Effects of Varying Lactation Length on Milk Production Capacity of Cows in Pasture-Based Dairying Systems

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ABSTRACT

The aim of this experiment was to quantify the milk production capacity of cows undergoing extended lactations while fed a pasture-based diet typical of those used in the seasonal-calving dairying systems of Victoria, Australia. One hundred twenty-five Holstein cows were randomly assigned to 1 of 5 groups. Breeding was progressively delayed after calving to enable management of the groups for lactation lengths of 10, 13, 16, 19, and 22 mo (equivalent to calving intervals of 12 to 24 mo). Cows were provided with a daily energy intake of at least 180 MJ of metabolizable energy/cow. This was supplied primarily by grazed pasture with supplementary cereal grain, pasture silage, and hay. Cows were dried off when milk volume fell below 30 kg/wk or when they reached 56 d before their expected calving date. Most cows (>96%) could lactate above this threshold for 16 mo, >80% for 19 mo, and >40% for 22 mo. There were negative relationships between lactation length and annual production of milk and milk solids (milk fat + protein), but losses were small until 16 mo. Annualized yields of milk solids were 497, 498, 495, 474, and 463 kg/cow for the 10, 13, 16, 19, and 22 mo groups, respectively. This reduction in annual production of milk solids with increasing lactation length was relatively less than for milk volume because during extended lactation, cows produced milk with higher concentrations of protein. Cows undergoing extended lactations also finished their lactations having gained more body weight and body condition than cows lactating for only 10 mo. The data showed that many cows on pasture-based diets were capable of lactating longer than the 10 mo that is standard for Victorian herds with seasonally concentrated calving patterns. Further, such extended lactations could be achieved with little penalty in terms of annual milk solids production.

Key words: extended lactation, milk production, pasture, protein

INTRODUCTION

In the pasture-based dairy industry in Victoria, Australia, cows have traditionally been managed to calve in late winter. Then, after a 10-mo lactation they are dried off for a period of 8 to 10 wk. This seasonally concentrated calving system has been used to maximize pasture utilization. Several changes in the Victorian dairy industry have recently prompted a reassessment of whether such systems are the most appropriate.

The increase in the use of semen from Holstein sires since 1970 has been associated with a general decline in the reproductive performance of Victorian herds (Morton, 1999). The Holstein breed has a higher milk yield potential than other breeds and undergoes greater weight losses in early lactation when body adipose reserves are mobilized to sustain these yields (Fulkerson et al., 2001; Snijders et al., 2001). These factors have been linked to lower conception and pregnancy rates (Beever et al., 2001; Lucy, 2001). Low reproductive performance in a seasonally concentrated calving system is exacerbated by insufficient time to recover from the negative energy balance of early lactation, because the required time of breeding coincides with peak lactation (Borman et al., 2004). As a consequence, herd owners can have difficulty maintaining a 12-mo calving interval. There is evidence that this has occurred in Victoria: between 2004 and 2006 the proportion of seasonal-calving herds in Victoria declined from 63 to 41% (Dairy Australia, 2006).

Attempts to maintain a seasonally concentrated calving system in combination with poor conception rates lead to high numbers of cows being removed from the herd because they were not pregnant (Evans et al., 2006). Additionally, there is increasing reliance on the induction of premature calving to maximize the duration between calving and breeding (Morton, 1999). Systems that incorporate lactations longer than the traditional 10 mo may alleviate these issues by providing cows with more time to conceive after calving and peak lactation (Schindler et al., 1991; Ratnayake et al., 1998; Larsson and Berglund, 2000). Overseas studies have shown that cows are capable of producing milk for sig-

Received October 18, 2006.

Accepted February 22, 2007.

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nificantly longer than 10 mo (Van Amburgh et al., 1997; Osterman and Bertilsson, 2003; Kolver et al., 2006). Similarly, cows in commercial herds in Victoria are known to have lactated for 22 mo or more (M. J. Auld, unpublished data). There are, however, no controlled studies demonstrating the potential for longer lactations among Victorian cows managed in pasture-based systems.

The aim of this experiment was to determine the effect of lactation length on production of milk, milk fat, and milk protein in grazing cows milked for between 10 and 22 mo.

MATERIALS AND METHODS

Cows and Design

One hundred twenty-five AI-bred Holstein cows that calved in July 2003 were selected from the research herd maintained at DPI Ellinbank (latitude 38°14'36.4", longitude 145°56'09.5"). Using the method described by Baird (1994), cows were assigned randomly to 1 of 5 groups of 25 (each group included 5 primiparous cows) with each group balanced for age of cow, calving date, BW, and yields of milk, protein, and fat in the preceding lactation (excepting primiparous cows).

One group of 25 cows was assigned to each of 5 designated lactation length targets of 10, 13, 16, 19, and 22 mo. These were equivalent to calving intervals of 12, 15, 18, 21, and 24 mo, respectively (allowing for a 56-d intercalving dry period). The breeding program for each group was initiated approximately 7 mo before the date at which its designated lactation length target would be met.

Control Herd

The group managed for a 10-mo lactation acted as a control. Cows in this group had two 10-mo lactations during the 2-yr duration of the experiment (separated by a 56-d dry period). Cows that failed to conceive in the first year were replaced by similar cows for the second lactation, including 5 replacement primiparous cows.

Management

All lactating cows were grazed together as a single herd and were subjected to the same management practices with the exception of the timing of their breeding program. Cows grazed on a dedicated series of paddocks distributed around the research farm at DPI Ellinbank. They were milked twice daily through a common parlor at approximately 0700 and 1500 h.

Nutrition for lactating cows was kept as similar as possible throughout the experiment by providing an estimated minimum daily dietary intake of 180 MJ of ME/cow. It was calculated that this level of intake would enable cows to produce 280 kg of milk fat in a 10-mo lactation (Standing Committee on Agriculture, 1990). This was slightly higher than the 2004–2005 Victorian average of 259 kg of milk fat for Holstein cows in herd-recording herds (National Herd Improvement Association, 2005). This energy was provided primarily by grazed pasture. When pasture availability or quality was limited, the balance of the 180 MJ of ME was met with cereal grain, pasture silage, and legume hay. Cows were allowed to consume more than 180 MJ of ME/d from pasture when it was available.

Because of the inherent difficulty in measuring how much pasture the cows consumed each day, their energy intake was back-calculated at regular intervals using equations based on known energy requirements for the prevailing levels of milk production, BW, and BW change (Standing Committee on Agriculture, 1990). In accordance with the calculated ME intake, the diet was then adjusted as necessary to ensure that 180 MJ of ME was being provided. This involved adjusting the pasture allowance (using electric fencing) and varying the supplementary grain and forage. The pasture intake of cows was supplemented with 2 to 7 kg DM/d of grain (mostly barley: a total of 1.6 t/cow in the first 10 mo), up to 9 kg DM/d of hay (pasture or legume), or up to 5 kg DM/d of pasture silage at different times. The concentrations of CP and fiber and the apparent digestible DM of pasture and other dietary components are presented in Table 1.

Dry Cows and Replacements

Cows were managed in the dry cow herd at DPI Ellinbank before the commencement of the experiment (calving). They were offered a maintenance allowance of pasture until approximately 2 wk before their expected calving date when they were brought to the calving pad and fed a barley-based dry cow ration with supplementary straw. Cows calved at an average BCS of slightly less than 5 on the 8-point scale of Earle (1976). Cows in the control group were managed in a similar fashion as above when they were dry between their two 10-mo lactations.

Breeding Program

All cows in the experiment were enrolled in a breeding program that involved the synchronization of estrus and 3 rounds of AI. The program commenced 10 d before the planned start of mating for each group (determined

Table 1. Digestible DM (DMD) and concentrations of CP and NDF of pasture and other dietary components¹

Season	Component	DMD (%)	CP (% of DM)	NDF ² (% of DM)
Winter	Pasture	79.7 (4.9)	23.5 (3.1)	46.2 (5.0)
	Pasture silage	—	—	—
	Grain (barley)	78.8 (5.4)	14.3 (0.9)	10.2 (2.9)
Spring	Hay (pasture and legume)	68.9 (2.7)	19.4 (1.1)	40.8 (0.8)
	Pasture	77.2 (5.0)	20.4 (3.5)	49.3 (4.5)
	Pasture silage	—	—	—
	Grain (barley)	84.5 (1.8)	15.3 (1.6)	6.3 (2.8)
Summer	Hay (pasture and legume)	—	—	—
	Pasture	73.0 (3.5)	16.0 (3.3)	53.6 (4.2)
	Pasture silage	70.3 (2.3)	14.1 (0.7)	54.1 (2.8)
	Grain (barley)	84.7 (1.2)	15.0 (2.0)	6.3 (0.8)
Autumn	Hay (pasture and legume)	70.2 (3.1)	20.0 (4.0)	38.5 (5.1)
	Pasture	73.7 (2.6)	17.8 (4.7)	54.2 (4.1)
	Pasture silage	71.7 (6.8)	15.3 (2.5)	53.7 (4.0)
	Grain (barley)	82.5 (3.3)	15.2 (3.0)	7.5 (1.2)
	Hay (pasture and legume)	67.0 (6.1)	18.8 (3.6)	41.7 (6.0)

¹Data are means from all samples ($\pm$ standard deviation).²ADF for grain.

by target lactation length) at which time every cow not previously observed in estrus was physically examined by a veterinarian to determine whether they were anestrus. All cows then had a controlled internal drug-releasing (CIDR) device (Pfizer Australia, West Ryde, NSW, Australia) inserted vaginally and received an i.m. injection of estradiol benzoate (1 mg for anestrus cows, 2 mg for cycling cows). Each device was removed 8 d after insertion at which time all cows received an injection of prostaglandin F_{2 α} (Lutalyse, Pfizer Australia) and had an estrus detection aid applied. Estruses occurred from 2 d after CIDR removal and cows were artificially inseminated to detected estrus by a trained technician.

Three weeks after initial CIDR insertion, devices were reinserted into each inseminated cow and each cow received an injection of 1 mg of estradiol benzoate. The program was repeated and resynchronized cows were again inseminated to detected estrus. The program was repeated a third and final time for those cows inseminated during the second round. Subsequently, any cows still not pregnant were inseminated to observed estrus.

Dry-Off Threshold

Cows that had an average milk yield of less than 30 kg/wk for 2 consecutive weeks were dried off irrespective of whether they had met their lactation target. Those cows that maintained production above this level for the entire lactation were dried off 56 d before their expected calving date. The dry-off threshold was deliberately set at a low level to ensure cows were not removed from the experiment prematurely (e.g., some cows undergoing extended lactations are capable of re-

covering from low production levels when pasture quality improves in spring; Kolver et al., 2006).

Measurements and Analyses

Milk yield was measured daily for each cow using a DeLaval Alpro milk metering system (DeLaval International, Tumba, Sweden), with the exception of a 12-wk period at the start of the trial when it was measured every 2 wk using Tru-Test milk meters (Tru-Test Ltd., Auckland, New Zealand). A composite sample was taken of the daily milk (p.m. and a.m.) from each cow using inline milk meters once every 2 wk and tested for concentrations of fat, protein, and lactose using an infrared milk analyzer (model 2000, Bentley Instruments, Chaska, MN).

Cows were weighed approximately monthly, at which time their BCS was also assessed. Samples of pasture and other feeds offered to cows were collected once every 2 wk. These feed samples were oven dried, ground through a 0.5-mm sieve, and then analyzed for composition by near-infrared spectroscopy by a commercial laboratory (FeedTest, Hamilton, Victoria, Australia).

Statistical Analyses

The data were used to calculate total lactation yields for each cow. The log-transformed data were then subjected to analysis using an additive mixed model with fixed effects for lactation length [6 levels: 10 mo (A), 10 mo (B), 13 mo, 16 mo, 19 mo, and 22 mo] and for age (2 levels: heifer and cow). The 10 mo (A) and (B) groups were the continuation of the same herd in 2 successive lactations, but with necessary replacement cows. The mixed model specified random effects for cow and re-

Table 2. Number of cows in each treatment, percentage reaching their target, and average DIM for cows managed to achieve lactations between 10 and 22 mo¹

Item	Target lactation length					
	10 mo (A)	10 mo (B)	13 mo	16 mo	19 mo	22 mo
Cows, n	24	25	25	24	24	24
Target days	300	300	393	486	579	670
Cows reaching target, n	24	24	25	23	20	10
Cows reaching target, %	100	96	100	96	83	42
Average DIM	300	300	393	485	561	643

¹A and B denote the first and second 10-mo lactations for the control group.

peated measures within cow. The analysis provided a vector of treatment group mean estimates adjusted for age group and where relevant (10-mo groups) for cow, and a corresponding variance-covariance matrix, as well as Wald significance tests for differences between groups (and between age groups). Graphs of residuals vs. fitted values were used to check constant variance, and histograms and q-q plots of residuals were used to check the normal distribution assumption. The log-transformation was applied to meet these statistical requirements.

Group means were “annualized” to estimate the production on a per-year basis and thus more fairly compare the levels of production of the different lactation lengths over time. This was achieved by multiplying each mean by 12/CI, where CI was the calving interval for the treatment in months; namely, the specified lactation length + 2. This was equivalent to, and was effected by, adding $\log(12/CI)$ to the means on the log scale.

An attempt was made to address the fact that treatments were measured over different periods of time by comparing the different groups with a control (10-mo lactation) estimate that as far as possible represented the period over which the lactation length of interest was measured. For each lactation length group, a reference control estimate was therefore defined as a weighted mean of the 2 available control groups (10-mo A and 10-mo B), with the weighting apportioned as $w = 11/(\text{lactation length})$, and $1 - w$ respectively. For example, for the 22 mo group, $w = 11/22 = 0.5$. The reference control mean for this treatment was the unweighted average of the 10-mo (A) and (B) group estimates (using estimates from the mixed model analysis). For the 13-mo group, $w = 11/13 = 0.846$, and the reference control was therefore 85% of the 10-mo (A) group estimate plus 15% of the 10-mo (B) group estimate.

These results have been further adjusted to present a single control estimate (while retaining the lactation length treatment to reference-control differences). Each of the above adjustments to treatment means was achieved by linear transformations applied to the vector

of group estimates and its corresponding quadratic product with variance-covariance matrix, saved from the mixed model analysis.

Linear and quadratic orthogonal polynomial contrasts were applied to the adjusted treatment means to test for relationships with lactation length. The adjusted treatment means and their variance covariance matrix were also used to compute 5% least significant intervals (Snee, 1981) for the treatment means. These were back-transformed (antilogged) to the original scale for presentation. Pairs of means with nonoverlapping least significant intervals were significantly different at the $P < 0.05$ level.

Fisher's exact test was used to compare the proportions of cows reaching target lactation length.

RESULTS

Proportion of Cows Reaching Their Target Lactation Length

Proportions of cows reaching their target lactation length are presented in Table 2 together with average DIM for each group. At least 96% of all cows were able to maintain milk weight greater than the designated dry-off threshold of 30 kg/wk for target lactation lengths up to and including 16 mo. Only 83% (20/24) and 42% (10/24) of cows were able to sustain their milk production above the required amount for 19- and 22-mo lactations. The proportion of cows reaching 19 and 22 mo was less ($P < 0.05$) than for 10 to 16 mo.

Yields of Milk and Milk Solids

There was an increase ($P < 0.001$) in the kilograms produced per cow as lactation length increased for total lactation yields of milk, milk solids (protein + fat), protein, and fat (Table 3). Lactation yields increased with increasing target lactation length for all production parameters measured.

There were fewer differences between lactation group means for annualized yields of milk, milk solids, protein, and fat (Table 4). The annualized milk yield was

Table 3. Total lactations yields of milk, milk solids (protein + fat), protein, and fat, and concentrations of protein and fat (average for lactation) for cows undergoing lactations between 10 and 22 mo¹

Yield	Lactation length (mo)					P-value ²
	10	13	16	19	22	
Milk, kg/cow	6,454 ^a	7,902 ^b	9,420 ^c	10,316 ^d	11,549 ^e	<0.001
Milk solids, kg/cow	497 ^a	623 ^b	743 ^c	830 ^d	925 ^e	<0.001
Protein, kg/cow	214 ^a	268 ^b	321 ^c	359 ^d	401 ^e	<0.001
Fat, kg/cow	283 ^a	355 ^b	423 ^c	470 ^d	525 ^e	<0.001
Protein, g/kg	33.3 ^a	34.0 ^{ab}	34.2 ^b	34.9 ^b	34.8 ^b	<0.001
Fat, g/kg	44.1	45.2	45.1	45.9	45.7	0.137

^{a-e}Group means with different superscripts are significantly different ($P < 0.05$).

¹Data are means for all cows in each group; data in 10-mo column are means of adjusted data from 2 lactations.

²P-value denotes significance of the linear contrast applied to group means to test for overall effect of lactation length.

higher ($P < 0.05$) for the control herds than for the herds managed for 19- and 22-mo lactations. The annualized milk solids production was higher ($P < 0.05$) for the control herd than for the herd managed for a 22-mo lactation. There were no differences ($P > 0.05$) between any of the group means for annualized protein yield. The control herd yielded more ($P < 0.05$) than the group managed for a 22-mo lactation for annualized production of milk fat.

Patterns of milk and milk solids (protein + fat) production for the different lactation length groups are presented in Figure 1.

Changes in BCS and BW

Every herd gained BCS and BW between calving and its respective dry-off date (Table 5). Gains in mean BCS between calving and dry off were lower ($P < 0.05$) for groups managed for 10-, 13-, and 16-mo lactations than for groups managed for 19- and 21-mo lactations. Gains in mean BW between calving and dry off were less ($P < 0.05$) for groups managed for 10- and 13-mo lactations than for groups managed for 16-, 19-, and 22-mo lactations.

Linear Contrasts

Linear contrasts applied to the group means showed significant positive relationships between lactation length and total lactation yields of milk, milk solids, protein, and fat, as well as BCS and BW change between calving and dry off (data not shown). Linear contrasts showed significant negative relationships between lactation length and annualized yields of milk, milk solids, protein, and fat (Table 6).

DISCUSSION

This experiment provided a detailed assessment of the potential of cows managed in a pasture-based dairy system to complete lactations ranging between 10 and 22 mo in duration. Over 95% of cows were able to lactate for at least 16 mo, albeit in the context of the low dry-off (lactation termination) threshold applied in this experiment. Some cows were unable to maintain milk production and were dried off before their target was reached, especially when managed for lactations longer than 16 mo. Nevertheless, these data show that a lactation of 16 mo (i.e., an 18-mo intercalving interval) is a

Table 4. Annualized yields of milk, milk solids (protein + fat), protein, and fat for cows undergoing lactations between 10 and 22 mo¹

Yield	Lactation length (mo)					P-value ²
	10	13	16	19	22	
Milk, kg/cow	6,454 ^a	6,321 ^{ab}	6,280 ^{ab}	5,895 ^b	5,775 ^b	<0.001
Milk solids, kg/cow	497 ^a	498 ^{ab}	495 ^{ab}	474 ^{ab}	463 ^b	0.011
Protein, kg/cow	214	214	214	205	201	0.027
Fat, kg/cow	283 ^a	284 ^{ab}	282 ^{ab}	269 ^{ab}	262 ^b	0.009

^{a,b}Group means with different superscripts are significantly different ($P < 0.05$).

¹Data are means for all cows in each group; data in 10-mo column are means of adjusted data from 2 lactations.

²P-value denotes significance of the linear contrast applied to group means to test for overall effect of lactation length.

Figure 1. Lactation curves for production of milk and milk solids (protein + fat) for cows undergoing lactations of 10 (2 lactations: $\square$), 13 ($\blacksquare$), 16 ($\circ$), 19 ($\bullet$), or 22 mo ($\blacktriangle$). Data are means for all lactating cows; arrows indicate time of dry off for the control herd in their first lactation.

realistic target for cows in a pasture-based dairy system. Many cows could milk for longer; up to 22 mo in some cases. Further analyses are required to assess the proportion of cows that complete extended lactations while sustaining milk production at more economic levels than the dry-off threshold used in this experiment.

Dairy herd owners in Australia and New Zealand receive payment for milk on the basis of the quantity of protein and fat, with a penalty for milk volume. As a consequence, the term “milk solids” (representing the quantities of protein + fat) is widely regarded as a more important production parameter than milk volume. In

Table 5. Body condition score and BW at calving, and changes in BCS and BW between calving and dry off, for cows undergoing lactations between 10 and 22 mo¹

Item	Lactation length (mo)					<i>P</i> -value ²
	10	13	16	19	22	
BCS at calving ³	4.59	4.53	4.44	4.41	4.52	—
BCS change	0.20 ^a	0.41 ^a	0.37 ^a	1.25 ^b	0.88 ^b	<0.001
BW at calving, kg	496	490	474	473	481	—
BW change, kg	77 ^a	89 ^a	160 ^b	179 ^b	188 ^b	<0.001

^{a,b}Group means with different superscripts are significantly different ($P < 0.05$).

¹Data are means for all cows in each group; data in 10-mo column are means of adjusted data from 2 lactations.

²*P*-value denotes significance of the linear contrast applied to group means to test for overall effect of lactation length.

³Condition scored by trained assessors using an 8-point scale (Earle, 1976).

this experiment there was an increase in both the amount of milk and milk solids produced as lactation length increased, primarily because of additional DIM (Table 3). A more meaningful estimate by which to compare the production of extended lactation systems is to use annualized production figures (Table 4) that take into account the fact that, compared with traditional seasonal-calving systems, cows with extended lactations spend less time in peak production but also more time lactating.

The current experiment showed a negative relationship between lactation length and the annualized production of milk and milk solids (Table 6). Nevertheless, there were few significant differences between individual treatment means for the different lactation length groups (Table 4). Extending lactation from 10 to 16 mo resulted in a numerical milk solids loss of <2 kg/cow per year. This amount of loss was much less than the 31-kg loss reported by Osterman and Bertilsson (2003) for cows producing 616 kg of milk solids per year. Even when lactation length was extended to 22 mo the loss of milk solids in the current experiment was only 32 kg/yr (around 5%). This was similar to the milk solids loss of 6% reported by Kolver et al. (2006) for cows that were genetically of North American origin grazing pasture in New Zealand and offered a similar level of supplements as the cows in the current experiment.

Table 6. Linear contrast analysis testing the significance of the relationship between annualized production of milk, milk solids (protein + fat), protein, and fat with increasing lactation length¹

Item	Contrast term	SE	<i>t</i> -value	<i>P</i> -value
Milk	-0.1168	0.0338	-3.462	<0.001
Milk solids	-0.0772	0.0298	-2.587	0.011
Protein	-0.0688	0.0308	-2.236	0.027
Fat	-0.0832	0.03116	-2.667	0.009

¹Contrasts were applied to treatment (lactation length) means on the natural log scale. The contrast term represents the slope of a linear trend of the means with lactation length, in units of years.

Cows with extended lactations had higher average concentrations of milk protein compared with cows in the control group undergoing normal lactations of 10 mo (Table 3). This was one reason why the loss of milk solids with increasing lactation length was smaller than the loss of milk volume. This increase in milk protein concentration was because of elevated protein during the extended lactation component of the lactation (after 300 d). This phenomenon has been observed among individual cows completing lactations of >1,000 d in commercial Victorian dairy herds (M. J. Auldist, unpublished data), and for cows in New Zealand undertaking 600-d lactations (Kolver et al., 2006).

Cows in the longer lactation groups completed their lactations with greater BW and BCS compared with cows undergoing 10-mo lactations (Table 5). This was also observed by Kolver et al. (2006) and would be because of cows spending more time in positive energy balance after peak milk production. Higher BCS at calving can increase production of cows in the ensuing lactation (Grainger et al., 1982; Pryce and Harris, 2006), although the effect of consecutive extended lactations remains untested within grazing dairy systems.

In summary, the current experiment has shown that cows managed under a pasture-based system were able to sustain extended lactations with good persistency, even up to 22 mo. Compared with standard 10-mo lactations, there were small annual losses of milk solids yield during extended lactations. Cows undergoing extended lactations had greater milk protein concentrations and gained more body condition and BW during their lactation than control cows. The data indicate a potential role for extended lactations in Victorian pasture-based dairying systems in which Holstein dairy cattle now predominate.

ACKNOWLEDGMENTS

The authors are grateful to D. Mapleson, I. Robinson, R. Case, T. Hookey, and staff at the DPI Ellinbank

research farm for technical assistance with cow husbandry, grazing management, and sampling procedures, and to M. Hannah for conducting the statistical analyses. This research was funded by the Department of Primary Industries (Victoria) and the Geoffrey Gardiner Dairy Foundation Limited.

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