Seasonal and lactational influences on bovine milk composition in New Zealand

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Summary. This study was designed to evaluate the respective influences of stage of lactation (SOL) and time of year on the seasonal variation in milk composition for pasture-fed dairy cows in New Zealand. Four herds of ~ 20 Friesian cows were used, one herd calving in a 6 week period beginning in each of January, April, July and October. Cows grazed rye-grass–white clover pasture only, except during June when all cows received supplementary pasture silage. Milk samples were collected from each cow in milk on four occasions during the year (September, December, March and June), to give a total of three samples per cow (early, mid and late lactation; about 30, 120 and 210 d respectively after calving). Samples were analysed for a detailed range of components. Concentrations of many milk components (e.g. total protein, fat, casein and whey protein) increased as lactation progressed; the extent of these increases depended on the time of year. These results indicated that spreading calving throughout the year would lessen seasonal variations in the gross composition of milk supplied to factories, leading to a more even distribution of product yield across the year. Despite this, variations in some important manufacturing properties were affected by time of year but not by SOL. Ratios of protein:fat and casein:whey protein were not significantly affected by SOL, but were affected by time of year. The solid fat content of milk was also affected by time of year. Seasonal variations in the manufacturing properties of milk may be reduced but not eliminated by changing the time of calving.

The New Zealand dairy industry is based around the use of pasture as a low-cost feed source, which has led to the wide adoption of seasonal calving in order to maximize pasture utilization. Most cows calve just before spring, and are dried off for periods of 8–10 weeks during winter. This practice has created irregularities in the supply of milk to processors in terms of both quantity and composition, and is accompanied by seasonal variations in the manufacturing properties of the milk. In particular, milk from late in the production season can have manufacturing properties that differ from those of early and mid-season milk, and some products cannot be made at all at this time (see Lucey, 1996). This reduces the ability of manufacturing companies to react to market forces, and necessitates storage of product to meet demand out of season.

Seasonal variation in the composition of milk is associated with several factors. Nutritional factors associated with changing availability and quality of pasture through the year, physiological changes associated with the stage of lactation (SOL) of the cows, and pathological factors associated with a changing incidence of mastitis have all been identified as playing a significant role (O'Keeffe *et al*. 1982; Lucey &

Fox, 1992; Kefford *et al.* 1995; Auldist *et al.* 1996). The precise effect of any one factor, however, is often confounded by the effects of others. The aim of the present study was to evaluate the respective effects of time of year and SOL on seasonal variation in milk composition.

MATERIALS AND METHODS

Animals and management

A total of 80 mixed age Friesian cows were divided into four herds of 20 (excepting the January calving group at the September sampling, when only 16 cows were available). The breeding of each herd was arranged so that calving occurred at intervals of 3 months, with one herd calving during each of January, April, July and October. This meant that there were always at least three herds in milk grazing similar pasture, but each at a different SOL.

The cows were managed as separate herds on the Dairying Research Corporation's no. 3 Dairy (28 ha) but milked twice daily through a common dairy. The usual stocking rate was ~ 3·5 cows/ha. Each herd was offered a daily pasture allowance sufficient to meet metabolizable energy (ME) requirements deemed appropriate for the particular level of production and SOL, based on the UK dairy cow feeding standards (Agricultural Research Council, 1984), and as determined using the nutritional model RUMNUT (A. T. Chamberlain, University of Reading, Reading RG6 2AT, UK). Whenever possible, cows grazed rye-grass–white clover pasture only. When insufficient pasture was available to meet requirements, each cow received supplementary silage as a similar proportion of their diet. At the June sampling, ~ 20% of all cows' dry matter (DM) intake was silage. Herds were dried off ~ 270 d after calving, depending on feed availability and cow body condition.

Mean cow age, days since calving, breeding index, live weight, condition score and estimated DM intakes for each herd (excluding cows with somatic cell counts (SCC) > 400000 cells/ml) at each sampling time are presented in Table 1. Average pasture DM intake for each herd was estimated on each day of milk sampling by visual appraisal of pasture cover before and after grazing (L'Huillier & Thomson, 1988). Cow live weight and condition score (Macdonald & Macmillan, 1993) were assessed before and after each milk sampling period.

Mean composition of pasture and silage offered to cows in each herd at each sampling time is presented in Table 2.

Sampling of milk and pasture

On four occasions during the year (September, December, March and June), in-line milk meters were used to collect a sample of milk from each cow at six consecutive milkings. This facilitated the calculation of milk yield and enabled a representative composite sample to be prepared for each cow on each sampling occasion. Each cow was therefore sampled from on three occasions (early lactation, EL; mid lactation, ML; and late lactation, LL).

Samples of pasture offered to each herd on each of the 3 d of the milk sampling period were collected by hand clipping to grazing height (40 mm). Samples of silage (June sampling only) were also collected on each day for each herd. Pasture and silage samples were dried in an oven at 96 °C for 12 h, then ground and analysed.

Table 1. *Cow age, days since calving, breeding index, live weight, condition score and estimated dry matter intake for herds in early, mid and late lactation in spring (September), summer (December), autumn (March) and winter (June)*

(Values are means ± SD) †

	Spring Early	Spring Mid	Spring Late	Summer Early	Summer Mid	Summer Late	Autumn Early	Autumn Mid	Autumn Late	Winter Early	Winter Mid	Winter Late
Age, years	3·9 ± 1·8	5·8 ± 2·2	6·7 ± 2·1	5·5 ± 2·2	4·1 ± 2·2	5·7 ± 2·2	6·5 ± 3·0	5·3 ± 2·3	3·9 ± 1·9	6·2 ± 2·8	6·3 ± 2·9	5·3 ± 2·1
Days since calving	43 ± 9	118 ± 10	220 ± 10	33 ± 16	127 ± 9	202 ± 11	50 ± 11	140 ± 19	233 ± 9	43 ± 10	140 ± 13	229 ± 17
Breeding index	138 ± 8	131 ± 6	131 ± 5	131 ± 7	137 ± 8	131 ± 6	133 ± 7	131 ± 8	138 ± 8	133 ± 4	133 ± 6	131 ± 7
Live weight, kg	396 ± 51	428 ± 45	438 ± 54	461 ± 51	483 ± 65	512 ± 47	464 ± 53	454 ± 41	469 ± 54	443 ± 61	444 ± 55	434 ± 45
Condition score	3·7 ± 0·5	3·8 ± 0·3	3·9 ± 0·7	4·6 ± 0·4	4·4 ± 0·4	4·4 ± 0·4	4·5 ± 0·6	4·5 ± 0·5	4·4 ± 0·5	4·7 ± 0·6	4·2 ± 0·4	4·3 ± 0·6
Daily dry matter intake, kg/cow	16·2	13·0	11·5	17·3	15·9	14·1	16·8	15·7	14·6	16·0‡	14·4‡	12·8‡

† Values exclude cows with somatic cell counts > 400 000 cells/ml.
‡ Includes ~ 20% pasture silage on a dry matter basis.

Table 2. *Composition of pasture and silage offered to herds in early, mid and late lactation in spring (September), summer (December), autumn (March) and winter (June)*

(Values are means ± SD)

	Spring Early	Spring Mid	Spring Late	Summer Early	Summer Mid	Summer Late	Autumn Early	Autumn Mid	Autumn Late	Winter Early	Winter Mid	Winter Late
Pasture												
Protein, g/kg	234 ± 21	217 ± 27	246 ± 33	145 ± 17	141 ± 22	154 ± 16	193 ± 14	185 ± 13	185 ± 8	225 ± 11	230 ± 17	240 ± 8
Digestibility †	0·788 ± 0·015	0·797 ± 0·030	0·795 ± 0·020	0·751 ± 0·017	0·727 ± 0·016	0·761 ± 0·030	0·656 ± 0·036	0·684 ± 0·026	0·653 ± 0·040	0·787 ± 0·030	0·816 ± 0·012	0·836 ± 0·075
ME, MJ/kg DM	11·8 ± 0·2	11·9 ± 0·5	11·9 ± 0·3	11·2 ± 0·3	10·8 ± 0·3	11·3 ± 0·5	9·7 ± 0·6	10·1 ± 0·4	9·6 ± 0·6	11·7 ± 0·5	12·2 ± 0·2	12·5 ± 1·2
NDF, g/kg DM	467 ± 59	525 ± 106	485 ± 13	519 ± 16	512 ± 33	505 ± 15	470 ± 39	480 ± 11	507 ± 39	559 ± 18	549 ± 42	552 ± 25
ADF, g/kg DM	286 ± 57	257 ± 19	265 ± 42	286 ± 20	279 ± 12	267 ± 14	244 ± 18	253 ± 31	261 ± 26	195 ± 12	192 ± 21	187 ± 15
Silage												
Protein, g/kg	—	—	—	—	—	—	—	—	—	162 ± 61	163 ± 7	152 ± 8
Digestibility †	—	—	—	—	—	—	—	—	—	0·719 ± 0·028	0·732 ± 0·032	0·740 ± 0·022
ME, MJ/kg DM	—	—	—	—	—	—	—	—	—	107 ± 4	109 ± 5	110 ± 3
NDF, g/kg DM	—	—	—	—	—	—	—	—	—	590 ± 45	593 ± 40	594 ± 43
ADF, g/kg DM	—	—	—	—	—	—	—	—	—	285 ± 24	274 ± 10	268 ± 22

ME, metabolizable energy; DM, dry matter; NDF, neutral detergent fibre; ADF, acid detergent fibre.
† *In vitro* DM digestibility, expressed as a proportion.

Milk analyses

Milk samples were analysed for fat and lactose using an i.r. milk analyser (Milkoscan 133B; Foss Electric, Hillerød, Denmark). SCC were measured using an automated cell counter (Fossomatic 215; Foss Electric). Total N (TN), non-protein N (NPN) and non-casein N (NCN) were measured using macro-Kjeldahl techniques (Barbano *et al*. 1991), and urea N using a commercially available test kit (Boehringer, D-68298 Mannheim 31, Germany). These N fractions were then used to calculate protein ((TN − NPN) × 6·38), casein protein ((TN − NCN) × 6·38) and whey protein ((NCN − NPN) × 6·38). Bovine serum albumin (BSA) and immunoglobulin G (IgG) were tested for using commercially available radial immunodiffusion kits according to the manufacturer's instructions (The Binding Site Ltd, Birmingham B29 6AT, UK). Concentrations of Na and K were determined using flame photometry. The fatty acid profiles of milk fat were obtained by gas chromatography (MacGibbon, 1988) following extraction of the milk fat using a modification of the Röse–Gottlieb technique (International Dairy Federation, 1987). Solid fat content at 10 °C (SFC_{10}) was measured by pulsed nuclear magnetic resonance (MacGibbon & McLennan, 1987). The total colour (β-carotene equivalents) of milk was measured by the absorbance of milk fat after the samples had been dissolved in petroleum ether (Norris *et al*. 1971).

Pasture and silage analyses

N contents of pasture and silage were measured using a macro-Kjeldahl digest (Model 16210, Foss Electric) by reduction with alkaline sodium phenate (Gehrke *et al*. 1972). Samples for *in vitro* digestibility analysis were oven dried at 60 °C for 16 h before analysis according to the method of Tilley & Terry (1963). Acid detergent fibre and neutral detergent fibre contents were measured using the method of Goering & van Soest (1970). ME contents of pasture were estimated using the equation (Anon. 1990)

$$\text{ME (MJ/kg DM)} = 0{\cdot}156 \times \text{in vitro DM digestibility} - 0{\cdot}535.$$

Statistical analyses

Results were analysed using SAS (1989) with the restricted maximum likelihood method of the mixed model procedure. Cow was specified as a random effect, and SOL and time of year were specified as fixed effects. On any sampling occasion, cows with SCC > 400 000 cells/ml (between one and six cows per group) were excluded from the analyses so as to avoid the confounding effect of SCC on milk composition (Munro *et al*. 1984).

RESULTS

Yields of milk, fat and protein

There were effects ($P < 0{\cdot}01$) of both SOL and time of year on daily yields of milk, fat and protein (Table 3). At all sampling times, yields of milk, fat and protein were highest in EL and lowest in LL. Overall, yields of milk, fat and protein were highest in summer and lowest in winter. There was also an interaction ($P < 0{\cdot}05$) between the effects of SOL and time of year on yields of milk and fat; the effect of SOL was greater in winter than in summer.

Milk composition

Mean concentrations of milk components and ratios of selected milk components relative to each other at each sampling occasion are presented in Table 3. There was an effect of SOL ($P < 0{\cdot}01$) on all milk components measured, with the

Table 3. *Yields and concentrations of milk components for cows in early, mid and late lactation in spring (September), summer (December), autumn (March) and winter (June)* †

	Sampling																
	Spring			Summer			Autumn			Winter			SED within herds	SED across herds	Main effects		
	Early	Mid	Late	Early	Mid	Late	Early	Mid	Late	Early	Mid	Late			Stage	Season	Interaction
No. of cows	17	18	13	19	17	17	14	14	14	19	18	18	—	—	—	—	—
Milk yield, kg/d	18·5	14·3	11·7	20·4	17·4	13·6	19·6	14·8	12·8	19·0	12·3	8·9	0·75	0·98	**	**	*
Fat yield, kg/d	0·77	0·64	0·53	0·86	0·76	0·65	0·83	0·73	0·62	0·84	0·61	0·47	0·035	0·046	**	**	*
Protein yield, kg/d	0·55	0·44	0·38	0·61	0·56	0·46	0·57	0·48	0·43	0·55	0·41	0·31	0·024	0·031	**	**	NS
Fat, g/kg	42·2	45·3	46·3	42·0	44·4	48·3	42·1	49·8	49·7	44·5	50·1	53·2	1·73	2·28	**	**	NS
Protein, g/kg	29·7	30·7	33·0	29·9	32·7	33·7	28·9	32·7	34·0	28·7	33·6	34·9	0·80	0·92	**	*	*
Lactose, g/kg	49·4	49·2	47·8	48·9	49·9	49·0	49·2	47·5	49·3	48·1	46·4	44·9	0·45	0·82	**	**	**
Casein, g/kg	24·9	25·5	27·2	25·0	27·5	28·2	23·8	26·9	28·3	23·6	27·7	28·4	0·69	0·79	**	*	*
Whey protein, g/kg	4·90	5·18	5·77	4·94	5·20	5·44	5·08	5·75	5·77	5·04	5·90	6·42	0·228	0·270	**	**	NS
Bovine serum albumin, mg/l	164	213	233	236	239	264	207	226	224	209	269	256	14·2	18·1	**	**	NS
Immunoglobulin G, mg/l	469	474	602	667	534	608	708	669	698	709	757	901	52·4	58·6	**	**	NS
Non-protein N, g/kg	0·34	0·34	0·38	0·29	0·26	0·31	0·36	0·36	0·35	0·35	0·34	0·35	0·011	0·012	**	**	**
Non-casein N, g/kg	1·11	1·15	1·29	1·07	1·07	1·17	1·15	1·27	1·25	1·14	1·27	1·36	0·037	0·043	**	**	NS
Urea, mM	6·45	6·13	7·48	4·57	4·11	5·15	6·85	6·89	6·57	7·31	6·49	7·16	0·342	0·369	**	**	*
Na, g/kg	0·45	0·48	0·53	0·45	0·43	0·46	0·45	0·48	0·49	0·45	0·50	0·58	0·016	2·0	**	**	**
K, g/kg	1·59	1·59	1·52	1·61	1·59	1·59	1·57	1·54	1·48	1·52	1·48	1·37	0·025	3·8	**	**	NS
Total colour‡	0·42	0·43	0·46	0·30	0·28	0·31	0·25	0·32	0·30	0·48	0·42	0·41	0·030	0·037	NS	**	*
Casein N : total N	0·779	0·776	0·768	0·785	0·801	0·791	0·763	0·769	0·779	0·764	0·774	0·766	0·006	0·007	**	**	NS
Casein : whey protein	5·14	4·97	4·76	5·13	5·38	5·26	4·74	4·75	4·95	4·75	4·79	4·48	0·203	0·238	NS	**	NS
Protein : fat§	0·713	0·683	0·726	0·720	0·745	0·702	0·696	0·665	0·689	0·647	0·679	0·666	0·025	0·028	NS	**	NS
Na : K	0·286	0·301	0·354	0·282	0·273	0·289	0·291	0·310	0·336	0·297	0·343	0·428	0·016	0·018	**	**	**

† Values are means with cows with somatic cell counts > 400 000 cells/ml excluded.
‡ Expressed as β-carotene equivalents, μg/g milk.
§ Calculated using true protein.
NS not significant, *$P < 0·05$, **$P < 0·01$.

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Table 4. *Proportions of selected fatty acids and solid fat content at 10 °C in milk from cows in early, mid and late lactation in spring (September), summer (December), autumn (March) and winter (June)*

(Values are percentage of total fatty acids) †

Fatty acid	Sampling												SED within herds	SED across herds	Main effects		
	Spring			Summer			Autumn			Winter							
	Early	Mid	Late	Early	Mid	Late	Early	Mid	Late	Early	Mid	Late			Stage	Season	Interaction
16:0	26·1	26·3	25·5	28·8	31·5	29·6	27·6	31·7	29·0	26·5	30·0	31·2	0·89	1·05	**	**	**
18:1	23·1	22·2	24·1	19·6	17·3	18·7	23·9	19·5	21·4	25·2	20·5	20·8	0·94	1·04	**	**	**
Conjugated 18:2 ‡	0·97	1·11	1·27	0·63	0·74	0·79	0·95	0·89	0·94	0·60	0·94	0·87	0·079	0·095	**	**	NS
Short (4:0–8:0)	7·89	7·90	7·56	7·87	7·56	7·58	8·16	7·91	7·73	7·95	7·57	7·37	0·167	0·172	**	**	NS
Medium (10:0–12:0)	7·31	7·38	6·79	7·13	7·73	7·48	6·35	6·74	6·52	5·90	6·79	6·01	0·357	0·378	**	**	NS
Long (14:0–18:0)	50·1	51·0	48·6	55·3	56·8	55·2	52·0	56·0	54·1	50·7	53·2	54·0	0·74	0·98	**	**	*
Monounsaturates	26·3	25·4	27·8	22·8	20·8	22·3	27·1	22·8	24·5	28·4	24·7	25·0	0·89	1·01	**	**	*
Polyunsaturates	4·29	4·27	4·70	3·31	3·30	3·52	3·96	3·95	4·44	3·90	4·08	4·08	0·170	0·197	**	**	NS
SFC_{10}, g/kg fat §	522	542	500	582	640	610	516	587	569	513	568	575	12·3	17·4	**	**	*

† Values are means with cows with somatic cell counts > 400000 cells/ml excluded.
‡ Conjugated linoleic acid
§ Solid fat content at 10 °C.
NS not significant, $*P < 0·05$, $**P < 0·01$.

exception of casein:whey protein and fat:protein ratios and total colour. Overall, concentrations of fat, protein, casein, whey protein, BSA and Na were highest in LL and lowest in EL. For IgG, concentrations were lowest in ML and highest in LL. For lactose and K, concentrations decreased as lactation progressed.

Time of year had an effect ($P < 0{\cdot}05$) on all milk components (Table 3). Overall, concentrations of casein, BSA, lactose and K and ratios of casein:whey protein, casein N:TN and protein:fat were highest in summer, whereas concentrations of NPN, NCN, urea, whey protein and Na were lowest in summer. Concentrations of fat, protein, whey protein, IgG and Na were highest in winter, whereas concentrations of lactose and K and the ratios of casein:whey protein, casein N:TN and protein:fat were lowest in winter.

There were also interactions ($P < 0{\cdot}05$) between the effects of SOL and time of year for concentrations of lactose, true protein, casein, NPN, urea and Na (Table 3). Generally, the difference between the concentrations of these components in EL and LL milk was greater in winter than in summer.

Milk fatty acid profiles and solid fat content

Mean proportions of selected fatty acids and SFC_{10} for each SOL at each sampling occasion are presented in Table 4. Time of year and SOL had effects ($P < 0{\cdot}01$) on proportions of most fatty acids measured. Overall, milk from cows in EL had higher proportions of monounsaturated fatty acids, particularly 18:1, than milk from ML or LL. Proportions of monounsaturated fatty acids were lowest in summer and highest in winter and spring, while medium-chain saturated fatty acids were lowest in winter. Long-chain saturated fatty acids were lowest in spring, whereas polyunsaturated fatty acids, including conjugated linoleic acid, were highest in spring. There was an interaction ($P < 0{\cdot}05$) between the effects of SOL and time of year for most fatty acids measured, including the long-chain saturated fatty acids as well as the monounsaturated fatty acids (Table 4). The differences between the proportions of these fatty acids in milk from EL and LL were greatest in autumn and winter.

Effects of SOL and time of year on SFC_{10} are presented in Table 4. Overall, SFC_{10} was lower in EL milk than in ML or LL milk, although this was not apparent in spring. Irrespective of SOL, SFC_{10} was lowest in spring and highest in summer. The effect of time of year was greater than the effect of SOL. There was an interaction ($P < 0{\cdot}05$) between the effects of SOL and time of year.

DISCUSSION

Seasonal variation in milk characteristics and the processing problems associated with late lactation milk from seasonally calving, pasture-based dairying systems have been well described (for review, see Lucey, 1996). Some previous studies have attributed seasonal variation in milk composition to changes in the availability and quality of pasture through the year (O'Keeffe, 1984; Lucey & Fox, 1992; Kefford *et al.* 1995). Others have attributed it to increases in proteolytic activity associated with the SOL of the cows (Donnelly & Barry, 1983). In the current experiment, the detailed composition of milk from cows at different SOL was compared concurrently at intervals throughout the year, while holding other variables constant. This allowed the effects of SOL to be separated from those of time of year, and a quantitative comparison made of the effects of each. It is conceded that the nutritional status of the cows would have been different during the different sampling occasions, particularly at the winter sampling when pasture was supplemented with silage (Table 2). Nevertheless, these nutritional fluctuations are considered to be seasonal factors related to a changing availability and quality of pasture. This experiment was not designed to partition the effects of nutrition from the effects of other factors associated with time of year (e.g. photoperiod, temperature) which impact on the cows directly.

The effect of SOL on milk yield (Table 3) was probably due to physiological changes in the number and activity of secretory cells within the mammary gland. Peak yield is reached some 40 d post partum, owing at least partly to a rapid increase in secretory tissue volume caused by a combination of cellular hyperplasia followed by hypertrophy. Thereafter follows a programmed decline in secretory cell numbers (apoptosis) until involution, which is accompanied by a concurrent decline in milk volume (Knight & Wilde, 1993). Concentrations of many milk components (e.g. protein, fat, casein) increased as lactation progressed, which concurs with previous observations (Rogers & Stewart, 1982; Auldist *et al*. 1995, 1996; Kefford *et al*. 1995). This probably was due largely to the concentrating effect of decreasing milk volumes, since yields of fat and protein decreased with advancing lactation. Nevertheless, this result implies a greater yield efficiency of dairy product from LL milk, even though such milk can be associated with product quality defects (O'Keeffe, 1984; Kefford *et al*. 1995).

O'Keeffe (1984) and Lucey & Fox (1992) both observed that LL milk was not always unsuitable for manufacturing. The manufacturing potential of milk in these studies was affected by the time of year at which the cows entered LL, which probably reflected differences in pasture availability. Further, Kefford *et al*. (1995) demonstrated that the suitability of LL milk for cheese manufacture was enhanced when the diet of the cows was improved by feeding supplementary concentrates. The results of the present experiment are consistent with these previous observations. Ratios of casein : whey protein and protein : fat (indices of the manufacturing quality of milk) were highest in summer and lowest in winter, but were not affected by SOL (Table 3). Casein N : TN ratios were similarly affected by time of year. These results indicate that having cows in EL or ML during autumn–winter would not improve the manufacturing properties of milk at these times.

A reduction in the availability of pasture can increase the proportions of whey proteins in milk (Gray & Mackenzie, 1987). A reduced pasture intake could also reduce the availability of amino acids for casein synthesis. These factors may therefore have contributed to the low relative proportions of casein found in the current experiment during autumn and winter (even though absolute casein concentrations increased with decreasing milk volume). Despite this, comparisons of DM, energy and protein intakes in the context of requirements across the year (Tables 1 and 2) revealed no obvious connection with milk composition. Indeed, the time of year during which pasture protein contents were lowest (summer) coincided with the time of maximum quality of milk for manufacturing (as indicated by casein concentration and casein : whey protein ratios). Concentrations of urea in milk (Table 3) were also lowest in summer, which similarly indicates a depressed protein intake at this time (for review, see Westwood *et al*. 1997).

Elevated Na : K ratios in LL (Table 3) imply an increased permeability of the mammary epithelium as lactation progressed, possibly indicating the approach of involution in healthy animals. Concentrations of BSA, which originates from the blood, have also been used as an index of the permeability of the mammary epithelium (Stelwagen *et al*. 1994). In this experiment, the effect of SOL on concentrations of BSA was small and inconsistent. This suggests that the notable absence of any significant effect of SOL on casein:whey protein ratios may be explained by the cows not being late enough into lactation, and the disruption to the integrity of the mammary epithelium not severe enough, to exhibit this previously reported phenomenon. This is further supported by previous research in New Zealand (Lacy-Hulbert *et al.* 1995) which showed that significant increases in BSA concentrations during LL did not occur until the daily milk yield fell below 5 l/d; in the current study, mean milk yields in LL were well above this level.

The changes in milk fatty acid profiles (Table 4) presumably reflected changes in energy balance of the cows. When cows are in negative energy balance, the synthesis of short- and medium-chain fatty acids by the mammary gland declines, while the mobilization of fatty acids from the adipose tissue increases (Palmquist *et al.* 1993). Rowney & Christian (1996) reported no effect of SOL on the fatty acid composition of milk fat; however, in that experiment cows in EL were not studied. In the present experiment, the effect of SOL on fatty acid profiles was mostly due to differences in EL milk. This is consistent with a physiological incapacity of cows in EL to consume sufficient DM to meet energy requirements (Bines, 1979). Nevertheless, the overall effects of time of year were quantitatively greater than the effects of SOL. This observation provides new evidence that the seasonal variation in milk fat composition reported in New Zealand (Gray, 1973), Australia (Thomas & Rowney, 1996) and Ireland (Cullinane *et al.* 1984) is due mostly to time of year rather than SOL. The variation in the proportions of conjugated linoleic acid is pertinent given recent evidence of its anticarcinogenic properties (for review, see Parodi, 1997).

The seasonal variation in the SFC_{10} of milk (Table 4) was consistent with the variation reported by MacGibbon & McLennan (1987) and Papalois *et al.* (1996). Under constant processing conditions there is a positive correlation between SFC_{10} and the sectility hardness of butter, which reflects the spreadability of the product (Taylor & Norris, 1977; MacGibbon & McLennan, 1987). Irrespective of SOL, SFC_{10} was highest in summer and lowest in spring, indicating that butter would have been hardest in summer and softest and most spreadable in spring. It is also consistent with the proportions of fatty acid 18:1 (and the monounsaturated acids as a group) being lowest in summer, given the strong negative correlation between these fatty acids and SFC_{10} (Mackle *et al.* 1997). The effect of time of year was greater than that of SOL, although there were effects of SOL that again were consistent with the changes in fatty acid profiles described above.

In the case of milk yield, and concentrations of some milk components (e.g. protein, lactose, casein), there were interactions between the effects of SOL and time of year (Table 3). The difference in milk yield and composition between EL and LL became greater as the year progressed from spring through to winter. This demonstrates that the effect of SOL was greatest in autumn and winter, when pasture availability may have been limiting. This is again consistent with the findings of O'Keeffe (1984) and is possibly due to a diet-induced increase in the decline of secretory cell numbers after peak lactation.

In conclusion, these results indicate that spreading calving throughout the year would lessen seasonal variations in the gross composition of milk supplied to factories, by reducing the peak to trough ratio of the concentrations of the major milk components. This would result in a more even distribution of product yield across the year. Despite this, the most important factor affecting some other manufacturing properties of milk (the ratios of casein:whey protein, casein N:TN and protein:fat, and SFC_{10}) was time of year. These results therefore provide new evidence that altering the time of calving in the New Zealand dairying system would have a minimal impact on the variation of these important milk characteristics.

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