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Feeding frequency for lactating cows: effects on digestion, milk production and energy utilization

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1. The results are reported of four feeding experiments in which lactating cows were given fixed rations of hay and high-cereal concentrates at different meal frequencies. In Expt 1 the total ration was given in two and twenty-four meals daily and in Expts 2–4, the concentrates were given in two and five or six meals and the hay was given twice daily. The diets contained 600–900 g concentrate/kg.

2. In all the experiments, more frequent feeding of these low-roughage diets reduced milk fat depression and increased milk fat yield. In each experiment the increase was greater with the diet containing the lower proportion of hay. There was no significant effect on milk yield, the protein or lactose contents of the milk or live-weight gain. Digestibility of dry matter, organic matter and energy was increased in one of the experiments but not in two others in which it was measured.

3. More frequent feeding was calculated to increase the net energy secreted in milk and there was a tendency for it to increase the net energy in live-weight gain with diets containing 600 or 700 g concentrate/kg but to decrease it with diets containing 800 or 900 g concentrate/kg. These results are discussed in relation to theories of energy partition in lactating cows.

4. It is concluded that at fixed feed intakes, the main response to increased meal frequency is likely to be a reduction in milk fat depression and that this will be confined to diets containing not more than about 200 g modified acid-detergent fibre/kg dry matter.

Cows housed indoors are traditionally given their concentrates twice daily around milking time. This is also the commonest routine in most lactation experiments. It has been frequently pointed out that this may not be the best routine for maximizing the efficiency of utilization of feed for milk production. Twice daily feeding of large amounts of concentrates results in two bursts of fermentation in the rumen 2 or 3 h after each meal. This causes the pH of the rumen contents to fall sharply, often to values well below 6·0 which have been shown to reduce cellulolysis. A further consequence is that the supply of volatile fatty acids (VFA) to the body fluctuates widely over the day and this almost certainly adds to the very considerable metabolic stress of the high-producing dairy cow at peak lactation.

Despite the theoretical disadvantages of twice-daily feeding, the results of experiments in which the number of daily meals of concentrates has been increased have only occasionally shown clear benefits from the more even distribution of feed intake (see reviews by Burt & Dunton, 1967; Kaufmann *et al.* 1975). On the basis of their own experiments Kaufmann *et al.* (1975) suggested that the main benefits of more frequent feeding were confined to diets containing relatively small amounts of roughage. The present paper describes a series of experiments in which the effects of meal frequency on feed utilization for milk production were examined for diets of hay and concentrates in which the proportion of concentrates was varied between 600 and 900 g/kg. The principal response to frequent feeding was a marked reduction in the milk fat depression caused by low-roughage diets.

A brief report of some of these results was published earlier (Sutton *et al.* 1982).

Table 1. *Expts 2–4. The composition (g/kg) of the concentrate mixtures*

	Concentrate mixture		
	A	B	C
Barley	696	703	715
Fishmeal	49	49	35
Decorticated groundnut meal*	186	40	10
Protein concentrate†	49	198	240
Mineral supplement	20	10	0

* In Expt 4 soya-bean meal replaced the decorticated groundnut meal because of supply difficulties.

† Concentrate composed of mixed vegetable proteins with additional vitamins and minerals and contained 400 g crude protein (nitrogen × 6·25)/kg dry matter.

MATERIALS AND METHODS

The results of four experiments are reported. In each experiment two diets, varying in the ratio, concentrate:hay, were given at two meal frequencies to Friesian cows. The cows were housed in concrete standings with rubber mats and individual feeding facilities. They were milked at 06.00 and 14.30 hours in their standings and the weight of milk was recorded on each occasion.

Expt 1 was designed primarily to examine aspects of rumen fermentation in detail and involved three cows, each with a permanent rumen fistula. Expts 2, 3 and 4 were feeding experiments, each involving sixteen cows. In all the experiments the diets consisted of long or coarsely-chopped hay and pelleted concentrates containing about 700 g barley/kg; in Expt 1 only, flaked maize was also given. The constituents of the concentrates A, B and C used in Expts 2–4 are given in Table 1.

Expt 1

Three Friesian cows in their second or later lactation and weighing approximately 550 kg were used. Each was fitted with a large permanent rumen fistula with a rubber cannula and bung (Balch & Cowie, 1962).

All the cows were offered two diets, each at two meal frequencies in a sequence dictated largely by the needs to develop techniques for measuring rates of VFA production by isotope-dilution procedures (Sutton & Schuller, 1974). For each diet frequent feeding preceded twice daily feeding. The diets were a ‘normal’ diet (660 g concentrate/kg) consisting of 5·5 kg hay and 10·8 kg dairy concentrate daily to give 180 MJ digestible energy (DE)/d, and a low-roughage diet (LR1, 920 g concentrate/kg) consisting of 1·0 kg hay, 5·5 kg dairy concentrate and 5·5 kg flaked maize daily and providing 145 MJ DE/d. One cow (C) refused to consume this diet and was given 1·6 kg hay and 13·9 kg dairy concentrate daily (LR2, 900 g concentrate/kg), providing 180 MJ DE/d.

Each diet was given in two different feeding frequencies. With twice-daily feeding, the daily ration was given in two equal portions at 08.00 hours and 20.00 hours. With frequent feeding, the daily ration was divided into twenty-four equal portions and delivered by automatic equipment at hourly intervals. The hay was given in the long form with twice daily feeding but was coarsely chopped (50–100 mm) with hourly feeding.

All the measurements were made when the cows were in their third to twelfth month of lactation. Before any measurements were made, at least 3 weeks were allowed for change-over and adapation to the change of diet and at least 2 weeks for adaptation to a change of frequency. Measurements of milk composition are reported for 14-d periods during which time feed digestibility and various aspects of rumen metabolism (Sutton & Schuller, 1974; J. D. Sutton and E. Schuller, unpublished results) were also measured.

Milk samples were taken at each milking during the period of measurement and weighted bulks for each day were prepared for analysis. Faeces were collected in a pit behind each cow and urine was diverted by a light harness and tube arrangement for 10 d.

Expt 2

Sixteen first-calf Friesian cows in mid-lactation with a mean live weight of 480 kg in mid-experiment were used. They had previously been used in a comparison of high- and low-protein diets for the first 70 d of lactation (Oldham *et al.* 1979) and they were re-randomized orthogonally on to four treatments for the present study. They were given a control ration of 3·6 kg hay and 10·8 kg dairy concentrate per d for 3 weeks between the two experiments, a further 3 weeks was allowed for change-over and adaptation to the new treatments and observations were made during the following 7 weeks which constituted weeks 17–23 of lactation.

The four experimental treatments consisted of two values for concentrate:hay, 60:40 and 90:10, and two frequencies of feeding, twice and five times daily, to give four treatments designated 60:2, 60:5, 90:2 and 90:5. The diets, which were similar to those used in another experiment (Broster *et al.* 1979), were designed to provide similar amounts of DE and total nitrogen. The 600 g concentrate/kg diet consisted of 6·0 kg hay and 9·0 kg concentrate A daily, and the 900 g concentrate/kg diet consisted of 1·4 kg hay and 12·6 kg concentrate C daily. With twice daily feeding, half the daily ration of hay and concentrates was given at each milking. With five times daily feeding, the hay was given in approximately three equal amounts at 06.00, 14.30 and 17.00 hours and the daily ration of concentrates was divided into five portions and given at 06.00, 10.30, 14.30, 17.00 and 21.30 hours. Uneaten feed was removed and weighed at 14.00 hours. Milk samples were taken on four successive milkings each week and a weighted bulk was prepared for analysis. Cows were weighed on 3 d each week.

Expts 3 and 4

Sixteen second- and third-calf Friesian cows were used in each experiment and the two experiments took place in successive years. Mean live weight of the cows in mid-experiment was 499 kg in Expt 3 and 523 kg in Expt 4. Before calving the cows were given increasing amounts of feed such that the ration 2 weeks before calving consisted of 5 kg hay and 5 kg dairy concentrate daily. After calving, the ration was increased steadily from 4 kg hay and 4 kg concentrate B at calving to 4·3 kg hay and 13 kg concentrate B on day 17. From day 22 the ration was gradually changed over a period of up to 10 d to one of the experimental diets and the cows were then kept on this diet for the remainder of the experiment which lasted until week 27 of lactation.

In each experiment four experimental treatments were given and consisted of two values for concentrate:hay and two frequencies of feeding, twice and six times daily. In Expt 3 the two concentrate:hay values were 70:30 and 90:10 giving four treatments designated 70:2, 70:6, 90:2 and 90:6. In Expt 4 the two concentrate:hay values were 60:40 and 80:20 giving four treatments designated 60:2, 60:6, 80:2 and 80:6. All the diets were designed to provide similar amounts of DE and total N. In Expt 3 the cows were given 5·0 kg hay and 11·5 kg concentrate B daily on the 700 g concentrate/kg diet, and 1·6 kg hay and 14·0 kg concentrate C daily on the 900 g concentrate/kg diet. In Expt 4 the cows were given 6·7 kg hay and 10·0 kg concentrate A daily on the 600 g concentrate/kg diet, and 3·2 kg hay and 12·8 kg concentrate B daily on the 800 g concentrate/kg diet. With twice daily feeding half the daily ration of hay and concentrates was given at each milking. With six times daily feeding, half the hay was given at the morning milking and half at 16.45 hours. The daily ration of concentrates was dispensed in six approximately equal portions by a simple automatic dispenser every 4 h starting at 14.30 hours. Any uneaten feed was removed and weighed at 14.00 hours.

In both experiments milk yield and composition and live weight were measured throughout the 27 weeks of the experiments but mean values for weeks 7–27 were used for measuring treatment effects. Milk samples were taken on two successive milkings weekly and a weighted bulk was prepared for analysis. Cows were weighed on 2 d weekly. Digestibility of the diets was measured by collecting faeces by means of a harness and bag for 8 d in the middle of the experiments.

Sample processing and analyses

Milk samples were analysed for fat by the Gerber method in Expt 1 and for fat, protein and lactose by infra-red analysis (IRMA; Grubb Parsons, Newcastle upon Tyne) in Expts 2–4. Samples of feed were taken at monthly intervals throughout Expts 2–4 as well as during the digestibility trials and were freeze-dried, milled and stored for analysis. A fixed proportion of faeces was taken as a sample every 2 d, frozen and subsequently freeze-dried. The sub-samples for the whole collection period were bulked and the bulk sample was milled and stored for analysis. Samples of feed and faeces were analysed for organic matter (OM) by ashing at 550° for 4 h, gross energy by adiabatic bomb calorimetry and acid-detergent fibre (ADF) (Van Soest, 1963) in Expt 1, single-acid fibre (Whitehouse *et al.* 1945) in Expt 2 and crude fibre and modified ADF (Clancy & Wilson, 1966) in Expts 3 and 4. Feed samples were also analysed for total N by the Kjeldahl technique.

The energy content of milk was calculated from eqn (1) of Tyrrell & Reid (1965).

Statistical analyses

Expts 2–4 used a continuous-treatment design and results were examined by analysis of variance (Snedecor & Cochran, 1967). Covariance analysis was used to adjust experimental period values for incidental variation amongst cows in the preliminary control period when a significant covariance effect was established. In Expt 2 the values for milk variates obtained in the 3-week period before the start of the experiment were used to adjust those recorded in the experimental period. In Expts 3 and 4, milk yield and composition in week 3 of lactation, and live weight on days 4 and 5 of lactation, were used.

RESULTS

The composition of the feeds is given in Table 2. The concentration (g/kg dry matter (DM)) of crude protein and fibre respectively in the various diets was as follows: Expt 1: normal diet 135 and 176; low-roughage diets, LR1 134 and 83, LR2 155 and 112. Expt 2: 600 g concentrate/kg diet 215 and 155, 900 g concentrate/kg diet 225 and 84. Expt 3: 700 g concentrate/kg diet 183 and 162, 900 g concentrate/kg diet 193 and 100. Expt 4: 600 g concentrate/kg diet 181 and 193, 800 g concentrate/kg diet 195 and 124.

Expt 1

In each comparison of the effects of feeding frequency, milk fat concentration was higher when the cows were fed twenty-four times than when they were fed twice daily (Table 3). Although frequent feeding always preceded twice daily feeding, the effects of stage of lactation on milk fat concentration are small in mid-lactation and the large differences must be ascribed primarily to the effects of changing meal frequency. The low-roughage diets

Table 2. *Composition of the experimental feeds*

Expt no.		Dry matter (g/kg feed)	Organic matter (g/kg DM)	Gross energy (MJ/kg DM)	Fibre* (g/kg DM)	Nitrogen (g/kg DM)
1	Hay	840	925	17·76	339	9·7
	Dairy concentrate	860	941	18·35	92	27·8
	Flaked maize	847	988	18·38	35	16·0
2	Hay	853	921	—	290	21·4
	Concentrate A	869	938	—	66	43·0
	Concentrate C	869	925	—	62	37·6
3	Hay	828	938	18·30	416	15·1
	Concentrate B	860	924	17·85	56	35·2
	Concentrate C	859	921	17·87	65	32·6
4	Hay	848	923	18·06	396	15·0
	Concentrate A	860	938	18·30	58	38·3
	Concentrate B	863	927	17·98	57	35·2

DM, dry matter.

* Expt 1, acid-detergent fibre (Van Soest, 1963); Expt 2, single acid fibre (Whitehouse *et al.* 1945); Expts 3 and 4, modified acid-detergent fibre (Clancy & Wilson, 1966).

Table 3. *Expt 1. Mean milk fat concentration in three cows given a normal diet containing 340 g hay/kg and one of two low-roughage diets containing 80 or 100 g hay/kg in either two or twenty-four meals daily*

	Fat concentration (g/kg)	
Meals/d...	2	24
Normal diet*		
Cow A	30·1	33·3
Cow B	34·6	35·3
Cow C	33·4	40·3
Low-roughage diets*		
Cow A (diet LR1)	20·5	31·0
Cow B (diet LR1)	22·2	37·6
Cow C (diet LR2)	28·6	33·5

* For details of diets, see p. 118.

caused severe milk fat depression with twice daily feeding, reducing milk fat concentration from a mean of 32·7 g/kg on the normal diet to a mean of 23·8 g/kg on the low-roughage diets. In contrast, with frequent feeding the change of diet had no consistent effect on milk fat concentration, the mean values being 36·3 and 34·0 g/kg on the normal and low-roughage diets respectively.

Milk yield varied between cows and treatments over a range of 13–20 kg/d and tended to be higher when the cows were fed frequently. However, the design of the experiment did not allow the effects of the treatments on milk yield to be examined critically.

Feeding frequency had no consistent effect on the digestibility of DM, OM or gross energy for either diet type (Table 4).

Table 4. *Expt 1. Digestibility of dry matter, organic matter and gross energy by three cows given a normal diet containing 340 g hay/kg and one of two low-roughage diets containing 80 or 100 g hay/kg in either two or twenty-four meals daily*

	Dry matter		Organic matter		Gross energy	
Meals/d...	2	24	2	24	2	24
Normal diet*						
Cow A	0·753	0·717	0·769	0·740	0·741	0·702
Cow B	0·696	0·727	0·713	0·746	0·700	0·724
Cow C	0·705	0·738	0·730	0·759	0·685	0·729
Low-roughage diets*						
Cow A (diet LR1)	0·792	0·792	0·805	0·808	0·777	0·768
Cow B (diet LR1)	0·781	0·787	0·793	0·804	0·765	0·773
Cow C (diet LR2)	0·762	0·750	0·780	0·770	0·751	0·741

* For details of diets, see p. 118.

Table 5. *Expt 2. Mean daily yield and composition of milk† and live-weight change in weeks 17–23 of lactation in sixteen cows given two diets, each at two meal frequencies*

Concentrates:hay...	60:40		90:10			Main effects		
Meals/d...	2	5	2	5	SEM	Diet	Frequency	Interaction
Milk yield (kg/d)	17·1	19·2	22·9	23·8	1·09	***	NS	NS
Milk energy yield (MJ/d)	52·0	56·0	49·0	64·0	3·66	NS	*	NS
Composition (g/kg)								
Fat	39·9	36·3	18·6	28·7	1·73	***	NS	**
Protein	32·6	32·3	30·3	31·8	0·98	NS	NS	NS
Lactose	46·3	46·4	47·9	47·1	0·35	**	NS	NS
Yield (kg/d)								
Fat	0·68	0·68	0·40	0·70	0·057	*	*	*
Protein	0·57	0·59	0·70	0·75	0·098	**	NS	NS
Lactose	0·79	0·89	1·10	1·12	0·035	***	NS	NS
Live-wt change (kg/d)	−0·11	+0·28	+0·46	+0·09	0·167	NS	NS	*

NS, not significant.
* $P < 0·05$, ** $P < 0·01$, *** $P < 0·001$.
† Values for milk yield and for the yield and concentration of fat and lactose are adjusted by covariance on values for weeks 11–13 of lactation.

Expt 2

The effects on the yield and composition of milk and on live-weight change are given in Table 5. On average the yield of milk was increased by 5·1 kg/d by increasing the proportion of concentrates but feeding frequency was without significant effect. Significant ($P < 0·05$) main effects of proportion of concentrates and frequency of feeding on milk fat yield were established but there was also a significant ($P < 0·05$) interaction because there was no effect of more frequent feeding with 600 g concentrate/kg but an increase of 75% with 900 g concentrate/kg. On treatment 90:5, milk fat yield was similar to that on the two 600 g concentrate/kg diets whereas with treatment 90:2 it was severely reduced. The yields

Table 6. *Expt 3. Mean daily yield and composition of milk and live-weight change in weeks 7–27 of lactation in sixteen cows given two diets, each at two meal frequencies*

Concentrates:hay...	70:30		90:10			Main effects	
Meals/d...	2	6	2	6	SEM	Diet	Frequency
Milk yield (kg/d)	19·7	20·2	23·0	21·4	1·42	NS	NS
Milk energy yield (MJ/d)	55·8	62·1	51·7	57·3	3·36	NS	NS
Composition (g/kg)							
Fat	32·6	39·2	17·9	29·7	2·01	***	***
Protein	33·2	34·1	32·0	33·2	0·89	NS	NS
Lactose	47·3	46·3	48·0	47·1	0·54	NS	NS
Yield (kg/d)							
Fat	0·64	0·79	0·42	0·62	0·055	**	**
Protein	0·66	0·68	0·73	0·71	0·029	NS	NS
Lactose	0·93	0·94	1·10	1·01	0·066	NS	NS
Live-wt change (kg/d)	+0·18	+0·29	+0·36	+0·25	0·072	NS	NS

** $P < 0·01$, *** $P < 0·001$.

of protein and lactose were increased by about 30% by increasing the proportion of concentrates but were not significantly affected by feeding frequency. Milk fat concentration was severely reduced by the 900 g concentrate/kg diets and although no main effect of feeding frequency was established, there was a significant interaction ($P < 0·01$) because more frequent feeding caused a small reduction in fat concentration with 600 g concentrate/kg and a large increase with 900 g concentrate/kg. The concentration of protein was unaffected by treatments but there was a small but significant ($P < 0·01$) increase in the concentration of lactose when the proportion of concentrates was increased.

The calculated yield of energy in milk was increased by more frequent feeding, the effect being far greater with the higher proportions of concentrates.

There were no significant main effects on live-weight change but a significant ($P < 0·05$) interaction was established because more frequent feeding increased live-weight change with the 600 g concentrate/kg diet but decreased it with the 900 g concentrate/kg diet.

Expt 3

The responses in this experiment were similar to those in Expt 2 but only the milk fat responses achieved statistical significance (Table 6). Milk fat yield and milk fat concentration were significantly ($P < 0·01$ and $P < 0·001$ respectively) decreased by the higher proportion of concentrates and increased by more frequent feeding. The increase occurred with both diets but tended to be greater with the higher proportion of concentrates. As in Expt 2 there were increases in the yield of milk and in the yields of protein and lactose in milk with the higher proportion of concentrates but in this experiment none of these changes was significant. With both diets about 6 MJ extra energy were secreted in the milk with more frequent feeding but the effect was not significant. Differences in live-weight change were not significant.

The digestibilities of DM, OM and gross energy were higher for the 900 g concentrate/kg diet and with more frequent feeding (Table 7). In consequence, the intakes of digestible DM and DE were similar for the two concentrate:hay values with twice daily feeding and the intake of digestible OM was only slightly lower ($P < 0·05$) with the 900 g concentrate/kg diet but the intake of these digestible nutrients was consistently about 3–5% higher with

Table 7. *Expt 3. The daily intake, digestibility coefficient and digestible nutrient intake of dry matter, organic matter, energy and modified acid-detergent fibre (ADF) in sixteen cows given two diets each at two meal frequencies*

Concentrate: hay...	70:30		90:10			Main effects	
Meals/d...	2	6	2	6	SEM	Diet	Frequency
Dry matter (DM)							
Intake (kg/d)	14·0	14·0	13·4	13·4	—	—	—
Digestibility	0·719	0·754	0·748	0·775	0·0066	**	***
Digestible DM intake (kg/d)	10·1	10·6	10·0	10·3	0·09	NS	***
Organic matter (OM)							
Intake (kg/d)	13·0	13·0	12·3	12·3	—	—	—
Digestibility	0·746	0·778	0·773	0·802	0·0062	**	***
Digestible OM intake (kg/d)	9·7	10·1	9·5	9·9	0·08	*	***
Gross energy							
Intake (MJ/d)	252·2	252·2	239·1	239·1	—	—	—
Digestibility	0·718	0·752	0·758	0·784	0·0071	***	**
Digestible energy intake (MJ/d)	181·1	189·6	181·2	187·4	1·75	NS	**
Modified ADF (kg/d)							
Intake (kg/d)	2·28	2·28	1·33	1·33	—	—	—
Digestibility	0·538	0·577	0·304	0·400	0·0188	***	**
Digestible ADF intake (kg/d)	1·23	1·32	0·40	0·53	0·031	***	**

* $P < 0·05$; ** $P < 0·01$, *** $P < 0·001$.

Table 8. *Expt 4. Mean daily yield and composition of milk and live-weight change in weeks 7–27 of lactation in sixteen cows given two diets, each at two meal frequencies*

Concentrates: hay...	60:40		80:20			Main effects	
Meals/d...	2	6	2	6	SEM	Diet	Frequency
Milk yield (kg/d)	19·3	20·8	20·6	24·5	1·51	NS	NS
Milk energy yield (MJ/d)	55·2	60·0	55·4	69·2	3·91	NS	*
Composition (g/kg)							
Fat†	34·3	36·2	31·6	35·3	0·87	NS	**
Protein	31·4	31·8	31·7	31·2	1·02	NS	NS
Lactose	44·8	45·7	45·3	46·3	0·51	NS	NS
Yield (kg/d)							
Fat†	0·63	0·76	0·67	0·86	0·053	NS	*
Protein	0·59	0·65	0·64	0·75	0·030	*	*
Lactose	0·87	0·95	0·93	1·13	0·073	NS	NS
Live-wt change (kg/d)	+0·17	+0·13	+0·36	+0·18	0·072	NS	NS

* $P < 0·05$, ** $P < 0·01$.

† Values adjusted by covariance on week 3 of lactation.

Table 9. *Expt 4. The daily intake, digestibility coefficient and digestible nutrient intake of dry matter, organic matter, energy and modified acid-detergent fibre (ADF) in sixteen cows given two diets each at two meal frequencies*

Concentrate:hay...	60:40		80:20			
Meals/d...	2	6	2	6	SEM	Diet effect
Dry matter (DM)						
Intake (kg/d)	14·3	14·3	13·8	13·8	—	—
Digestibility	0·678	0·693	0·740	0·735	0·0092	***
Digestible DM intake (kg/d)	9·7	9·9	10·2	10·1	0·13	*
Organic matter (OM)						
Intake (kg/d)	13·3	13·3	12·7	12·7	—	—
Digestibility	0·706	0·721	0·770	0·766	0·0081	***
Digestible OM intake (kg/d)	9·4	9·6	9·8	9·8	0·10	*
Gross energy						
Intake (MJ/d)	260·1	260·1	247·7	247·7	—	—
Digestibility	0·675	0·689	0·743	0·738	0·0090	***
Digestible energy intake (MJ/d)	175·5	179·3	183·9	182·9	2·23	*
Modified ADF (kg/d)						
Intake (kg/d)	2·75	2·75	1·71	1·71	—	—
Digestibility	0·524	0·530	0·500	0·470	0·0230	NS
Digestible ADF intake (kg/d)	1·44	1·46	0·86	0·80	0·042	***

* $P < 0·05$, ** $P < 0·01$, *** $P < 0·001$.

six times daily feeding than with twice daily feeding. The digestibility of modified ADF was much lower ($P < 0·001$) on the 900 g concentrate/kg diet and was increased by more frequent feeding ($P < 0·01$).

Expt 4

As in Expt 3, the principal effect was an increase in the yield ($P < 0·05$) and concentration ($P < 0·01$) of fat in milk due to more frequent feeding (Table 8). The increase occurred with both diets but tended to be greater with the higher proportion of concentrates. Protein yield was increased ($P < 0·05$) by more frequent feeding of both diets, the increase tending to be greater with the higher proportion of concentrates. Differences in live-weight change were not significant.

Digestibilities of DM, OM and gross energy were higher ($P < 0·001$) for the 800 g concentrate/kg diet but were unaffected by feeding frequency (Table 9). In consequence the intakes of digestible DM, digestible OM and DE were about 3% higher for the 800 g concentrate/kg diets but unaffected by feeding frequency. The digestibility of modified ADF was lower, but not significantly so, on the 800 g concentrate/kg diet and was unaffected by feeding frequency.

DISCUSSION

Milk production

The first experiment was designed primarily to allow study of certain aspects of rumen metabolism but the effects of the treatments on milk fat content that were observed in that experiment established a clear pattern that was confirmed in the following, larger-scale experiments. This pattern was for the replacement of the normal diets by low-roughage diets to cause a reduction in milk fat concentration in cows given two meals daily and for substitution of frequent feeding for twice daily feeding to reduce or even eliminate this milk fat depression. In each of the feeding trials that followed, milk fat concentration and yield were increased by more frequent feeding.

In Expt 2, in which the two most extreme diets were compared, fat concentration and yield were only increased on the 900 g concentrate/kg diet, a significant interaction with diet type being established. In both the other experiments, the increases in fat concentration and yield were greater with the diets containing the higher proportion of concentrates but the differences in diet composition within each experiment were smaller and no interaction with diet type was established.

Milk yield was not significantly increased by more frequent feeding, but it was higher in the more-frequently-fed cows in all comparisons except when the 900 g concentrate/kg diet was given in Expt 3. The mean increase in Expts 2–4 was 1·2 kg/d or about 5%. The yield and concentration of lactose and the concentration of protein were unaffected. Protein yield was increased in Expt 4 only.

Taken together these results indicate that as the proportion of concentrates in a fixed amount of feed is increased, the response in milk fat concentration and yield to more frequent feeding of concentrates increases, from little or no benefit with diets containing 600 g concentrate/kg and about 200 g modified ADF or 180 g crude fibre/kg DM, to about 10 g fat/kg milk with diets containing 900 g concentrate/kg and about 100 g modified ADF or 80 g crude fibre/kg DM.

Earlier experiments in which the frequency of concentrate feeding was varied were reviewed by Burt & Dunton (1967) and Kaufmann *et al.* (1975). Only occasionally were clear benefits obtained from more frequent feeding. The results of Kaufmann *et al.* (1975) showed no improvement in milk yield from increasing feeding frequency from twice daily to between four and fourteen times daily, but in most cases an increase in fat concentration for diets containing relatively-small amounts of roughage was observed.

Kirchgessner *et al.* (1982) recently summarized a series of experiments they had conducted in which cows were given mixed diets of forages and concentrates with both feeds being given twice daily, the forage twice and the concentrates six times or both feeds six times daily. In successive experiments the crude fibre content of the diets was reduced from 184–190 g/kg DM to 162 g/kg DM by reducing forage intake from about 12 to 7·5 kg DM daily. Only at the lowest level of forage inclusion was there an effect of feeding frequency on milk production. In this case more frequent feeding of concentrates significantly increased milk yield by a little over 1 kg/d, similar to the mean increase in the present experiments, and milk fat concentration by about 1 g/l. These increases in fat concentration, although significant, were very small compared with those reported in the present experiments but the lowest concentration of fibre (162 g crude fibre/kg DM) in the experiments of Kirchgessner *et al.* (1982) was only a little lower than the highest level (200 g modified ADF or 180 g crude fibre/kg DM) in the present experiments.

The present experiments, together with those of Kaufman *et al.* (1975), Johnson (1979) and Kirchgessner *et al.* (1982) strongly suggest that the basic response to more frequent feeding of concentrates is a reduction in the milk fat depression usually caused by feeding low-roughage diets. Hence little or no improvement is to be expected if milk fat concentration from animals being fed twice daily is already in the normal range as it was in the experiments of van der Honing *et al.* (1976), Thomas & Kelly (1976) and Gill & Castle (1983), none of whom found any benefit from more frequent feeding.

In view of the many dietary factors that contribute to dietary-induced milk fat depression (Sutton, 1981), it is not possible to identify any one concentration of dietary fibre below which more frequent feeding can be recommended. The present experiments suggest that, with fairly large amounts of high-barley concentrates, improvements may be expected when the total diet contains less than about 200 g modified ADF or 180 g crude fibre/kg DM. An alternative definition would be in terms of the fibre contributed from the forage alone rather than from the total diet, in which case benefits would be expected from diets containing less than about 160 g modified ADF or 155 g crude fibre, from forage alone, per kg DM. With less rapidly fermentable concentrates or at lower levels of feed intake, more frequent feeding may only be beneficial with diets containing still lower concentrations of fibre. None of the reported experiments satisfactorily defines the minimum number of meals necessary to maintain milk fat concentration on low-roughage diets. The response of milk fat concentration to hourly feeding of the total ration in Expt 1 was similar to the response to six times daily feeding of concentrates in the other experiments. Moreover, hourly feeding as in Expt 1 is clearly impractical and about six meals spread over the whole day appears to offer a satisfactory compromise for practical applications.

Digestibility

The effects of feeding frequency on diet digestibility in these experiments were inconsistent. In Expt 3, digestibility of DM, OM and gross energy was about 4% higher in the frequently-fed animals for both diets and the difference in fibre digestibility was even greater, yet in Expts 1 and 4 no consistent differences were detected for any of the diets. The compositions of the hay and concentrates were very similar in Expts 3 and 4 and it is particularly difficult to explain the different results of these two experiments. Van der Honing *et al.* (1976) and Kirchgessner *et al.* (1982) also found no improvements in digestibility by lactating cows when diets were given more frequently. In experiments with sheep and non-lactating cattle also, both at this Institute (J. D. Sutton, unpublished results) and by Kirchgessner and his colleagues (Roth & Kirchgessner, 1976; Müller *et al.* 1980), increased feeding frequency had no effect on diet digestibility.

A survey of previously published studies of the effects of feeding frequency with various classes of ruminants shows that responses in digestibility to more frequent feeding are highly variable and range from small decreases to increases of about 5%. The experiments by Graham (1967) with sheep given ground lucerne (*Medicago sativa*) pellets suggested that the size of the improvement increases with feed intake. On this basis improvements should be particularly large in lactating cows, yet this is clearly not so. There is no obvious means of predicting those situations in which improvements are to be expected and this difficulty is emphasized by the different responses between such similar experiments as Expts 3 and 4 in the present series.

Energy utilization

To facilitate comparison of the effects of feeding frequency among the various diets, it was planned that the DE intakes of the twice-daily-fed animals should be similar for the two diets used in Expt 2 and that they should also be similar for all four diets used in Expts 3 and 4 (Table 10). Digestibility was not measured in Expt 2, but on the basis of measurements made in another experiment in which the same rations, although different batches of hay and concentrates, were fed (Broster *et al.* 1979), DE intakes were calculated to be about 160 MJ/d. In Expts 3 and 4 the daily DE intakes in the twice-daily-fed animals only varied between 176 and 184 MJ.

The calculated amounts of net energy (NE) for maintenance, milk production and live-weight change in Expts 2–4 are also given in Table 10. NE was assumed to be 0·32 MJ/kg body-weight$^{0.75}$ for maintenance and 26 MJ/kg change in body-weight for live-weight change (Agricultural Research Council, 1980).

Table 10. *Expts 2–4. Digestible energy intake and estimates of net energy for maintenance, milk production and live-weight gain in cows given various diets, each at two meal frequencies*

Expt no.	Treatment*	Digestible energy (MJ/d)	Net energy (MJ/d) Maintenance	Milk	Live-wt gain	Total
2	60:2	†	33	52	−3	82
	60:5	—	33	56	7	96
	Difference‡	—	—	+4	+10	+14
	90:2	†	33	49	12	94
	90:5	—	32	64	2	98
	Difference	—	—	+15	−10	+4
3	70:2	181	34	56	5	95
	70:6	190	34	62	7	103
	Difference	+9	—	+6	+2	+8
	90:2	181	34	52	9	95
	90:6	187	33	57	7	97
	Difference	+6	—	+5	−2	+2
4	60:2	176	35	55	4	94
	60:6	179	35	60	3	98
	Difference	+3	—	+5	−1	+4
	80:2	184	36	55	9	100
	80:6	183	33	69	5	107
	Difference	−1	—	+14	−4	+7

* g concentrate/100 g: no. of meals/d.
† Not measured (estimated intake was about 160 MJ digestible energy/d).
‡ Response to more frequent feeding.

For each diet the gross energy intake was the same for both meal frequencies yet the more-frequently-fed animals produced between 4 and 15 MJ more NE in milk than the twice-daily-fed animals to give an average increase of 8 MJ or 16% more NE in milk from the same feed intake. In all comparisons except for the 600 g concentrate/kg diet in Expt 2, this increase was due primarily to the greater secretion of milk fat.

Effects of feeding frequency on the estimated NE in live-weight change were more variable with both increases and decreases but for each comparison the calculated total NE of the feed was greater with more frequent feeding of the concentrates. The increase varied from 2 to 14 MJ/d, about 8% on average. An improved efficiency of digestion undoubtedly contributed to this increase but at least some of the improvement appears to reflect a greater efficiency of converting DE to NE.

A particularly interesting aspect of the responses to more frequent feeding was the tendency for an interaction between feeding frequency and the proportion of concentrates in the diets. When the diets containing 600 or 700 g concentrate/kg were given in several meals rather than twice daily, live-weight gain was the same or greater and milk energy was always greater, the average increases being 4 and 5 MJ NE/d respectively. In contrast, when the meal frequency of the 800 and 900 g concentrate/kg diets was increased, live-weight gain was smaller on each occasion (mean difference −5 MJ NE/d) and milk energy was increased by an average of 11 MJ NE/d, twice the increase observed with the lower-concentrate diets.

A well-established response to reducing the roughage content of mixed diets is to alter energy partition by increasing energy retention in the body at the expense of milk fat synthesis (Flatt *et al.* 1969; Sutton *et al.* 1980). Thus an interpretation of the responses in the present series of experiments is that with the lower-concentrate diets, more frequent feeding led to a general improvement in the efficiency of energy utilization resulting in increased energy in both milk and live-weight gain. However, when the proportion of concentrates in the diets was increased, superimposed on this generalized improvement in energy utilization was a reversal of the tendency for energy to be partitioned away from milk and towards body gain by large amounts of concentrates in the diet with the result that live-weight gain was less and milk energy was considerably greater in the frequently-fed animals.

This interpretation of the effects of feeding frequency must remain largely speculative at this stage. Only in Expt 2 did interactions between diet type and meal frequency achieve statistical significance and in none of the experiments were direct measurements of complete energy balances made. However, direct measurements of the effects of meal frequency on energy exchanges in lactating cows have been reported by other workers. Van der Honing *et al.* (1976) failed to obtain any significant effect of meal frequency on energy utilization. On the other hand, it can be calculated from the results of Kirchgessner *et al.* (1980) and Müller *et al.* (1980) that increasing meal frequency for lactating cows from two to six times daily increased the efficiency of retention of DE from 35·4 to 37·8%, values very similar to the mean values of 33·9 and 36·5% respectively for all the diets used in Expts 3 and 4 of the present series. Kirchgessner *et al.* (1980) further calculated that more frequent feeding caused a small increase in energy retention in body tissue and an increase in the partial efficiency of metabolizable energy retention in milk and body tissue from 61·5 to 64·1%. These experiments were with diets containing 157 g crude fibre/kg DM and it would clearly be of great interest to make similar measurements in lactating cows receiving the more extreme diets used in the present experiments.

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