, 1999, 2001, 2005). The profile of pasture growth and pasture quality were most aligned with herd demand for the JUL herd, with ample pasture growth throughout early to mid-late lactation, when the herd ME demand for lactation was high. In contrast, for the APR calving cows, the period of lowest pasture growth coincided with early lactation ($P < 0.01$), when the herd had the greatest ME demand; therefore, conserved silage needed to be fed to meet herd demand. The JAN and OCT herds did not have sufficient pasture growth during early-mid and mid-late lactation ($P < 0.05$), when the herd demand was greatest, and also needed to rely heavily on pasture silage during this period to meet the herd energy demand; this resulted in the lower proportion of pasture in their total DMI.

Although the different timing of DM demand relative to supply in the different mean calving date systems was catered for by conserving surplus pasture as silage and feeding silage when demand exceeded supply, the nutrient composition and, in particular, the ME content of pasture silage is inferior to fresh pasture. Therefore, this asynchrony can explain some of the milk production difference between the treatment herds. In addition, however, the ME content of pasture also follows a sinusoidal pattern during the calendar year (Figure 4.2), in much the same profile as DM, peaking between August and October, and coinciding with the period of early lactation for the JUL herd. Therefore, when the demand of the herd was highest, the most pasture was available and available pasture had the most ME, crude protein, and the highest OM digestibility (Figure 4.2; Roche et al., 2009b). In other words, moving calving away from JUL (in the region where the research was undertaken) led to an asynchrony of pasture supply and pasture quality away from the peak nutrient demands of the cow.

Because of the greatest synchrony of nutrient supply and demand profiles in the JUL herd, they also had the greatest milk production, 4% FCM, fat, protein, and lactose yield (kg/cow; $P < 0.1$), in comparison with the other herds. This superior milk production is confirmation of the best synchrony between nutrient supply and demand, particularly with DM yield and the quality of pasture, in terms of ME, WSC, and crude protein concentrations through lactation (Figure 4.2; Roche et al., 2009b).

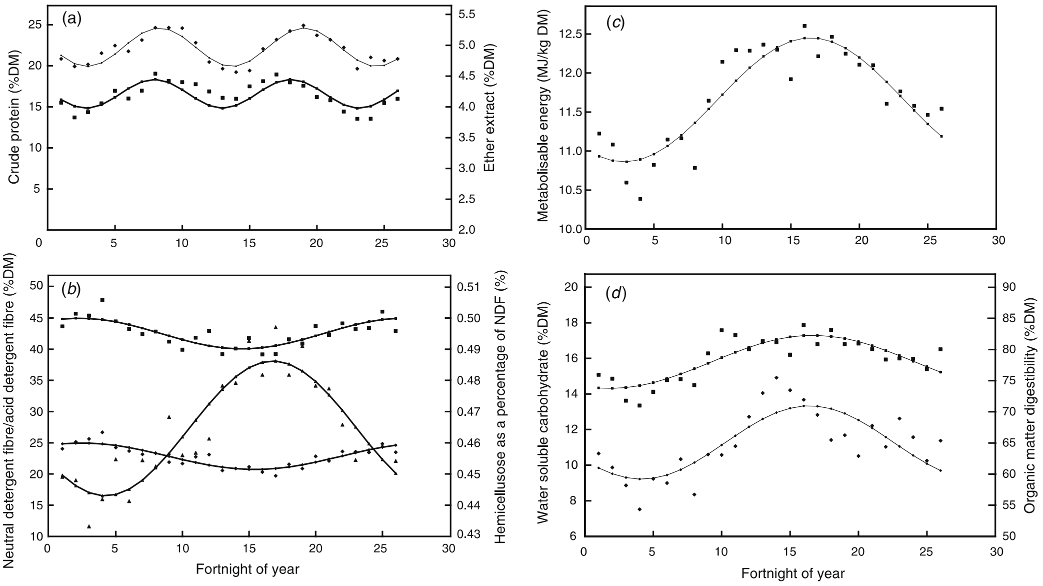

Figure 4.2 Change in a) crude protein (♦) and ether extract (■) concentrations; b) acid detergent fibre (♦) and neutral detergent fibre (NDF; ■) concentrations, and hemicellulose as a percentage of NDF (▲); c) metabolisable energy content (■); and d) water-soluble carbohydrate (♦) and organic matter digestibility (■) concentrations for the duration of the calendar year. Source: Roche et al. (2009b).

In Chapter 2, the results highlight the importance of monitoring and achieving target post-grazing residuals in future pasture quality and growth and it is an important aspect of matching feed supply and demand. Since the JER breed was satiated earlier than the HF (Chapter 2; L'Huillier et al., 1988); they tended to leave a higher post-grazing residual; this was an important breed x CSR interaction, as the HF breed at CSR100 grazed lower than the JER, particularly during the summer and autumn, which led to a cumulative reduction in annual pasture growth ($P < 0.05$) that materially impacted milk production per hectare (another breed x CSR interaction). Within the HF breed, at CSR100, milk yield, 4% FCM, fat, protein, and lactose per cow and per hectare was lower than at CSR80, which is consistent with Macdonald et al. (2008a), who defined optimum CSR as close to 80 kg BW/t feed DM. The HF-CSR100 herd produced more per cow than the JER-CSR100 herd, but yield of milk components per hectare was less.

In Chapter 3, I investigated the economics of a premium for milk supplied during the winter, between 16 May and 15 July, as historically there was little focus in NZ on the economics of changing mean calving dates for the herd. The equivalent to autumn calving is the APR calving herd, whilst for the Waikato region, spring calving is represented by the JUL herd. Economic stochastic modelling for the base scenario of no premium included in the milk payment (NZ$6.16/kg fat and protein) revealed the JUL calving herd was $960/ha more profitable than the APR herd, with the difference coming from the higher net milk revenue/ha (NZ$6,889 and NZ$5,990/ha, respectively). The APR herd had slightly lower operating expenses per hectare than the JUL herd (NZ$4,099 and NZ$4,142, respectively), with a small difference in the cost to conserve silage, (NZ$174 and NZ$245, respectively), as the JUL herd farmlet had a higher annual pasture yield.

The alternative scenario, which included an adjustment for the premium earned by supply of 'winter milk' resulted in an average milk payment variable of NZ$6.60/kg MS for the APR treatment and NZ5.97/kg MS for the JUL treatment, because of a downward adjustment in milk price for capacity adjustment (i.e., Fonterra reduce the average milk price to farmers that produce more milk at peak relative to winter). Even with the inclusion of a premium for milk supplied during the 16 May – 15 July period for the APR herd, when the JUL herd does not produce milk, the increased milk revenue per hectare for the APR herd was not sufficient to produce a higher gross farm revenue than the JUL herd. However, the difference between herds was reduced. With the alternative milk payment, milk revenue per hectare was NZ$6,418 and NZ$6,677 for the APR and JUL herd, respectively, and gross farm revenue was NZ$6,849 and NZ$7,211, respectively.

Therefore, under the alternative scenario, including a ‘winter milk’ premium, the JUL herd remained about 10% more profitable than the APR herd (NZ$3,069 and NZ$2,749 operating profit/ha, respectively).

In conclusion, interactions between breed and CSR, and the effect of changing the month of calving are important strategic factors to consider in animal and pasture management of the farm business, in order to maximise profitability. At CSR100, the JER breed was more profitable than the HF breed, whilst the opposite was true at CSR80. Mean calving date in July in the Waikato was more profitable than herds with mean calving date in January, April, or October, even with a premium for milk supplied during the winter months.

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Appendix I

Chapter 1 publication.

The paper 'Dairy cow breed interacts with stocking rate in temperate pasture-based dairy production systems' is to be published in the 101st volume, issue 5 of the Journal of Dairy Science 2018 by Spaans et al. I am first author on this publication. Due to copyright considerations, the journal paper has not been included in this version of the thesis. It is available for online access at

http://www.journalofdairyscience.org/article/S0022-0302(18)30182-6/fulltext

or

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Appendix II

Metabolisable energy calculations.

Metabolisable energy requirements for maintenance, activity, pregnancy, BCS change, and milk production were calculated using the equations outlined by the Primary Industries Committee on Agriculture (2007).

(1) Production (MEp) = kg milk * E/k_l

$E = 0.0381 * F + 0.0245 * P + 0.0165 * L$

$K_l = (0.02\ M/D) + 0.4$

Where F = Fat, g/kg; P = Protein, g/kg; L = Lactose, g/kg;
M/D = MJ ME per kg of feed DM

(2) Activity (MEa) = [C * DMI * (0.9-D) + 0.0026 * H] * W/k_m

$H = T * [(1/(0.057 * GF + 0.16)) + M]$

$k_{m=} (0.02 * M/D) + 0.5$

Where C = 0.0025 for cattle, DMI = dry matter intake from pasture (kg/day), D = digestibility of DM, GF = availability of green forage (t DM/ha), M = total distance walked each day from pasture to milking shed (km), T = 1.0 for level terrain.

(3) Maintenance (MEm) = K.S.M (0.28 * $BW^{0.75}$ exp(-0.03 * A)) / k_m + 0.1 * MEp + Mea

Where K = 1.4 for *B. Taurus*; S = 1.0 for females; M = 1 (weaned); W = BW, excluding conceptus (kg); A = age in years; k_m = efficiency of utilization of ME for maintenance.

(4) Pregnancy (MEpg) = 288/k_c * SBW/ 40

Where k_c = 0.133 (mean efficiency of use of ME for conceptus energy gain), SBW = scaled body weight (kg) of calf.

(5) BCS change (MEbcs) loss = N.B.C * 0.84 / k_l

gain = N.B.C / 0.35

Where N = MJ net energy per kg BW, B = BW in 1 unit BCS unit (0.0658 x BW), C = change in BCS (kg; i.e., loss or gain), 0.35 is the efficiency of use of ME from autumn pasture for BCS gain (Mandok et al., 2014)

Total ME required/cow (MJ ME/cow) was calculated by adding the results of each equation. These values were multiplied by the stocking rate (cows/ha) to calculate ME requirements/ha (MJ ME/ha).

Appendix III

Supplementary Table 1. Effect of dairy cow breed (Jersey; JER and Holstein-Friesian; HF) and comparative stocking rate[1] (CSR) on gross revenue (NZ$), operating expenses (NZ$), operating profit (NZ$), and cost of production (NZ$).

Breed	JER		HF		Expense category[2]	
Stocking Rate	CSR80	CSR100	CSR80	CSR100	Per cow	Per ha
Milk price[3]	$5.88	$5.85	$5.97	$5.96		
Revenue						
Net Milk sales/ha	6,870	7,059	6,578	6,218	100	0
Net Stock income	396	495	413	550	100	0
Income from surplus silage sales	86	0	47	0	0	100
Change in Dairy Livestock value	170	213	177	237	100	0
Gross Farm Revenue	7,522	7,767	7,216	7,005		
Expenses						
Wages	734	895	627	806	85	15
Labour Adjustment[4]	580	707	495	637	85	15
Total Labour Expenses	1,314	1,602	1,122	1,442		
Animal Health	313	384	265	344	90	10
Breeding & Herd Testing	202	250	176	228	95	5
Farm Dairy Expenses	69	83	60	76	75	25
Total Farm electricity	141	171	120	154	85	15
Total Stock Expenses	725	888	621	802		
Supplements purchased	0	250	0	234	100	0
Silage conservation	200	0	154	0	100	0
Calf Rearing (Excluding Labor)	40	50	34	45	100	0
Heifer & general grazing	74	93	62	83	100	0
Total Feed Expenses	315	394	249	361		
Fertilizer	389	389	389	389	0	100
Pasture Renovation	58	60	56	59	15	85
Weed and Pest	31	31	30	31	10	90
Farm Vehicle Expenses excl. fuel	179	210	158	193	65	35
Fuel & Oil	43	51	38	46	65	35
Repairs & maintenance	396	451	359	420	50	50
Freight/general farm working	56	63	50	59	50	50
Total Other Working Expenses	1,151	1,256	1,081	1,197		
Administration Expenses	110	117	106	113	20	80
Farm insurance	67	71	65	69	20	80
Rates - Land & water	150	159	143	154	20	80
Depreciation	355	404	322	376	20	80
Total Overheads	682.4	751.0	636.6	712.9	50	50
Total Dairy Operating Expenses	4,186	4,891	3,710	4,515		
Dairy Operating Profit[5]	3,336	2,876	3,505	2,490		
Expenses - cost/kg FCM	0.27	0.31	0.25	0.31		
Expenses - cost/kg MS	3.51	3.97	3.29	4.24		

[1]Comparative stocking rate (CSR) is a more complete measure of stocking rate and, therefore, feed allowance/cow; it accounts for the number of cows/ha (i.e., stocking rate), the BW of the cow (i.e., as a proxy for milk production potential), the pasture producing potential of the farm (t pasture DM/ha), the amount of supplement imported from off the farm (t DM/ha), and whether replacement stock are reared on the farm or on land remote from the milking platform (CSR = kg BW/t feed DM allowance; Macdonald et al., 2008).

[2] Percentage of each variable attributed to per cow and per hectare costs are presented.

[3]NZ$/kg fat and protein supplied. It differs for each treatment because the value of protein differs to the value of fat in component-pricing markets. Therefore, if breed or stocking rate affects protein % or fat %, it will affect milk price.

[4]Non-paid & Management

[5]Operating profit is the gross farm revenue less the operating expenses

Appendix IV

Supplementary Table 2. Average financial performance (NZ$) of benchmark dairy farms used in the economic modelling over the the three years 2012-13, 2013-14, and 2014-15. (n = 87 farms over 3 years; DairyBase, DairyNZ, Hamilton, NZ).

	$/ha	$/cow
Net Milk Sales	6465	2233
Net revenue from dairy livestock	381	135
Change in Dairy Livestock Value	162	58
Total Other Dairy Farm cash revenue	51	18
Dairy Gross Farm Revenue	7058	2444
Wages (incl. ACC, less subsidies)	579	207
Labour Adjustment - Non-paid	107	36
Labour Adjustment - Management	368	128
Total Labour Expenses	1055	372
Animal Health	246	87
Breeding & Herd Testing	158	56
Farm Dairy Expenses	57	20
Total Farm electricity	112	39
Total Stock Expenses	574	202
Supplements purchased, made & cropped	735	254
Feed Inventory Adjustment	8	2
Calf Rearing (Excluding Labour)	33	11
Total Supplement Expenses	760	264
Net heifer/General grazing	262	89
Net winter grazing	6	2
Net cost of leased runoff land	53	18
Owned Run-off Adjustment	29	10
Total Grazing & Run Off Expenses	349	119
Total Feed Expenses	1109	383
Fertiliser	375	133
Nitrogen	66	23
Total irrigation expenses	0	0
Total cost of Pasture Renovation	56	19
Weed and Pest	26	10
Total Farm Vehicle Expenses excluding fuel	147	52
Fuel & Oil	36	13
Repairs and maintenance – land/buildings	257	92
Repairs and maintenance	76	27
Freight/general farm working expenses	46	17
Total Other Working Expenses	1085	385
Total Administration Expenses	102	36
Total farm insurance	63	22
ACC	30	10
Rates - Land and water	136	48
Total Depreciation	311	108
Total Overheads	641	225
Total Dairy Operating Expenses	4463	1566
Dairy Operating Profit	2594	878

Appendix V

Supplementary Table 3. Effect of changing month of calving; base economic model using fixed values[1] for input variables milk price, meat price, urea price, cost to buy, sell and make silage, and pasture growth.

					Expense category[2]	
Treatment[3]	JAN	APR	JUL	OCT	/cow	/ha
Milk price	$6.60	$6.60	$5.97	$6.54		
Revenue						
Net Milk sales/ha	6,123	6,415	6,674	5,919	100	0
Net Stock income	423	396	387	339	100	0
Income from surplus silage sales	0	1	27	0	0	100
Gross Farm Revenue	6,546	6,812	7,088	6,258		
Expenses						
Wages	645	645	645	645	85	15
Additional cost feed supplement	7	1	0	7	85	15
Moving dry stock to feedpad[4]	3	3	9	0	85	15
Labour Adjustment[5]	509	509	509	509	85	15
Total Labour Expenses	1,165	1,158	1,164	1,162		
Animal Health	273	273	273	273	90	10
Breeding & Herd Testing	174	174	174	174	95	5
Farm Dairy Expenses	62	62	62	62	75	25
Extra days in milk	19	16	0	1	90	10
Total Farm electricity	124	124	124	124	85	15
Total Stock Expenses	651	648	632	633		
Supplements purchased	49	0	0	30	100	0
Silage conservation	197	116	125	203	100	0
Calf Rearing (Excluding Labor)	35	35	35	35	100	0
Heifer & general grazing	64	64	64	64	100	0
Total Feed Expenses	344	215	224	332		
Fertilizer	410	410	410	410	0	100
Nitrogen	176	176	176	176	15	85
Pasture Renovation	56	56	56	56	15	85
Weed and Pest	30	30	30	30	10	90
Additional farm vehicle and fuel[4]	7	1	0	7	65	35
Farm Vehicle Expenses excl. fuel	162	162	162	162	65	35
Fuel & Oil	39	39	39	39	65	35
Repairs & maintenance	365	365	365	365	50	50
Freight/general farm working	51	51	51	51	50	50
Total Other Working Expenses	1,297	1,290	1,289	1,297		
Administration Expenses	107	107	107	107	20	80
Farm insurance	65	65	65	65	20	80
Rates - Land and water	30	30	30	30	20	80
Depreciation	145	145	145	145	20	80
Additional depreciation effluent pond	6	7	0	1	20	80
Cost capital adjustment effluent pond	10	11	0	1	20	80
Total Overheads	363	365	347	349	50	50
Total Dairy Operating Expenses	3,819	3,675	3,656	3,772		
Dairy Operating Profit[6]	2,727	3,137	3,432	2,486		

[1]Input fixed values: Milk price = NZ$/kg fat and protein supplied, differs for each treatment because the value of protein differs to the value of fat in component-pricing markets. Includes winter milk calculations; Meat price = NZ3cents/kg; urea price = NZ$500/t; silage purchase = NZ$250/t DM; silage sale = NZ$150/t DM; make silage = NZ$100/t DM

[2]Percentage of each variable attributed to per cow and per hectare costs are presented.

[3]JAN = planned calving date of herd 10th January; APR = planned calving date of herd 10th April; JUL = planned calving date 10th July; OCT = planned calving date 10th October.

[4]If supplement was fed

[5]Non-paid and management

[6]Operating profit is the gross farm revenue less the operating expenses.

Appendix VI

Supplementary Table 4: Winter milk calculations used in milk price calculation for base economic model.

Treatment[1]		JAN		APR		JUL		OCT	
		kg	NZ$	kg	NZ$	kg	NZ$	kg	NZ$
Peak[2]	Fat	1,073	4,347	1,643	6,655	2,494	10,100	962	3,895
	Protein	879	7,117	1,281	10,374	1,911	15,475	705	5,709
	Adjustment[3]		-70		-70		-214		-98
	Total	1,952	11,394	2,924	16,959	4,404	25,361	1,667	9,507
Non-peak[4]	Fat	2,708	10,966	2,286	9,258	2,044	8,280	2,784	11,277
	Protein	1,959	15,871	1,638	13,267	1,467	11,883	2,043	16,551
	Adjustment		2,212		1,931		1,676		2567
	Total	4,667	29,049	3,924	24,456	3,511	21,839	4,828	30,094
Winter Premium									
Period 1[5]	Total	273	777	287	818			223	634
Period 2[6]	Total	255	892	300	1,052			238	801
Period 3[7]	Total	264	925	327	1,144			240	838
Period 4[8]	Total	269	765	323	916	12	36	234	666
	Penalty[9] 40km		-106		-124		-1.27		-92
	Total	1,060	3,252	1,236	3,806	13	35	925	2,847
Year		6,619	43,695	6,848	45,221	7,916	47,235	6,494	42,448

[1]JAN = planned calving date of herd 10th January; APR = planned calving date of herd 10th April; JUL = planned calving date 10th July; OCT = planned calving date 10th October.

[2] Peak months are September, October, November, December.

[3] Volume adjustments made based on Fonterra's average for year (NZ$ 0.0298) and peak months (NZ$ 0.0141). Capacity adjustment of NZ$ 0.51 /kg MS in non-peak months.

[4] Non-peak months are the rest of the months in a calendar year.

[5] 16-31 May at NZ$ 2.85 (North Island).

[6] 1-15 June at NZ$ 3.50 (North Island).

[7] 16-30 June at NZ$ 3.50 (North Island).

[8] 1-15 July at NZ$ 2.85 (North Island).

[9] Penalty of NZ$ -0.025 /10km in distance from factory.