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Reducing milking frequency from twice each day to three times each two days affected protein but not fat yield in a pasture-based dairy system

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ABSTRACT

Milking 3 times in 2 d (3-in-2) could enhance the attractiveness of the dairy workplace relative to twice-a-day milking (TAD) by reducing labor requirements for milking and increasing workforce flexibility. The objective of this study was to quantify the farm system interactions associated with milking 3-in-2 at 3 stages of lactation, with the aim of providing guidance to pasture-based dairy farmers and advisors on the likely consequences of adopting 3-in-2 milking on farm productivity and business performance. Seventy-nine multiparous and 37 primiparous cows were randomly allocated to 4 experimental farms stocked at 3.5 cows/ha. One herd was milked TAD for the whole lactation (August 2019 to May 2020), with the remaining 3 milked 3-in-2 for either the whole lactation, after December 1 when cows were an average of 101 d in milk, or after March 1 when days in milk averaged 189 d. Milking intervals over 48 h were 10-14-10-14 h for TAD and 12-18-18 h for 3-in-2. Animal, pasture, and farm system data were analyzed by linear regression, with the dependent variable being the annualized value of the performance metric of interest, and the number of days in the lactation milked 3-in-2 as the independent variable. For the proportion of the season milked 3-in-2, there was a significant effect on milk (−11%), protein (−8%), and lactose (−12%) yield per cow per year, but no effect of fat. Additionally, there was a positive effect (+6%) on body condition score before dry-off and the energy required for liveweight change (+26%), and a negative effect on the energy required for walking (−30%). There were no differences in estimated feed eaten, or pasture herbage accumulation, composition, or quality. Therefore, pasture management and feed allocation under 3-in-2 should be similar to TAD. On commercial farms, the degree to which reduced milk income can be offset by lower costs will be highly farm-specific, but opportunities for savings were identified in the results. The short walking distances on the research farm and potential to improve farm management using the time saved from fewer milkings suggests better production may be achieved with 3-in-2 milking on a commercial farm.
Key words: milking interval, labor, workplace, farm systems

INTRODUCTION

Increasing the attractiveness of dairy farm workplaces is a challenge for many major dairy nations (DairyNZ et al., 2017; Teagasc, 2018). Milking has a strong influence on 2 aspects of the workplace in pasture-based dairy farm systems where cows are typically batch milked twice a day (**TAD**). This milking frequency is likely chosen over more frequent milking used in other production systems or with robotic milking because the cost of the additional milkings are greater than the additional production (Culotta and Schmidt, 1988).

Batch milking cows TAD requires significant time in the work day, with estimates of 30 to 34% of annual labor hours in Ireland (Deming et al., 2018). In New Zealand, dairy farm workers average 19 h/wk milking from first cluster on to last cluster off at peak lactation (not including herding or parlor cleaning time), which is approximately half of a standard 40-h work week (Edwards et al., 2020). Second, milking determines work schedule start and end times, potentially creating long work days and work at undesirable hours, for example before 0500 h (Edwards et al., 2020). Widespread adoption of alternatives to TAD, with fewer milkings, have been limited by farmer concerns primarily related to milk production and profitability (Edwards, 2018a).

Milking once-a-day (**OAD**) is one option to reduce labor requirements and increase flexibility because milking can occur at any time during the day. In a recent survey, OAD was associated with less time spent milking per worker, by 9.5 h/wk, at peak lactation compared with TAD (Edwards et al., 2020). The concept of milking OAD is not new (Claesson et al., 1959).

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However, the majority of studies have investigated short-term or part-lactation effects of a 24-h milking interval (Stelwagen et al., 2013), and lactation yields necessary for system evaluation are rarely reported, notable exceptions being Phyn et al. (2014) and Kennedy et al. (2021). Comparatively few have investigated OAD over a full lactation (Clark et al., 2006; Dalley et al., 2008). From a workplace perspective, full-lactation use of OAD offers the greatest opportunity to reorganize on-farm labor.

An analysis of commercial herds that have adopted full-lactation OAD indicated that, on average, there was an 11% decrease in the kilogram of fat + protein (milk solids; **Ms**) produced per herd following switching from TAD to OAD (Edwards, 2018b). Further analysis revealed that this decrease was influenced by the pre-OAD level of milk production (kg of Ms/cow), with a smaller effect of switching seen in herds producing ≤300 kg of Ms/cow and a greater effect in herds producing 351 to 400 kg of Ms/cow. There were few herds producing >400 kg of Ms/cow in that data set that had adopted OAD. To retain an equivalent level of profitability, farm costs must permanently reduce on the adoption of OAD milking by the proportional decrease in milk production multiplied by the milk price (Edwards, 2018b). For herds producing >350 kg of Ms/cow, assuming a goal of maintaining profit, OAD is a difficult option to justify without a significant reduction in costs, which may erode potential advantages for workplace attractiveness (Edwards, 2018a).

Component research has determined that milk secretion is linear up to ~16 h postmilking, with variation between cows (Turner, 1955; Elliott et al., 1960; Wheelock et al., 1966; Davis et al., 1998). This knowledge supports potential options such as milking 3 times in 2 d (**3-in-2**), to achieve some of the benefits of OAD without the expected loss of production for higher producing herds. However, the use of equal 16-16-16 h intervals results in a late-night milking; therefore, the use of uneven intervals, with some longer than 16 h (to prevent a night milking), is more likely to improve workplace attractiveness.

Previous research on 3-in-2 has been limited, with only 2 published studies identified. Eldridge and Clark (1978) reported that milking 3-in-2 with a 10-19-19 h interval reduced milk production (kg of milk/cow) by 11% when introduced at wk 20 of lactation or by 18% when initiated at wk 4. On the other hand, Woolford et al. (1985), using an 11-18.5-18.5 h interval over a full lactation, reported an 8% decrease in milk, a 6% decrease in milkfat per cow, and an increase in liveweight and body condition. However, since these studies were conducted, there has been considerable genetic selection for milk production as well as farm system changes (LIC and DairyNZ, 2020). Further, Eldridge and Clark (1978) only evaluated effects on milk production, whereas Woolford et al. (1985) also included liveweight and body condition. In a pasture-based dairy system, interactions between animal production and pasture production exist (Macdonald et al., 2008). With reduced milking frequency, there may be changes in DMI (Holmes et al., 1992) that, combined with less time spent milking and more time spent in-paddock, may affect (positively or negatively) grazing intensity and correspondingly pasture grown, pasture quality, or pasture harvested.

The objective of the present study was to quantify the farm system trade-offs that may occur when milking 3-in-2, with a 12-18-18 h milking interval, at 3 stages of lactation. To explore this objective, 4 experimental farms (farmlets) were established as follows: (1) herd milked TAD for the whole lactation; (2) herd milked TAD for the first 7 mo of lactation, then switched to 3-in-2; (3) herd milked TAD for the first 4 mo of lactation then switched to 3-in-2; and (4) herd milked 3-in-2 for the whole lactation. Pasture production and quality, milk production, and characteristics were measured. The information provided by this study allows pasture-based dairy farmers and advisors to make informed decisions and recommendations about the potential effects of adopting 3-in-2 milking on farm production and business performance.

MATERIALS AND METHODS

Experimental Site and Design

The experiment was carried out at the Lincoln University Research Dairy Farm (43°38′23″S 172°27′2″E, 10 m above sea level), Lincoln, New Zealand, between June 2019 and May 2020. A 32.6-ha area of the farm was divided into 44 paddocks of approximately 0.75 ha. Paddocks were blocked for management history, soil fertility status, and pasture type (predominantly perennial ryegrass) and randomly allocated to 4 farmlets, each with 11 paddocks. The area was irrigated via center pivot and sprinklers in accordance with soil moisture levels. A total of 450 mm of rain fell during the experimental period, which was supplemented with an additional 368 mm of irrigation. Monthly totals for rain and irrigation were 59, 68, 50, 32, 55, 94, 114, 106, 112, 77, 28, and 23 mm starting with June 2019 and ending with May 2020. Penman-Monteith evapotranspiration values for the same period were 19, 25, 40, 58, 84, 132, 153, 152, 121, 87, 62, and 32 mm.

Farmlet herds were milked according to the following schedule (the experimental treatments). Herd 1 (**FS-TAD**) was milked TAD at approximately 0600 and

1540 h each day of the lactation. Herd 2 (**late-3-in-2**) was milked TAD at approximately 0540 and 1520 h each day until March 1, 2020 (mean DIM 189 d), when it was moved to the 3-in-2 milking schedule at 0540, 1740 (on d 1), and 1140 (on d 2) h. Herd 3 (**mid-3-in-2**) was milked TAD at approximately 0520 and 1500 h each day until December 1, 2019 (mean DIM 101 d), when it was moved to the 3-in-2 milking schedule at 0520, 1720 (on d 1), and 1120 (on d 2) h. Herd 4 (**FS-3-in-2**) was milked 3-in-2 at approximately 0500, 1700 (on d 1), and 1100 (on d 2) h for each day of the lactation. This equated to a 10-14 h interval for TAD and 12-18-18 h interval for 3-in-2. A date-based switch-point for herds 2 and 3 was chosen over a production-based trigger as it was considered more valuable to farmers for work-force planning because milking labor requirements are known from the outset of the season. The date-based switch-points were also chosen to provide a range of durations of 3-in-2 milking to enable the results to be analyzed by regression. A timeline of treatments is illustrated in Figure 1.

On March 25, 2020, the New Zealand Government placed the country in a nationwide lockdown in response to the COVID-19 pandemic, which allowed only essential workers to leave home for work. In the context of this experiment, this placed pressure on the availability of farm labor, and, as a result, the milking times were adjusted on April 3, 2020, to minimize workload. Herd 1 was milked with an alternating 9-15 h interval (on d 1) and 8-16 h interval (on d 2). Herds 2, 3, and 4 were milked with a 9-21-18 h interval. On May 5, 2020, all herds switched to OAD milking as part of standard drying off practice for the farm.

Each farmlet consisted of 8.2 ha of perennial ryegrass–dominant pasture and 29 cows, giving a stocking rate of 3.5 cows/ha. Before the experiment, 116 predominantly Holstein-Friesian cows (79 multiparous and 37 primiparous) were randomly allocated to the 4 farmlets. Before allocation, multiparous cows were blocked for age, genetic merit, expected calving date, BCS, and liveweight at the end of the previous lactation, as well as the previous lactation DIM, milk weight, and Ms yield. Primiparous cows were blocked by liveweight and genetic merit. The planned start of calving was August 1, 2019. Before calving, in spring and during dry-off in autumn, cows that were not lactating were run in a single combined herd that rotationally grazed a similar area of the 4 farmlets. As cows calved, they were transferred to a single “colostrum” herd before transfer into their treatment herd after clearing their milk-withholding period. During the spring calving period, a total of 6 cows were replaced for reasons not attributable to experimental treatment; 3 died during calving, 1 failed to produce milk, 1 had Johne’s disease,

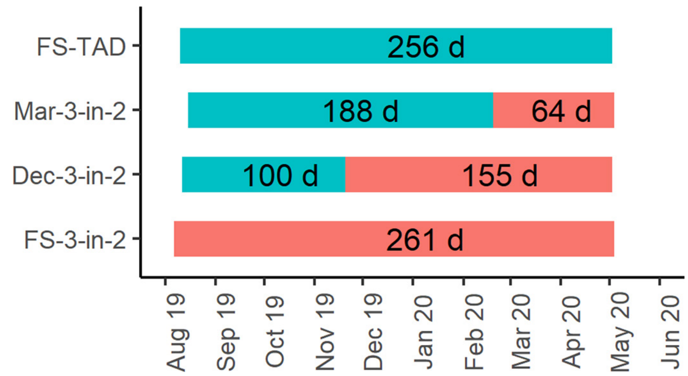

Figure 1. Timeline of milking frequency by herd; cows milked twice a day (TAD; blue) or 3 times in 2 d (3-in-2; red). Labels are average days of each milking frequency from mean calving date to mean herd removal or dry-off date. FS-TAD was milked TAD at approximately 0600 and 1540 h each day of the lactation. FS-3-in-2 was milked 3-in-2 at approximately 0500, 1700 (on d 1), and 1100 (on d 2) h for each day of the lactation.

and 1 had significant unexplained weight loss. Replacement animals were matched as closely as possible to the blocking groups of the animals they replaced.

Animal Data Collection

All animal measurements were approved by the Lincoln University Animal Ethics Committee, under application number 2019–05.

Cows were milked in a 12-aside double-up herringbone equipped with milk meters and walk-over weigh scales (DeLaval). Cow identification, identification time, milk yield (kg), milking duration (s), and average milk flow rate (kg/min) were recorded by the herd management software (DelPro, DeLaval) at each milking session.

Milk composition was analyzed (for fat, protein, lactose, SCC, and milk urea) at fortnightly intervals throughout lactation (CRV Ambreed) using a Combi-Foss milk analyzer (Foss Electric). Each fortnight, a sample of 20 mL was collected into bronopol-containing tubes from each individual cow. When the herd was milked with the TAD milking frequency, a morning and afternoon sample was collected in a 24-h period, and for herds milked 3-in-2, morning, afternoon (on d 1), and mid-morning samples (on d 2) were collected in a 48-h period. During the COVID-19 lockdown period, milk samples were not collected, resulting in 4 wk without milk composition data between late March and late April.

Body condition score was recorded for all cows monthly using a 10-point scale as described by Roche et al. (2009). Animal health treatments were recorded and grouped into lameness, clinical mastitis, and other, which included teat-wounds, milk fever, grass staggers, and fly strike.

Metabolizable energy requirements were estimated using equations provided by Nicol and Brookes (2007). Daily liveweight (**LWT**; kg) data were used to estimate requirements for maintenance and liveweight change. Metabolizable energy for maintenance (ME_m) was calculated using the equation $ME_m = 1.5 \times 0.28 \times e^{(-0.03 \times \text{age in years})} \times LWT^{0.75}/k_m$, where k_m = ME concentration of the feed × 0.02 + 0.5. Liveweight gain (**LWG**; kg) was calculated using the equation

$$ME_g = 1.1 \times (0.92 \times LWG) \times \left[\left(6.7 + \left\{\left[(920 \times LWG)/(4 \times SRW^{0.75})\right] - 1\right\}\right) + \left(20.3 - \left\{\left[(920 \times LWG)/(4 \times SRW^{0.75})\right] - 1\right\}\right) / \left\{1 + e^{-6\times[(LWT/SRW)-0.4]}\right\} \right] \Big/ 0.95 \times k_l,$$

where ME_g is metabolizable energy for LWG, SRW is a standard reference weight, assumed to be 495 kg/cow, and k_l = ME concentration of the feed × 0.02 + 0.4. The energy made available by liveweight loss (**LWL**; kg) was calculated using the equation 25 × LWL × 0.84/k_l. Walking distance to the parlor was measured for each paddock and a cumulative distance (**WD**; km) determined using daily grazing records. The energy required for walking was calculated by ME_a = LWT × 0.0026 × WD/k_m (vertical distance climbed was assumed to be 0 as it was a flat farm). The energy for milk production (**MY**; kg of milk) was calculated using the equation $ME_L = 1.1 \times MY \times (0.376 \times \text{milk fat \%} + 0.209 \times \text{milk protein \%} + 0.976)/k_l$. These were combined to estimate the farmlet average energy requirements (MJ of ME; Table 1).

Farm System Data Collection

Pasture mass in each paddock was assessed once in June 2019 and weekly from July 15, 2019, until May 27, 2020, using a rising plate meter (Jenquip). The rising plate meter measurements were calibrated monthly against DM mass data from 20 quadrats of 0.26 m^2 (8 pregrazing, 8 postgrazing, and 4 at intermediate pasture mass), cut to ground level, washed, and dried at 60°C for 48 h.

Pre- and postgrazing mass was measured monthly by rising plate meter at each weekday grazing (Monday to Friday) for each farmlet. Pasture removed was estimated using the difference between pre- and postgrazing pasture mass and averaged across all months to produce an average for the lactation.

Weekly pasture mass measurements were used to calculate pasture herbage accumulation rate (kg of DM/ha per day) for each paddock by the difference between the previous and the current pasture mass values divided by 7 d. Where the paddock was grazed between weekly measurements, the farmlet average growth rate

Table 1. Comparison of animal-related metrics for different milking schedules, twice a day (TAD) or 3 milkings in 2 d (3-in-2), for either a whole lactation (FS) or changing from TAD to 3-in-2 in mid- or late lactation[1]

					Intercept		Slope		
Metric	FS-3-in-2	Mid-3-in-2	Late-3-in-2	FS-TAD	Estimate	SE	Estimate	SE	*P*-value
Cumulative milking duration (min/cow)	2,708	2,711	3,205	3,083	3,152	137	−1.87	0.88	0.166
Average milk flow rate (kg/min)	1.62	1.65	1.47	1.58	1.54	0.06	0.0003	0.0004	0.485
Season average liveweight (kg/cow)	480	482	482	491	488	2.6	−0.04	0.02	0.170
BCS on May 8, 2020	4.61	4.57	4.41	4.37	4.37	0.03	0.001	0.0002	0.032
Percent of herd with a treatment	34	31	31	41	37	4	−0.02	0.03	0.546
Percent of herd treated for lameness	0	3	7	14	12	2	−0.05	0.01	0.042
Percent of herd treated for mastitis	31	28	24	24	23	1	0.03	0.00	0.028
Distance walked to parlor (km)	535	617	717	743	754	12	−0.836	0.08	0.008
Milk protein (%)	4.07	4.00	3.99	3.92	3.93	0.02	0.0005	0.0001	0.039
Milk fat (%)	5.41	5.25	5.00	5.04	4.98	0.06	0.0016	0.0004	0.052
Milk lactose (%)	4.81	4.86	4.91	4.87	4.90	0.02	−0.0003	0.0002	0.185
Maintenance energy (MJ of ME/cow)	14,237	13,944	13,969	14,189	14,052	141	0.273	0.91	0.792
Walking energy (MJ of ME/cow)	900	1,031	1,203	1,277	1,282	16	−1.487	0.10	0.005
Liveweight change energy (MJ of ME/cow)	1,422	1,342	1,262	1,111	1,149	35	1.123	0.22	0.038
Lactation energy (MJ of ME/cow)	28,951	29,050	29,908	30,600	30,397	266	−6.398	1.71	0.065
Total energy[2] (MJ of ME/cow)	45,510	45,368	46,342	47,178	46,880	382	−6.489	2.46	0.119

[1]Values presented are raw means and results of linear regression. Values relate to the 10-mo period from August 2019 to May 2020.

[2]Total energy does not include pregnancy requirements, which contribute to less than 3% of total requirements during the observation period.

for the week was assumed. Herbage accumulation for each 7-d period for each paddock was summed for the year to estimate total pasture grown (Table 2).

The area grazed each day was recorded for each farmlet, as well as any supplement offered (baleage or barley grain), nutrients applied (fertilizer amount or effluent volume), and mechanical cutting (for forage conserved as pasture baleage or postgraze mowing). Fertilizer was managed consistently across the farmlets. A total of 169 kg of nitrogen/ha, 41 kg of phosphorus/ha, and 60 kg of sulfur/ha was applied to each farmlet via applications of 75 kg/ha of ammonium sulfate (31% N, 14% S) in September of 2019; 450 kg/ha of superphosphate (9% P, 11% S) in December of 2019; and 82, 82, 50, 50, and 60 kg/ha of urea (46% N) in October 2019 (excluding pasture renewal paddocks), December 2019, January 2020, February 2020, and March 2020, respectively.

The composition of pasture and effluent was analyzed monthly. Pasture samples were collected from the next 3 paddocks in line for grazing in each farmlet to estimate DM %, and botanical and chemical composition. A 30-g (fresh weight) subsample was collected to grazing height (~4 cm) at every fourth step along a random transect of at least 20 m across the paddock and separated into ryegrass leaf and sheath, ryegrass reproductive stem, white clover, herbs and other grass species, weed species, and dead matter components. The sample was then dried at 60°C for 48 h, and the dry weight of each component was recorded. A second sample of approximately 100 g (fresh weight) was dried at 60°C for 48 h, ground to 1 mm, and analyzed for digestible organic matter in the dry matter (**DOMD**) using near-infrared spectrophotometer (FOSS NIRSystems 5000, Foss Electric). Metabolizable energy concentration (MJ/kg of DM) was estimated using the equation ME = DOMD × 0.16. Pasture baleage DM % and composition was analyzed using the same method, but with a different near-infrared spectrophotometer calibration. Barley was assumed to have an ME value of 13 MJ/kg of DM with 89% DM. A 1-L sample of effluent was collected monthly and analyzed (Hill Laboratories) to determine the composition of nitrogen, phosphorus, potassium, and sulfur applied to pastures as fertigation. Despite the intention of keeping effluent applications the same across the farmlets, there were some differences, with a total of 1,487 m^3 applied to the FS-TAD farmlet, 2,183 m^3 applied to the late-3-in-2 farmlet, 2,079 m^3 applied to the mid-3-in-2 farmlet, and 2,041 m^3 applied to the FS-3-in-2 farmlet. This was equivalent to 28 kg of nitrogen/ha, 5 kg of phosphorus/ha, and 34 kg of potassium/ha for FS-TAD farmlet, and 42 ± 1 kg of nitrogen/ha, 8 kg of phosphorus/ha, and 52 ± 1 kg of potassium/ha for the other farmlets.

Table 2. Comparison of pasture-related metrics for different milking schedules, twice a day (TAD) or 3 milkings in 2 d (3-in-2), for either a whole lactation (FS) or changing from TAD to 3-in-2 in mid- or late lactation[1]

Metric	FS-3-in-2	Mid-3-in-2	Late-3-in-2	FS-TAD	Intercept		Slope		
					Estimate	SE	Estimate	SE	*P*-value
Average pasture cover (kg of DM/ha)	2,071	2,122	2,094	2,067	2,086	24	0.0246	0.1545	0.888
Pasture grown (tonnes of DM/ha)	12.1	11.8	12.0	12.0	11.9	0.092	0.0002	0.0006	0.733
Average pasture quality (MJ of ME/kg of DM)	12.1	12.2	12.2	12.2	12.2	0.016	−0.0002	0.0001	0.270
Average supplement quality (MJ of ME/kg of DM)	10.5	10.5	10.4	10.4	10.4	0.02	0.0003	0.0001	0.112
Annual area grazed (ha)	88.0	86.7	88.2	90.2	89.3	1.04	−0.0085	0.0067	0.328
Average rotation length (ha/d)	26	26	26	25	25.2	0.30	0.0029	0.0019	0.269
Area mown postgrazing (% of farmlet)	152	131	134	103	111.4	8.82	0.1581	0.0568	0.108
Average pregrazing mass	2,726	2,636	2,647	2,616	2,611	22	0.4	0.1	0.115
Average postgrazing	1,630	1,727	1,690	1,687	1,705	34	−0.2	0.2	0.497
Average mass removed	1,171	935	950	936	897	63	0.8	0.4	0.176

[1]Values presented are raw means and results of linear regression. Values relate to the 10-mo period from August, 2019, to May, 2020.

Total estimated feed eaten (tonnes of DM/cow) was calculated using the estimated ME requirements for each herd, divided by the ME value of pasture (MJ/kg of DM), as the predominant feed type, and dividing by 1,000 (Table 3). Estimated pasture harvested (tonnes of DM/ha) was calculated by subtracting the ME offered in supplementary feed, which included an adjustment for changes in starting and ending average pasture cover, and adding the ME conserved as baleage. Net supplement was calculated by subtracting the amount of pasture conserved as baleage from the amount of purchased supplementary feed on each farmlet.

Farmlet Management

Each farmlet was managed individually using the same set of management decision rules, with the criteria for each decision being identical between farmlets, except the timing of implementation of that decision could differ depending on the individual situation of the farmlet. Cows were rotationally grazed and management decision rules were based on the guidelines of Macdonald and Penno (1998). On August 1, 2019, (planned start of calving) each farmlet had an average pasture cover (**APC**) of ~2,400 kg of DM/ha, and the target APC for May 31, 2020, was ~2000 kg of DM/ha.

The weekly pasture mass measurements were used to generate a feed wedge by ranking paddocks from highest to lowest mass within each farmlet (Van Bysterveldt, 2005). Paddocks of the highest mass and longest regrowth interval were selected for grazing first. The area offered each day was determined using a spring rotation planner (Bryant and L'Huillier, 1986) from July 18, 2019, when cows arrived back on-farm from their winter grazing, to October 3, 2019, where the daily area offered was increased each week from 0.1 ha/d (74-d rotation) for each farmlet to 0.375 ha/d (22-d rotation). Between October 3, 2019, and autumn, each herd strip grazed a 0.75-ha paddock over 2 d. Cows were offered a fresh allocation of pasture after each milking. This meant that, for each 2-d period, TAD paddocks were subdivided into 4 allocations using temporary electric fences, and 3-in-2 paddocks were subdivided into 3 allocations. The area offered each day could differ between each farmlet and was determined by pre- and postgrazing pasture mass. Therefore, at times when pasture growth rate declined, and particularly during autumn, 5 allocations (TAD) and 4 allocations (3-in-2) were used to achieve a 28-29 d rotation (from April 1, 2020). Alternatively, for a 44-d rotation, cows spent 4 d in each paddock (from May 1, 2020), divided into 4 allocations (TAD; fresh break each day) and 6 allocations (3-in-2). The amount of pasture offered in each allocation was approximately equal, irrespective of the number of hours until the next

Table 3. Comparison of farm system-related metrics for different milking schedules, twice a day (TAD) or 3 milkings in 2 d (3-in-2), for either a whole lactation (FS) or changing from TAD to 3-in-2 in mid- or late lactation[1]

Metric	FS-3-in-2	Mid-3-in-2	Late-3-in-2	FS-TAD	Intercept		Slope		
					Estimate	SE	Estimate	SE	*P*-value
Milk solids (kg/ha)	1,508	1,519	1,551	1,589	1,578	11	−0.30	0.07	0.053
Total estimated feed eaten (tonnes of DM/ha)	13.76	13.68	13.98	14.15	14.08	0.11	−0.002	0.001	0.148
Pasture conserved (tonnes of DM/ha)	0.62	0.43	0.76	0.24	0.42	0.20	0.001	0.001	0.597
Imported supplement offered (tonnes of DM/ha)	2.16	2.37	2.28	2.02	2.16	0.14	0.004	0.001	0.659
Net purchased supplement (tonnes of DM/ha)	1.55	1.94	1.52	1.78	1.74	0.19	−0.0003	0.001	0.809
Estimated pasture harvested (tonnes of DM/ha)	12.21	11.74	12.45	12.37	12.34	0.27	−0.001	0.002	0.553

[1]Values presented are raw means and results of linear regression. Values relate to the 10-mo period of August 2019 to May 2020.

milking. The herds were not back-fenced; therefore, they could access previous allocations within that paddock. For context, the approximate daily pasture (and supplement) allowance was 17, 19, 20.5, 19, 18, 17.5, 16.5, 16, and 12 kg of DM/cow per day for the months of September 2019 to May 2020.

Supplementary feed was offered to ensure that postgrazing residuals and rotation lengths were maintained when there was insufficient pasture to meet animal demand. The maximum area offered each day was 0.375 ha/d per farmlet, and target postgrazing residual was 3.5 to 4.0 cm compressed height above ground level as measured with the rising plate meter. Conserved pasture, in the form of baleage, was the preferred supplementary feed as it could be used where necessary to suit individual paddock and farmlet requirements. If the feed wedge indicated a prolonged period of feed deficit, particularly across all farmlets, then barley grain was offered in-parlor.

Pasture could be conserved, in the form of baleage, at times of surplus. Pasture surplus occurred when growth rate exceeded herd demand, and a feed wedge for each farmlet was used to determine if paddock(s) could be conserved. If the paddock cover was above 3,100 kg of DM/ha or if postgrazing residuals were higher than target or expected to be higher than target for 3 consecutive paddocks and subsequent paddocks were at target pregrazing cover of 2,700 to 3,100 kg of DM/ha, then baleage could be cut. A maximum of 2 paddocks per farmlet could be cut for baleage at any one time to avoid creating a pasture deficit in the subsequent grazing rotation because mowing pasture removes leaf area and reduces regrowth. If the postgrazing pasture mass was uneven (visually estimated >1,600 kg of DM/ha), then the paddock was mown to remove excess residual mass, with the aim of preserving pasture quality and removing areas which might be avoided during subsequent grazings.

Decisions around the removal of cows and dry-off date were based primarily on farmlet APC (relative to target), expected pasture growth rates, and BCS (relative to target) for each farmlet, but could also be influenced by supplementary feed availability and production levels. The priority for all farmlets was to milk as many cows as possible to the end of the season at the lowest possible cost. Cows could not be removed or dried off before pregnancy testing (February 2020). The criteria for removing cows were pregnancy status, animal health (e.g., incidences of mastitis, lameness, or high SCC), and production. Despite the ability within the management decision rules to remove animals and dry herds off at different dates, removal and dry-off events occurred at the same time across the 4 herds, likely due to farmlets having the same stocking rate. Three cows (10%) from each herd were removed on March 22, 2020, and a further 3 cows (10%) removed on April 30, 2020. All cows were progressively dried off between May 9, 2020, and May 12, 2020, according to milk yield. The average number of days of 3-in-2 milking were 0, 64, 155, and 261 d for the FS-TAD, late-3-in-2, mid-3-in-2, and FS-3-in-2 herds, respectively (Figure 1).

During spring, one paddock per farmlet, representing 9% of the farmlet area, was selected for pasture renewal. These paddocks were taken out of the grazing rotation on November 6, 2019, and re-entered the rotation on December 28, 2019.

Data Analysis

All data analyses were performed using SAS/STAT 15.1 from SAS 9.4 (2016, SAS Institute Inc.). Analyses were based on farmlet averages or cumulative totals. Linear regression models included number of days of milking 3-in-2 as the independent variable. Due to the small number of degrees of freedom, nonlinear relationships were not explored. Results are presented as mean (estimate) and standard error of the mean for intercept and slope as well as the probability of the slope being 0 (i.e., no effect of the number of days milked 3-in-2 on the metric). Significance was declared if $P \leq 0.05$.

RESULTS

Animal Metrics

Results are presented in Figure 2 and Table 1, with the following results in text presented as a percentage change for FS-3-in-2 relative to the FS-TAD. This percentage change can also be used to estimate the effect for shorter durations of 3-in-2 by multiplying it by the proportion of the lactation using 3-in-2. Annual milk production decreased, equivalent to −11%. Conversely, milk fat and protein % increased, by 8% and 3%, respectively. Fat % increased to sufficiently offset the decrease in milk production so that there was no significant effect of milking frequency on fat yield (Figure 2). The increase in protein % was insufficient to maintain protein yield, with an 8% decrease as a result of milking 3-in-2. Combining fat and protein results, there was a tendency for a 5% decrease ($P = 0.05$) in total Ms yield/ha when cows were milked 3-in-2 (Table 3). There was no effect on lactose %; consequently, there was a 12% decrease in lactose yield. There was no effect on SCC, and a tendency for lower (−18%) milk urea concentration with 3-in-2 milking ($P = 0.08$). There was no significant effect of 3-in-2 on milk flow rate (Table 1).

There was a significant, positive effect of milking 3-in-2 on BCS near the end of lactation, equivalent to a 6% increase for FS-3-in-2 relative to FS-TAD. Cows milked 3-in-2 walked significantly ($P < 0.05$) less distance between the paddock and parlor, equivalent to −29%. There was significantly less lameness ($P < 0.05$) with increasing duration of 3-in-2 milking, although overall, there was no difference in the percentage of the herd receiving a health treatment due to an increase in the percentage of the herd treated for mastitis ($P <$ 0.05). A total of 4, 2, 1, and 0 cows received treatment for lameness and 7, 7, 8, and 9 cows received treatment for clinical mastitis for the FS-TAD, late-3-in-2, mid-3-in-2, and FS-3-in-2 herds, respectively.

There was a significant ($P < 0.01$) decrease in the energy required for walking (−30%), increase in the energy requirements for liveweight change (+26%), and a tendency for a decrease in the energy required for lactation (−6%) with increasing duration of 3-in-2 milking. Combined, there was no significant difference in the total energy requirements.

Pasture Metrics

Pasture results are presented in Table 2. There were no differences in pasture grown, pasture quality, or botanical composition. There were also no differences in APC, pregrazing pasture mass, postgrazing pasture mass, area grazed, or percentage of area mown postgrazing over the season. The average botanical composition of the pasture of all farmlets was 80% perennial ryegrass, 4% reproductive perennial ryegrass, 5% white clover, 2% other pasture species, 2% weed species, and 7% dead material.

Farm System Metrics

Farm system results are presented in Table 3. There was no significant effect of 3-in-2 milking on the total estimated feed eaten/ha as determined from energy requirements ($P = 0.15$), the total feed external to the farm offered to cows ($P = 0.68$), the net amount of feed brought (purchased) into the farm system ($P = 0.81$), nor the estimated amount of pasture harvested ($P =$ 0.55) with 3-in-2 milking.

DISCUSSION

The objective of this farmlet study was to investigate the farm system trade-offs when milking 3-in-2 for differing durations within a lactation. This enables pasture-based dairy farmers and advisors to make informed decisions and recommendations about the effects of adopting 3-in-2 milking on farm management and potential implications for business performance. In terms of key drivers of farm revenue, the results for fat, protein, and lactose yield support findings from previous component research (Elliott et al., 1960) and work exploring different intervals within a TAD milking frequency and OAD (Rémond et al., 2009; Dutreuil et al., 2016). Elliott et al. (1960) explored variations in the rate of milk secretion over 2 to 24 h in 4 experiments and concluded that the rate of fat secretion appeared linear up to 24 h, whereas the secretion of solids-not-fat declined rapidly once the milking interval exceeded 16 h. However, the authors provided the caveat that no reliable estimates could be made of the effect of the repeated long milking intervals required to milk 3-in-2, such as the 11–18.5–18.5 h interval tested by Woolford et al. (1985).

Our results for a 12-18-18 h interval differed from those of Woolford et al. (1985), who reported a significant 6% decline in fat production (other components not reported), although the authors noted, similar to others (Turner, 1955; Elliott et al., 1960), that there was considerable variation among animals in response to extended milking intervals. The herds milked 3-in-2 in this study likely partitioned less energy into condition score gain than the herd used by Woolford et al. (1985), with a difference of 0.25 compared with 0.7 BCS units between FS-3-in-2 and FS-TAD. The level of production reported here was considerably more than Woolford et al. (1985; e.g., 248 compared with 182 kg of fat/cow for cows milked TAD). Previous work has indicated higher yielding animals were less affected by consecutive long milking intervals (Schmidt, 1960), which may explain the differences between studies. However, Elliott et al. (1960) reported a greater negative effect of extended milking interval for higher yielding animals, independent of stage of lactation, suggesting that decades of animal selection has exploited variation among animals in response to extended milking intervals, an opportunity identified by Davis et al. (1998). Turner (1955) reported that tolerance of long milking intervals is morphologically determined and is relatively independent of functional attributes such as secretion pressure, secretion rate or daily yield. Morphologically, a proportionally large cisternal holding space relative to alveolar space was beneficial (Turner, 1955). Similarly, more recent research indicated that cows with a predisposition to cisternal milk storage should be more tolerant of OAD milking, and the size of the cisternal compartment was a factor in production loss (Knight and Dewhurst, 1994; Knight et al., 1994; Stelwagen and Knight, 1997; Davis et al., 1998). Consequently, the effect of extended milking intervals on high-yielding cows likely depends on whether their higher yield is due to a high intensity of tissue function (little effect)

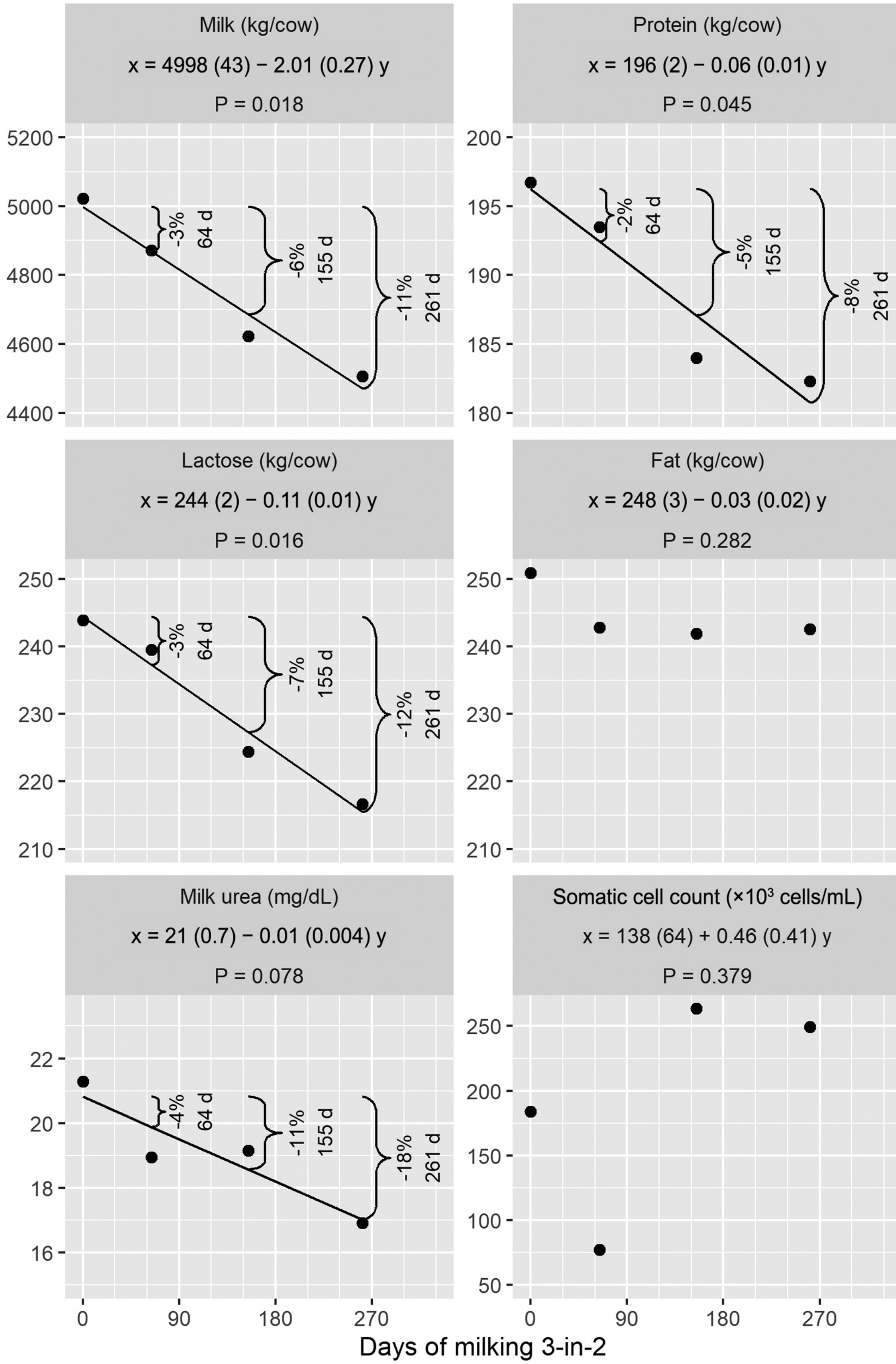

Figure 2. Graphical representation of key milk production metrics analyzed by linear regression. *P*-value indicates the significance of the effect of days milked 3 times in 2 d (3-in-2). Within the equations, values in brackets are SE of the constant and slope. The estimated percentage change for each herd milked 3-in-2 relative to the herd milked twice a day, and the number of days milked 3-in-2, are annotated for each metric where $P < 0.1$.

or a large amount of secretory tissue (negative effect; Turner, 1955). High functional intensity may also be related to lactation persistency (Turner, 1955), potentially explaining the mechanism of genetic selection, given cistern size has not been directly selected for in the population of cows used in the present study. To increase the adoptability of extended milking intervals (3-in-2, OAD) and to assist with achieving workplace attractiveness goals, greater selection for traits such as movement of milk to the cistern and its capacity, using techniques such as genomic selection, warrants consideration for pasture-based systems.

Although we were not able to test for curvilinear effects, the significant linear effects on lactation yields of milk, protein, and lactose (Figure 2) are consistent with Elliott et al. (1960), who reported no curvilinearity of the regression of milk secretion on duration of milking interval and stage of lactation independent of milk yield. This does not support the farmer hypothesis and experimental evidence of a slight increase in tolerance to long milking intervals as lactation progresses (Turner, 1955). Further, this linear relationship makes the on-farm estimation of the effect of milking 3-in-2 simple; the percentage loss over a full lactation can be estimated by multiplying −8% (in the case of protein) by the percentage of the lactation where 3-in-2 would be used (i.e., −4% when using 3-in-2 for 50% of the lactation). Given the shape of a lactation curve, this result implies that, at a daily level, the percentage decrease in yield is less in early lactation and greater in late lactation. Interestingly, FS-3-in-2 yielded similar lactation yield percentage changes to short-term (3–8 wk) use of OAD in early lactation (Phyn et al., 2014; Kennedy et al., 2021), while requiring considerably fewer milkings, a result also reported by Woolford et al. (1985). Previous studies (e.g., Grala et al., 2016) using OAD in late lactation have not included production information before the experimental period, meaning the effect on lactation yield cannot be discussed in relation to our results.

The financial implications of the production results will be dependent on the milk payment system used and the relative value of each component. Using the 2018/19 component values and payment system outlined by Edwards et al. (2019), milk revenue in the present study would have been −4% with 3-in-2 milking. The fat value used in this calculation was 1.3 times that of protein, and lactose had no value. A larger decrease in revenue could be expected for a payment system that includes lactose, or with a higher value for protein. Nevertheless, these results indicate the scale of the savings required to maintain profitability when switching from TAD to 3-in-2 milking. As well as direct savings in the parlor and potential reduction in labor, some other system changes that could lead to reduced costs are discussed below.

Previous research has reported reduced energy demand as a result of decreasing milking frequency, for example −15 MJ of ME/cow per day in the case of cows milked OAD (Holmes et al., 1992). Energy required for milk production made up approximately two-thirds of total energy requirements in the present study, and the tendency for lower Ms production means it is likely that cows milked 3-in-2 had slightly lower energy requirements, although this was not significant ($P = 0.11$; Table 1). The lack of significance could be a result of assumptions in energy back calculation. Nevertheless, the results do not support the hypothesis that cows milked 3-in-2 use the time made available by fewer milkings to eat more. The lack of an effect on estimated energy requirements, estimated feed eaten, and net supplement offered resulted in no differences in estimated pasture harvested or its nutrient composition. Therefore, pasture management and feed allocation for a herd milked 3-in-2 should be similar to one milked TAD and an increase in stocking rate, as proposed with OAD systems (Holmes et al., 1992; Clark et al., 2006), appears unjustified.

Farmers utilizing a 3-in-2 milking schedule claim there are benefits to animal health as a result of 25% fewer milkings. In the present study, there was a significant effect on the percentage of the herd treated for lameness. This result is understandable given the significant decrease in cow walking distance when milked 3-in-2. However, previous research has indicated aspects of track design were related to prevalence of lameness, not the distance walked, although the longest walk in that study was only 1.1 km (Chesterton et al., 1989). Distances walked by cows in the present study were also small, an average of 2.8 km/d for the FS-TAD herd, relative to distances that may be walked on commercial farms, where the one-way distance to the furthest paddock may be over 2 km (Beggs et al., 2015). Consequently, the benefits of 3-in-2 milking on large commercial farms may be even greater. In practice, on commercial farms, it is unlikely that treatment of lameness would reduce to zero (in the case of the FS-3-in-2 herd), but the result illustrates that reducing the number of milkings could see a material reduction. Despite a reduction in lameness, overall, there was no significant effect on the percentage of the herd receiving a health treatment. A key driver of this result was an increase in clinical mastitis with 3-in-2 milking, although there was no effect on SCC. The incidence of mastitis across all the herds was approximately double the rate typical for seasonal calving pasture-based dairy systems (McDougall, 1999; Jury et al., 2010) but similar to that reported in some research herds (Lacy-Hulbert et al., 2005). Previous research has concluded that OAD and 3-in-2 milking does not significantly increase the prevalence of clinical mastitis or new IMI (Woolford et al., 1985; Lacy-Hulbert et al., 2005). Given the small number of animals in each farmlet and the unusually high mastitis prevalence, further research is needed to conclusively determine the effect of 3-in-2 milking on clinical mastitis. Body condition score near the end of lactation was greater for cows milked 3-in-2, a result also reported by Woolford et al. (1985). The importance of achieving target body condition at calving is well understood (Roche et al., 2009). Consequently, higher body condition at dry-off would either increase the likelihood of a farmer reaching the target or enable a reduction in feed required over the nonlactating period. Overall, the benefits to lameness and BCS, and the uncertainty around the effect on mastitis, lead us to the conclusion that 3-in-2 milking would likely be beneficial for animal health on a commercial farm.

There were 5 limitations to the study that should be considered when relating these results to a commercial farm. First, the study was 1 season in duration, meaning carry over effects could not be determined. For example, the greater body condition would likely be of value, either by reducing winter feed requirements or influencing milk production or reproduction in the next lactation (Roche et al., 2009). Second, the high proportion of primiparous animals (31%) relative to a typical pasture-based herd of 20 to 25% may have affected the degree to which 3-in-2 affected milk production because previous research has shown primiparous animals are less tolerant of extended milking intervals (Woolford et al., 1985; Clark et al., 2006). Third, as noted earlier, the small farm size relative to a large commercial farm may mean the value of less walking is under-represented in this study. Fourth, the change to a 9-21-18 h intervals for 3-in-2 as a result of availability of milking staff due to the COVID-19 lockdown may have compromised production. Finally, the study was conducted at a single site and production system. In terms of translating these results to what might be experienced on a commercial farm, a final consideration is how staff time released by fewer milkings is used. In the present study, an equal amount of time and effort was spent on each farmlet. However, on a commercial farm, the additional time could be used to either make better management decisions or improve their execution relative to what was previously possible with TAD milking. This may be a better strategy than using this time to adjust labor inputs. Therefore, the results do not represent a steady-state situation and imply better outcomes may be achieved with 3-in-2 milking on a commercial farm.

CONCLUSIONS

Using a 3-in-2 milking schedule did not affect milk fat production, but milk (−11%), protein (−8%), and lactose (−12%) decreased compared with TAD milking. In combination with increased body condition (+6%) and reduced walking distance (−29%), there was no significant effect on estimated energy requirements or estimated feed eaten. There were also no differences in the amount, quality, or composition of pasture grown, so pasture management and feed allocation for 3-in-2 milking should be similar to TAD milking. On commercial farms, the degree to which reduced milk income can be offset with reduced cost will be highly farm-specific, but opportunities for savings were identified in the results. The higher than normal proportion of primiparous cows in our herds, the short walking distances, and opportunity for improved farm management may mean better outcomes might be achieved with 3-in-2 milking on a commercial farm.

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