Pasture growth curve impacts the economic merit of extended lactation: a simulation study

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Abstract
Voluntarily increasing the calving interval beyond 12-months (extended lactation; EL) has possible benefits in reducing labour requirements, herd replacement rate, and surplus calf numbers. With limited information on feed balance and economic effects with EL, reductions in profitability were hypothesised. A MS Excel spreadsheet model was developed to compare calving systems: spring calving annually (Base), two herds between spring and autumn calving with 18-month calving intervals (EL18), or two herds calving in alternating springs with 24-month intervals (EL24). Weekly feed balances using pasture growth curves for four regions (Northland, Waikato, Canterbury, Southland) and partial budget analysis informed estimations of supplement costs and net income (NI). The EL24 system had lower supplement costs (-$240 /ha) and higher NI (+$439 /ha) than the Base system for Northland only. The EL18 system always had the highest annual milk production and total revenue, but highest supplement costs and lowest NI in the four regions. Replacement, calving, and mating costs were lower for EL systems than Base; however, costs for milking and repairs and maintenance were higher. This preliminary study indicates there is merit in investigating EL systems, particularly for Northland. Further data from EL systems are needed to increase confidence in the system's potential.

Keywords: profit, winter milk, autumn calving, non-replacement calves

Introduction
Most dairy cows in New Zealand calve annually each spring with lactation length of up to 300 days (DairyNZ, 2021). The resultant timing of peak milk production and, therefore, feed demand synchronises with peak pasture growth in spring, while the 60-day dry (non-milking) period matches the timing of low pasture growth in winter. This synchrony of the feed demand profile of the herd with pasture growth curves is key to the relatively low feed costs and profitability of pasture-based systems (Macdonald et al. 2010; Neal and Roche 2019). However, the practice of 12-month calving intervals also results in challenges for the dairy industry. Firstly, the springtime calving and mating period is highly labour intensive, involving long working hours. These demanding working conditions make dairy farm roles less attractive and contribute to challenges in recruiting staff (Eastwood et al. 2020). Secondly, mating all cows in the herd and incoming heifers each year produces a surplus of calves which are neither required for herd replacement nor preferred by the beef industry (Edwards et al. 2021). Finally, the 12-month calving interval requires cows to get back in calf within approximately three months of calving, which usually contributes to higher than desired culling rates of non-pregnant cows.

Voluntarily extending the calving interval beyond 12 months (extended lactation; EL) is one approach to address these challenges through spreading labour requirements more evenly across the year, reducing the number of calves born, and providing a longer rest period between calving and mating, leading to improved conception outcomes (Borman et al. 2004). Proposed benefits also include reduced costs per cow for calving and mating, fewer non-lactating days per cow per year (Borman et al. 2004), and greater per cow longevity in the herd (Knight 1998). In New Zealand, a few farms practice whole-herd 18-month calving intervals, which requires autumn calving where synchrony between feed demand and pasture growth is lower compared with spring calving (Garcia et al. 2000). Some farms also retain some non-pregnant cows and continue to milk these animals past herd dry off to undergo an EL as a subset of the herd. A New Zealand pasture-based farm with the entire herd having repeated intentional EL with 24-month calving intervals has not been reported to date. A system with 24-month calving intervals and half of cows calving each alternate spring may address the industry challenges noted above while retaining synchrony between herd feed demand and pasture growth.

A previous New Zealand component study of EL compared local versus North American Holstein-Friesian genetics for responses to varying levels of supplement offered (zero to 6 kg DM/day of pelleted concentrate, Kolver et al. 2007). Average lactation

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lengths of 567 to 630 days were achieved across the groups and, with production lower in the second year, annualised total milksolids production was 87% of that produced during the first 296 days of lactation. A later New Zealand component study compared EL in cows fed pasture and silage only or offered additional concentrate over winter (Phyn et al. 2009). The timing of cow dry off was expedited by a severe summer drought in 2008 and cows reached average and maximum lactation lengths of 569, and 620 days, respectively. Annualised total milksolids production of cows fed pasture and pasture silage only was 91% of that produced in the first 300 days of lactation (Phyn et al. 2009). These results indicate that New Zealand cows can be capable of achieving EL suited to 24-month calving intervals at a viable level of milk production.

Farming with intentional 24-month calving intervals for the entire herd is a considerable change from current practice, and the implications for feed balance and profitability are not known. The objective of this preliminary study was to simulate regional-specific feed budgets and compare the profitability of dairy systems with contrasting calving intervals of 12 months, 18 months, or 24 months. Our hypotheses were that a 12-month calving interval would require less supplement feed and be more profitable than EL systems, and a system with 24-month calving intervals would require less supplement feed and be more profitable than a system with 18-month calving intervals.

Materials and Methods

The study approach was to first establish herd characteristics and production for each calving system, then estimate weekly feed demand and compare it with feed supply from pasture growth, then finally simulate feeding supplement during feed deficits and harvest of pasture for silage during surpluses. A partial budget analysis followed.

Herd and farm characteristics

The systems differing in calving interval were modelled in a MS Excel® spreadsheet simulation (Figure 1). The Base system calved 300 cows once annually in spring, with time of calving determined by the match of peak feed demand and pasture growth. The first EL system had two equal sized herds, each calving with 18-month intervals and the season of calving for an individual herd alternating between spring and autumn (EL18). The second EL system had two approximately equal sized herds with each herd calving in alternating spring times with 24-month intervals (EL24). Annual predicted feed demand per cow differed between calving systems, thus herd sizes varied so that total annual feed demand was maintained.

Weekly milksolids production data on a per cow basis were available from a previous New Zealand study where cows achieved a maximum lactation length of 623 days (Phyn et al. 2009). The available data included production from cows offered diets of either pasture and silage only or pasture and silage plus 4.7 kg/cow/day of pelleted concentrate offered. Data from cows offered pasture and silage only were used in the current modelling exercise (Figure 2). Cows in the EL24 system were modelled as having a maximum lactation length of 623 days, as the interval between start of calving and dry off (according to days in milk on a weekly basis), with a resultant average lactation length in the herd of 600 days. For the Base and EL18 systems, the milksolids production curve in Figure 2 was truncated to a suitable length so that the herds had a dry period of 11 weeks. Maximum lactation lengths of 280 and 470 days and average lactation lengths of 259 and 449 days were modelled for herds in the Base and EL18 systems, respectively.

The Base system had 300 cows on 100 ha where an early calving cow with a lactation length of 280 days produced 469 kg milksolids per year (Table 1). With culling (20%) and deaths (2%) applied during the production year (replacement rate of 22%, DairyNZ 2021), the annual milksolids production of the farm was 1,277 kg/ha. With fewer opportunities for health issues around calving and for cows to be diagnosed as non-pregnant, the EL systems were assumed to have lower annual replacement rates, though these differences have not previously been quantified and the rates used in this study were assumed by the authors. The annual milksolids production of the EL18 and EL24 systems determined the herd size applicable to maintain the same total annual feed demand. Annualised milksolids were mainly driven by differences in stocking rate, annualised days in milk, and culling rate. Annual replacement rates for farms in the EL systems were a result of higher replacement rates applied to each individual herd during a lactation. For example, in the EL24 system each of the two herds had their lactation spanning two years during which a herd-level replacement rate of 30% was applied, resulting in an average annual replacement rate of 15%. Similarly, a herd-level replacement rate of 27% was applied to the EL18 herd per lactation, resulting in a farm-level annual replacement rate of 18%. Dry cows were kept on-farm for all systems and replacement heifers were grazed off-farm until joining the mixed-age herd prior to their first calving. Weekly cattle feed energy demand (megajoules of metabolisable energy, MJ ME, Figure 3) was estimated from milk production, an average liveweight of 500 kg, and equations from Nicol and Brookes (2007).

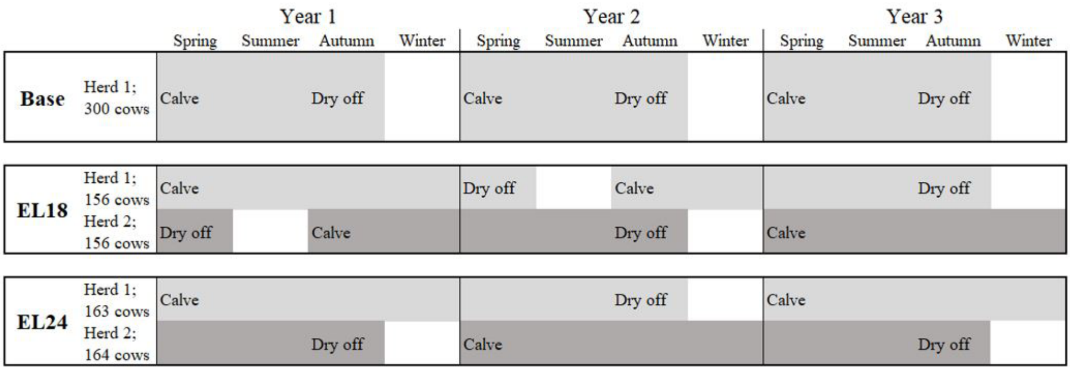

Figure 1 Timing of calving and dry off for three calving systems: spring calving annually (Base), two herds alternating between spring and autumn calving with 18-month intervals (EL18), or two herds calving in alternating springs with 24-month intervals (EL24).

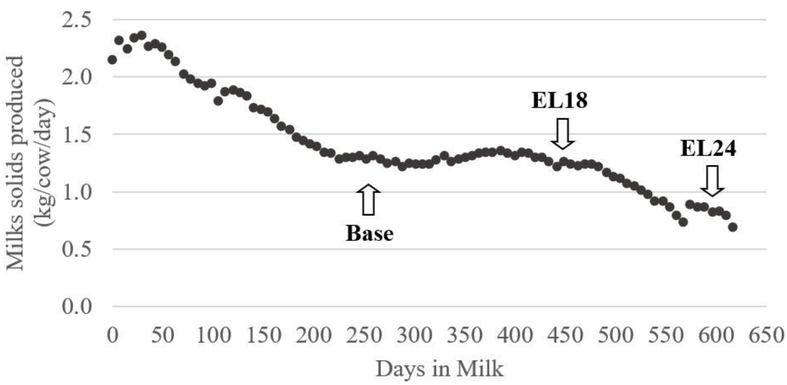

Figure 2 Milk production curve populated with data from Phyn et al. (2009) which informed modelling of the calving systems where arrows indicate the average lactation lengths of 259 (Base), 449 (EL18), or 600 (EL24) days.

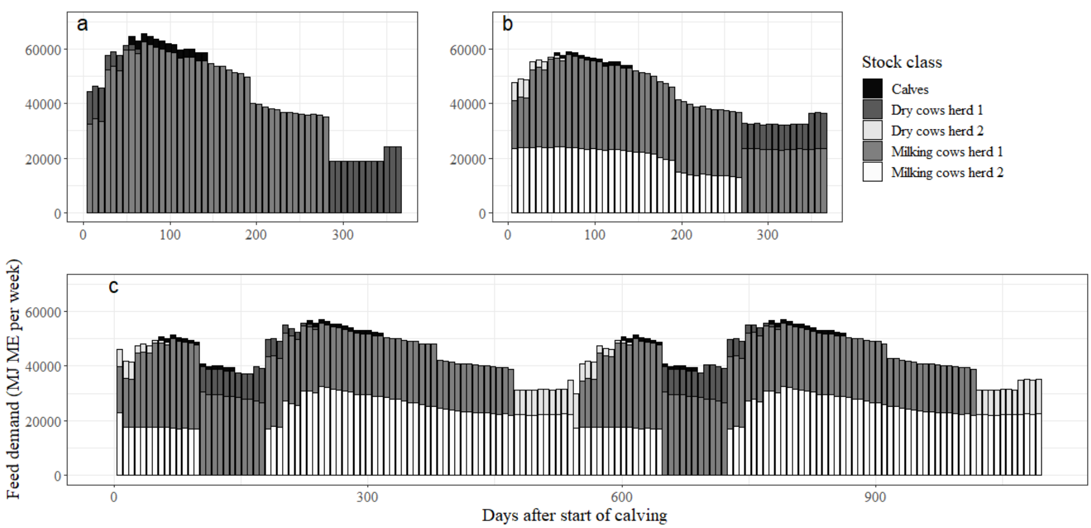

Figure 3 Feed energy demand (MJ ME/week) of various stock classes on-farm for scenarios comparing calving systems with a) 12-month calving intervals (Base) simulated over one year, b) 24-month calving intervals (EL24) simulated over one year, or c) 18-month calving intervals (EL18) simulated over three years due to inter-year variation in calving timing.

Table 1 Key model inputs for scenarios comparing calving systems with 12- (Base), 18- (EL18), or 24- (EL24) month calving intervals.

Calving system	Base	EL18	EL24
Cow numbers	300	312	327
Stocking rate (cows/ha)	3.0	3.1	3.3
Milksolids production (kg/cow/lactation)	469	720	867
Milksolids production (kg/ha/year)	1,277	1,330	1,301
Feed demand (t DM/cow/year)	4.74	4.54	4.34
Feed demand (t DM/ha/year)	14.2	14.2	14.2
Annual replacement rate (%)	22	18	15

Feed supply and balance

Pasture yield was based on four region-specific monthly dairy farm seasonal average pasture growth curves from multiple years: Northland, Waikato, Canterbury, and Southland, with data from Dargaville, Scott Farm, Lincoln University Research Dairy Farm, and Edendale, respectively (DairyNZ 2020). Region-specific pasture growth data were each combined with New Zealand average dairy farm monthly pasture quality data (Ministry for Primary Industries, 2020) to estimate ME feed supply from pasture. An adjustment factor was then applied so that total annual pasture yield was equal to 90% of total annual feed demand of the Base farm, making the farm a medium-input system and standardising the feed supply between regions for simplicity. The production year began with the start of calving and an average pasture cover (APC) of 2,100 kg DM/ha (Bryant 1990). Weekly feed supply from pasture and feed demand from cattle were used to estimate a feed surplus or deficit, which was converted to kg DM/ha and then added or subtracted from the previous week's APC. The weekly APC was maintained between 2,000 and 2,400 kg DM/ha across the year through adding or subtracting feed in multiples of 100 kg DM/ha to simulate supplement fed out or pasture conservation. This simulation of APC provided estimates of the timing and quantity of feed manipulation required for the different regional pasture supply and calving interval systems. The calendar date for planned start of calving was assumed to differ between regions and was set so that both maximum and minimum pasture growth and feed demand for the Base system were aligned (Figure 4). As shown in Figures 1 and 3, the Base and EL24 farms are both spring calving and weekly feed demand was therefore consistent between years, so for these scenarios APC was simulated over one year; whereas for EL18, APC was simulated for three years to capture inter-year variation in calving timing and weekly feed demand. For EL18, total supplement fed and pasture conserved for the three years were averaged to an annualised value. This simple approach to representing supplement feeding enabled comparisons of feed balance and supplement feed costs between treatment systems. However, it did not take into account differences in methods for increasing feed supply practised between regions, such as choice of supplement, forage crops, or impacts of management and regional-specific conditions on pasture quality. Differences between calving systems in the timing and quantity of supplement feed requirements for each regional pasture growth curve would be addressed in a wide variety of ways between farms and this level of detail was outside the scope of the current preliminary study.

Economics

Total revenue (income from sales) was estimated using farmgate net prices of $6.80/kg milksolids, $900/cull cow, and $25/non-replacement calf. Total revenue and operating costs (those assumed to differ between the modelled calving systems) were included in the partial budget analysis for estimations of net income as a profitability indicator, with economic values informed by DairyBase data (DairyNZ 2022). Pasture conservation and feeding out were assumed to cost $200 /t DM in total and bought-in supplement fed out was assumed to cost $500 /t DM. Costs for calving (labour), heat detection (labour and tail paint), and breeding (labour and artificial insemination) were first estimated for the Base system, each of these costs were then multiplied by 0.8 and 0.67 for the EL18 and EL24 systems, respectively. A proportion of these costs were assumed to be fixed with inherent inefficiencies, i.e., it was assumed that halving the calving costs (when shifting from Base to EL24 with approximately half the number of cows calving each year) would not be realistic. Costs for replacement heifers were assumed to be $1700 /head. Costs for milking (labour and farm dairy) and repairs and maintenance (tracks, fences, machinery, farm dairy rubberware, etc.) were estimated on a per milking day basis, where milking days were determined from lactation lengths for each calving system.

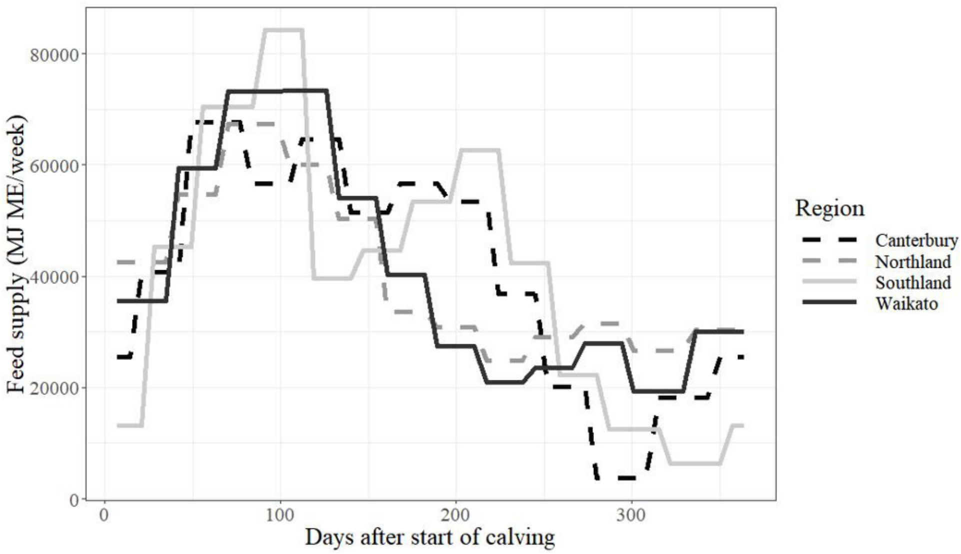

Figure 4 Weekly feed energy supply (MJ ME) from pasture based on four regional-specific pasture growth rate data sets, with an overall average curve fitted.

Results

Total revenue was highest for EL18 ($9,498 /ha) compared with the Base ($9,242 /ha) and EL24 ($9,221 /ha) systems, driven by increased revenue from milk sales (Table 2). Replacement, calving, and mating costs were lower for EL systems than Base, however, costs for milking and repairs and maintenance were higher. Supplement feed costs for each calving system varied between regions due to differences in pasture growth curves modelled. Supplement feed costs and net income from the partial budget analysis are discussed in the following subsections within the context of the feed balance modelling.

Northland

For the Northland pasture growth curve, the EL24 system required less supplement fed out during early lactation, summer, autumn, and overall compared with the Base system (Table 2, timing of supplement feeding and pasture conservation not shown). For EL24, APC peaked in early spring, but peaked in autumn for the Base system. Overall, the EL24 system required less intervention to maintain APC compared with the Base system and Northland was the only regional pasture growth curve modelled where EL24 had the lowest supplement feed costs and highest net income (+$439 /ha or +9% compared with Base, Table 2). The EL18 system during the first two years required the most intervention of the three calving systems modelled to maintain APC (i.e., greater supplement feeding and pasture conservation, Table 2). The first two years modelled for EL18 had both spring and autumn calving (Figure 1). The third year for the EL18 system had only a spring calving and a similar level of intervention was required to maintain APC compared with the other calving systems. Northland also had the smallest reduction in net income (-$160 /ha) for EL18 compared with other regions (Table 2).

Waikato

The EL24 system in the Waikato required more pasture conservation than the Base system in spring and more supplement fed out over the summer and autumn, with similar total purchased supplement (Table 2). Net income was slightly lower (-$31 /ha or -1%) for EL24 compared with the Base system (Table 2). The timing of peak APC occurred at 100 days after start of calving in spring for both the Base and EL24 systems. The EL18 system required more pasture conserved and supplement fed out to maintain APC than the other systems, resulting in almost double the supplement feed costs and $707 /ha lower net income than the Base system (Tables 2 and 3).

Canterbury

Compared with the Base system, EL24 in Canterbury required more pasture conservation in late spring and early summer, with more supplement fed out in autumn and winter when Canterbury pasture growth was low (Figure 4). The EL18 system required substantially more intervention to maintain APC compared with

Table 2 Pasture conserved and supplement fed out (kg DM/ha/year), revenue, costs, and net income ($/ha) for scenarios comparing calving systems with 12- (Base), 18- (EL18), or 24- (EL24) month calving intervals with varying pasture growth curves.

Measure	Region	Base	EL18	EL18 vs. Base	EL24	EL24 vs. Base
Pasture conserved	Northland	300	1,133	+833	100	-200
	Waikato	300	1,867	+1,567	700	+400
	Canterbury	200	1,867	+1,667	700	+500
	Southland	900	2,133	+1,233	1,300	+400
Bought-in supplement fed out	Northland	1,900	2,567	+667	1,500	-400
	Waikato	1,800	3,267	+1,467	2,100	+300
	Canterbury	1,600	3,267	+1,667	2,100	+500
	Southland	2,300	3,567	+1,267	2,800	+500
Milk sales revenue		8,680	9,047	+367	8,846	+166
Livestock sales revenue		562	451	-111	375	-187
Total revenue		9,242	9,498	+256	9,221	-21
Calves and replacements costs		1,155	974	-181	845	-310
Mating (labour and breeding) costs		314	215	-99	202	-112
Calving (labour) costs		214	171	-43	144	-70
Milking (labour and dairy) costs		1,075	1,268	+193	1,338	+263
Repairs and maintenance costs		599	645	+46	608	+9
Supplement feed costs	Northland	1,010	1,510	+500	770	-240
	Waikato	960	2,007	+1,047	1,190	+230
	Canterbury	840	2,007	+1,167	1,190	+350
	Southland	1,330	2,210	+880	1,660	+330
Total costs	Northland	4,367	4,783	+416	3,907	-460
	Waikato	4,317	5,280	+963	4,327	+10
	Canterbury	4,197	5,280	+1,083	4,327	+130
	Southland	4,687	5,483	+796	4,797	+110
Net income	Northland	4,875	4,715	-160	5,314	+439
	Waikato	4,925	4,218	-707	4,894	-31
	Canterbury	5,045	4,218	-827	4,894	-151
	Southland	4,555	4,015	-540	4,424	-131

Base and EL24 (Table 2). Of the four regional pasture growth rates modelled, EL18 in Canterbury had the largest increase in supplement feed costs (+$1,167 /ha from Base) and largest reduction in net income (-$827 /ha from Base, Table 2). The reduction in net income compared with the Base system was relatively smaller for EL24 (-$151 /ha).

Southland

The EL24 system in Southland required more pasture conserved and supplement fed out to maintain APC compared with the Base system (Table 2). The timings of supplement fed, pasture conserved, and peak APC were similar between Base and EL24 systems, with peaks in APC in both late-spring and late-summer, reflecting the Southland pasture growth curve having two peaks (Figure 4). The relative reduction in net income from the Base was similar for the EL24 system in Southland and Canterbury (both -3%, Table 2). The EL18 system had greater quantities of pasture conserved and supplement fed out compared with the Base system in Southland, resulting in higher feed costs (+$880 /ha) and lower net income (-$540 /ha, Table 2).

Discussion

The partial budget analysis in this study predicted the EL systems to have the highest net income with the Northland pasture growth curve compared with the other explored regions. The improved net income of the EL24 system over the Base system in Northland exceeded expectations. The analysis supported the hypothesis that the Base and EL24 systems would financially outperform the EL18 system.

The lower annual supplement feed requirements and higher net income of EL24 compared with the Base system in Northland were due to the smaller variation between peak and nadir pasture growth, which was similar to the feed demand profile of the EL24 system (Figure 3). The suitability of the EL24 system for the Waikato pasture growth curve was also promising in this analysis, with moderate winter pasture growth and the resultant small (1%) reduction in profit compared with the Base system. In contrast, for the South Island pasture growth curves where winter pasture growth was low, the higher winter feed demand of EL24 compared with the Base system reduced its suitability, indicated by supplement feed costs and net income (Figure 4).

The modelled EL18 system had calving timing for each herd alternating between spring and autumn. Autumn calving results in herd peak feed demand occurring at a different time of year to peak pasture growth. A recent modelling study by Chikazhe et al. (2017) compared spring, autumn, and split spring and autumn calving systems with 12-month intervals, finding that autumn calving could be more profitable than spring calving for Waikato and Northland pasture growth curves. This was mainly due to milksolids produced during winter being sold for a premium price (an additional price of ≥ $2.85/kg MS over the season's general milk price). The current study did not assume a premium price for winter milk or higher prices for cull cows outside of typical supply timings, which would economically favour the EL systems in comparison with the Base system. Winter milk premium contracts are not available to all farmers in all regions and may not be available in a future scenario with wide adoption of EL and/or high incidence of winter milking in the sector.

With the winter period consistently requiring more supplement feeding for the EL24 and EL18 systems compared with the Base system, off-paddock structures to support feeding of supplements during winter milking may be required for EL. The costs for off-paddock structures can have a large negative effect on profit (Chikazhe et al. 2022) and these were not included in the current analysis. Wintering practices (and their requirements) vary between and within regions in New Zealand. The merits of differing winter practices for EL systems could be explored in a future analysis.

The milk production predictions in the current study were based on available New Zealand data from cows undergoing EL without high levels of non-pasture supplement (Phyn et al. 2009). The data provided confidence in estimating potential production and lactation length achievable for New Zealand cows in a pasture-based system with relatively low purchased feed inputs. However, the primary goal of the Phyn et al. (2009) study was not an exploration of the potential of EL, and the study was cut short with expedited dry off due to the 2008 Waikato drought. The current study assumed that feeding and cow suitability for EL in New Zealand is biologically feasible and that cows in an EL24 system are capable of a herd average lactation length of 600 days. An EL24 system where cows require high levels of intensive supplement feeding or achieve much lower milksolids production and lactation lengths than modelled would clearly compromise the system's profitability. While the previous EL data which informed the current modelling are promising, accuracy for prediction could be improved with any data obtained in the future from cows in an intentional EL farm system with 24-month calving intervals. This study provides sufficient simulation evidence to justify the implementation of an EL24 system to provide such empirical data.

The calving systems compared in this study were modelled with differing replacement rates. Herd replacement rate on a per lactation basis was higher for the EL systems, with assumed culling of some cows that self-dried off early as well as maintaining realistic death rates and animal health issues (i.e., not halved for the EL24 system compared with the Base system). This translated to a lower annual replacement rate for EL systems, with involuntary culling of empty cows and calving-related mortality assumed to be lower than for the Base system. Suitable annual replacement rates for EL systems are not certain but can be assumed be lower than for typical 12-month calving intervals, resulting in positive effects for milk production from greater cow longevity and an older age structure in the herds (DairyNZ 2021). Further, with potentially lower incidence of involuntary culling of empty cows, there is more opportunity to cull undesirable problematic cows (e.g., those with high SCC, lameness, etc.). In addition, greater selection pressure could be applied to traits other than reproduction, which may improve overall performance due to a higher rate of genetic gain in productivity traits. The dynamics between genetic gain and cow lifetime productivity have not been accounted for in the current analysis and may favour the performance of the EL systems.

The current study assumed a moderate amount of imported supplement for all modelled calving systems, with homegrown pasture meeting 90% of total annual herd feed demand. This assumption was plausible due to the milk production data used originating from cows in EL fed only pasture and pasture silage (Phyn et al. 2009). Previous New Zealand studies of EL have compared the effect of the level of supplementing New Zealand cows in EL each with 3 or 6 kg DM/day of pelleted concentrate (totalling 1,817 to 3,123 kg DM per cow over the lactation) increased milksolids production by up to 21% (Kolver et al. 2007). However, increased rate of supplement feeding did not guarantee increased milksolids production or lactation length. Phyn et al. (2009) found that cows in EL fed 4.7 kg DM/day of maize-barley concentrate pellets (totalling to 544 kg DM per cow over 123 days) produced 14% more milksolids over the lactation compared with those fed only pasture and pasture silage. Lactation length comparisons were compromised by early dry off due to drought conditions, however per cow daily milksolids production was similar between the diets in the weeks leading up to dry off. Some improvement in milksolids production of cows in EL from feeding a high-quality supplement is evident from these studies, while the benefit for lactation length is not. Overall, the requirement for intensive supplement feeding to achieve EL has not yet been demonstrated and the economic merit of doing so needs to be investigated.

Detail of variation in farm systems and economics between regions was not included and thus general comparisons of dairy system feed balance and profitability in the different regions based on this study are not valid. The simple approach for modelling the feed balance imposed inflexible limits on APC which resulted in pasture conservation at atypical times of year. In reality, pasture surpluses would be addressed differently between farms and regions, including later culling or with cropping. Additional detail which could be added in a future analysis of EL calving systems include stocking rate, quantities and costs for imported feed and forage crops, pasture topping as a mitigation for high APC, youngstock and winter grazing, timing of culling, and use of off-paddock infrastructure. From the results of the current study, a more detailed analysis would be warranted for EL24 systems and for the North Island pasture growth curves with region specific data. Such factors could include pasture quality, pasture growth curves from years with contrasting climatic conditions, a lower stocking rate than 3 cows/ha (DairyNZ 2021), homegrown maize silage, and/or grazed crops.

Conclusions

This feed balance and partial budget analysis of calving systems suggested the EL system with spring calving at 24-month intervals was most profitable in the North Island, particularly in Northland where winter pasture growth was highest, and the net income exceeded that of the Base 12-month spring calving system. At this time, the modelled 24-month calving interval system remains an unproven concept and the results suggest further investigation in modelling and empirical data collection is warranted, particularly for farm systems with pasture growth curves similar to Dargaville and Ruakura. Collection of empirical data would provide more confidence in the worthiness of a pasture-based EL24 system and improve predictions from modelling.

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