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Effect of frequency of feeding upon food utilization by ruminants

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Introduction

Feeding pattern may be defined as the distribution of food intake over time. As such the term covers many widely divergent aspects of ruminant nutrition.

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This paper deals mainly with one facet of ruminant feeding patterns, that is diurnal variation in the distribution of a controlled food supply. Other well-recognized aspects of feeding patterns, such as seasonal and year-to-year variations in food supply under extensive grazing, compensatory growth, grazing behaviour and effects of physical form of the diet will not be discussed.

Since total gut contents form a much greater percentage of live weight in ruminants than in simple-stomached animals and since their food, particularly the fibrous materials present, is retained longer and digested more slowly than the simpler compounds fed to non-ruminants, it might be expected that ruminants would be quite resistant to changes in the daily feeding pattern. On the other hand, the presence of a vast, dense and active microbiological population in the forestomach which regularly produces large quantities of steam volatile acids is well known in practice to lead to disastrous results if the animal suddenly ingests very large quantities of highly available substrates at one meal. The pattern of daily food supply is therefore of some practical importance, especially if the cost of dividing it into portions is remembered.

Growth

Although Mochrie (1964) in an earlier review concluded that feeding more frequently than once or twice daily generally improved the live-weight gain of growing ruminants, there are numerous carefully controlled experiments which fail to show such responses. In some experiments, growth responses obtained could be largely attributed to increased food intake; for instance Mohrman, Albert, Neumann & Mitchell (1959) obtained increases in the live-weight gain and food intake of steers fed high-energy diets six times instead of twice daily.

Experiments conducted on growing sheep, in which daily food intakes appear to have been satisfactorily equalized are shown in Table 1 and those on growing cattle in Table 2. These tables list the rations used, the number of feeds and the length of the 'feeding day' over which these were distributed. Length of experimental period is shown, and the factor '2×' indicates those experiments in which a changeover design with two periods was used.

Table 1 lists seven experiments with sheep. Positive responses were reported in two of them, namely those of Gordon & Tribe (1952) who appreciably increased live-weight gain from a very low level by feeding eight times instead of once daily. Rakes, Lister & Reid (1961) showed responses in live-weight gain when feeding frequency was increased from once to eight times daily in lambs aged 6 months, but not in ewes aged 2-5 years and considered that increasing age eliminated the response. On the other hand, Rhodes & Woods (1962), who determined live weight after fasting, got no significant or appreciable response in a series of four experiments using ground and mixed, pelleted or conventional rations containing different proportions of roughage.

A similar preponderance of negative results (7:4) is shown for cattle in Table 2. Rakes, Hardison, Albert, Moore & Graf (1957) and Putnam, Gutierrez & Davis

Table 1. *Trials on frequency of feeding with growing sheep*

Authors	Ration	Approx. initial live weight (kg)	No. of feeds daily	Time first to last feed (h)	Live-weight gain (kg/day)	Experimental period* (days)
		Trials giving positive responses				
Gordon & Tribe (1952)	Hay 0·45 kg, concentrates 0·68 kg	34	1	24	0·02	2×63
			8	8	0·08	
Rakes, Lister & Reid (1961)	50% chopped hay, 50% concentrates	(Age 6 months)	1	24	0·10	2×49
			8	10	0·16	
		Trials giving no response				
Rhodes & Woods (1962)	Pelleted 67% concentrates, 37% hay	34	2	11	0·13	54
			4	11	0·17	
			6	11	0·12	
	50% hay, 50% concentrates ground and mixed	31	2	11	0·12	84
			4	11	0·15	
			6	11	0·15	
	49% or 74% concentrates, 51% or 26% hay	29	2	12	0·19	70
			4	12	0·18	
			4	24	0·18	
			6	24	0·17	
	50% brome or alfalfa hay, 50% concentrates	37	2	8	0·13	54
			4	12	0·12	
			6	24	0·12	
Rakes *et al.* (1961)	50% hay, 50% concentrates	(Age 2–5 years)	1	24	0·08	2×49
			8	10	0·08	

*'2×' indicates an experiment in which a changeover design was used.

Table 2. *Trials on frequency of feeding with growing cattle*

Authors	Ration	Approx. initial live weight (kg)	No. of feeds daily	Time first to last feed (h)	Live-weight gain (kg/day)	Experimental period* (days)
		(a) Trials giving positive responses				
Rakes *et al.* (1957)	Chopped alfalfa orchard grass hay 5·1 kg	180	2	9	0·22	2×50
			5	9	0·43	
Mochrie *et al.* (1956)	Concentrates 1·8 kg, hay 2·9 kg	145	1	24	0·47	2×42
			4	12	0·55	
Putnam *et al.* (1961)	Ground alfalfa hay	135	2	9	0·25	2×87
			10	9	0·34	
Campbell *et al.* (1963)	Concentrates+urea 2·5 kg, hay 3·2 kg	145	2 (conc.)	9	0·55	112
			6 (conc.)	15	0·69	
		(b) Trials giving no response				
Anonymous (1958)	Concentrates, hay and brewer's grains	(Age 6–12 months)	1	24	0·59	2×50
			2	?	0·60	
	Concentrates, hay and brewer's grains	(Age 6–12 months)	1	24	0·73	2×50
			6	?	0·76	
Clark & Keener (1962)	Hay to 10% refusal, concentrates 1·1 kg	125	2	9	0·69	245
			24	24	0·69	
	Hay restricted, soya-bean meal 0·25 kg	300?	2	9	0·35	60
			10	9	0·39	
	Hay to 10% refusal, soya-bean meal 0·34 kg	200?	2	9	0·82	60
			10	9	0·81	
	Restricted hay, soya-bean meal 0·34 kg	250?	2	9	0·74	60
			10	9	0·68	
Campbell *et al.* (1963)	Concentrates 2·7 kg, hay 3·0 kg approx.	145	2	9	0·71	112
			6	15	0·75	

*'2×' indicates an experiment in which a changeover design was used.

(1961) obtained substantial responses in live-weight gain when the frequency of feeding chopped or ground hays was increased from two to five or ten times in a 9 h day in reversal trials. Mochrie, Thomas & Lucas (1956) obtained responses when the frequency of feeding a mixed diet was increased from once to four times daily in a reversal trial with Holstein steers.

The results of the experiment of Campbell, Howe, Martz & Merilan (1963) on forty Guernsey heifers fed grain mixtures containing urea or soya-bean meal twice or six times daily have been divided into two parts in Table 2. The diet containing urea which gave a response to increased frequency is shown in part (a) of Table 2 and the part in which soya-bean meal was used, which gave no significant response, is shown in part (b). There were some differences in food intakes between animals fed twice and six times daily in both instances. The system used for the feeding of the hay was not described in detail, but was stated to be on a group basis, while concentrates were individually fed.

Apart from the negative response to more frequent feeding in part of the experiment of Campbell *et al.* (1963), negative responses were also reported by workers at Shinfield (Anonymous, 1958) using identical twin heifers in two reversal experiments and in a series of four experiments carried out by Clark & Keener (1962), who concluded that responses only occurred when the diet was restricted and that these disappeared after the 1st month of feeding. Although Horton (1964) also obtained no response to feeding concentrates twice or four or eight times between 07.00 and 17.00 h, values from this experiment were not included in Table 2 because hay, water and salt were offered *ad lib.* during the night from 17.00 to 07.00 h. More recently, Raleigh & Wallace (1965), in a very brief report, noted that increased frequency of feeding improved response only in calves given low-energy, high-nitrogen diets, as distinct from other combinations of high or low energy and nitrogen. In this experiment a major proportion of the nitrogen was provided by urea.

With both sheep and cattle, therefore, the majority of experiments on growth have shown no response to increasing feeding frequency and it is possible to discern a dietary pattern in those in which responses occurred. In some of the latter experiments, the control treatment was feeding once daily (Gordon & Tribe, 1952; Rakes *et al.* 1961; Mochrie *et al.* 1956), in others roughage supplied the whole of the diet (Putnam *et al.* 1961; Rakes *et al.* 1957) and in the remainder urea was included in the diet (Campbell *et al.* 1963). The only trials in which increasing the frequency from once-daily feeding failed to produce a response were those with identical twins at Shinfield (Anonymous, 1958) and of Rakes *et al.* (1961) with mature sheep.

One may conclude, therefore, that the growing ruminant will often respond to increasing the frequency of feeding from once to twice daily, but that response to further increases in frequency are governed by the nature of the diet and are unlikely to occur in animals fed sufficient roughage and concentrates to give reasonable live-weight gains.

The lactating cow

Since increased frequency of feeding sometimes improves the utilization of the diet of growing ruminants it might be expected that sizeable responses would occur in the lactating cow, because of its generally greater relative energy turnover. Similarly, the practical consequences of giving too much concentrates in one feed, which can rapidly lead to inappetence, are well known and might lead one to expect a response from more frequent feeding. There are, however, few well-established reports of such effects.

Although Campbell & Merilan (1960) obtained higher milk yields when frequency of feeding was increased from twice to four or seven times daily, these could be attributed to increased food intake. Mochrie *et al.* (1956) raised the frequency of feeding from twice to four or eight times daily without influencing milk yield or composition, but heifers in their first lactation were used, which may have been less responsive than older animals. Johnson, Trimberger, Wright, Van Vleck & Henderson (1966) have recently reported that cows fed hay and maize silage twice to five times daily ate less and produced more efficiently in mid-lactation than when fed once daily. We have carried out several carefully controlled experiments, using restricted intakes of roughage and concentrates, which will now be described, and which generally failed to show any benefit from increasing the feeding frequency above that normally practised in the herd in question.

Table 3. *Experiments on the frequency of feeding lactating cows*

Expt no.	Treatment: No. of meals daily	Treatment: Position of cows	Milk yield (kg/day)	Percentage in milk: Fat	Percentage in milk: Protein	Percentage in milk: Lactose	Live weight (kg)	Pulse rate (beats/min)
1	4 (normal)	—	10·52	4·03	3·19	4·63	419·1	63·0
	10 (equal)	—	10·66	4·01	3·20	4·70	420·9	68·8
	Significant difference ($P=0·05$)		0·16	0·08	0·04	0·06	2·0	1·4
2	10 (equal)	—	6·49	4·39	3·49	4·37	431·7	59·2
	4 (normal)	Adjacent	6·43	4·47	3·46	4·28	437·7	60·5
	4 (normal)	Different shed	5·80	4·36	3·58	4·23	438·1	60·5
	Significant difference ($P=0·05$)		0·83	0·23	0·21	0·15	4·3	2·0
3	10 (equal)	—	15·25	3·72	3·19	4·64	476·8	—
	4 (normal)	Adjacent	15·62	3·76	3·16	4·65	481·5	—
	4 (normal)	Distant same shed	15·95	3·61	3·16	4·66	483·1	—
	4 (normal)	Different shed	16·06	3·65	3·15	4·69	482·9	—
	4 (equal)	Different shed	15·72	3·72	3·19	4·69	477·4	—
	Significant difference ($P=0·05$)		0·65	0·17	0·05	0·10	4·4	—

The results of these experiments are shown in Table 3. In all of them a basal constant diet of 5 kg hay and 9 kg grass silage was fed for maintenance with adjustments to take account of individual live weight. Concentrates were fed for production at 4 kg/10 kg milk, using the equalized feeding system of Lucas (1943). The normal feeding routine in this herd already provided four daily meals, namely half the concentrates at 05.30 h, silage at 11.00 h, half the concentrates at 15.00 h and hay at 17.30 h. In the experimental routine, the whole of the daily food allocation was divided into approximately equal meals fed at 05.30, 07.30, 11.00, 12.00, 13.00, 14.00, 15.00, 16.00, 17.30 and 21.00 h.

In Expt 1, ten cows were used in a double-reversal design with 3-week experimental periods to compare the effects of normal, and ten times daily feeding of cows housed adjacently. There were no significant effects upon milk production, but the percentage of lactose was increased by increased feeding frequency. Pulse rates measured at 14.30 h were also increased but this was attributed largely to the effects of redistribution of food intake, which provided higher intakes of roughage and total dry matter before the determination in cows fed more frequently. During this experiment it was observed that the cows fed normally were stimulated into appreciable activity when the extra feeds were given to the more frequently fed cows in adjacent standings, corresponding to the observation of Rakes *et al.* (1961) of temporary increases in heat production in sheep housed alongside others fed frequently. A second experiment was therefore conducted in which cows fed ten times daily were housed alongside normal controls and then compared with other controls housed and fed in a second shed by the same staff in the same manner. There was some evidence from this experiment that the cows fed frequently, and those housed next to them, gave some response in milk yield. Yields were extremely low, probably owing to fungal contamination of the hay used (Burt, Dunton & Thomas, 1963). A third experiment was therefore carried out which attempted to establish whether there was a real difference between cows fed ten times daily and controls fed four times daily. The control animals were housed (a) alongside, (b) distantly but in the same shed or (c) in the second shed. The effects of feeding the diet as four equal feeds instead of the four different feeds of roughage and concentrates were also tested. Five treatments were compared using fifteen cows and 5×4 week periods in a latin square design. The results of this experiment showed that milk yield was lower on ten times daily feeding, significantly lower than on the two distant control treatments, with the adjacent control and four times feeding—equal feeds intermediate. Live weights were lower in cows fed ten equal portions or four times equal portions than on all other treatments. We must therefore conclude that there are no significant responses to be obtained from more frequent feeding of dairy cows, other than those to be achieved by sensible distribution of concentrate intake to avoid digestive disturbance. It is encouraging also to note that we have found no significant difference between the two cowsheds.

Bloomfield, Welsch, Garner & Muhrer (1961) reported that feeding a diet containing urea sixteen times daily instead of twice to lambs improved the utilization of nitrogen, and Campbell *et al.* (1963) reported that there was no difference in growth or the efficiency of utilization of diets containing soya-bean meal or urea when these were fed six times daily, but that there was a substantial difference in live-weight gain in favour of soya-bean meal when the diets were fed twice daily. In a further experiment we therefore examined the effects of frequent feeding with diets containing urea (Table 4). In this experiment, the urea treatments depressed the percentages of milk fat and lactose, but increased the percentage of milk protein. The depression in total milk output approached significance. Frequency

Table 4. *Effect of feeding frequency upon the utilization of urea by lactating cows*

Treatment	Milk yield (kg/day)	Percentage in milk: Fat	Lactose	Protein	Live weight (kg)
(1) Urea twice daily, roughages twice daily	15·69	3·51	4·86	3·07	458·1
(2) Urea and roughages ten times daily	15·66	3·53	4·88	3·11	455·8
(3) Vegetable protein and roughages fed as in (1)	15·99	3·73	4·94	3·00	458·5
Significant difference ($P=0·05$)	0·35	0·11	0·07	0·05	2·3

of feeding had no appreciable or significant effect upon the response to urea, except to depress live weight measured at 11.00 h.

We therefore conclude that increased frequency of feeding is not effective in overcoming the depression of milk production which usually occurs on diets containing urea.

In all four experiments differences in mean live weight related to changes in feeding frequency were recorded which were significant or nearly so. We were able to relate these to differences in dry-matter intake during the morning before recording weight at 11.00 h in three out of four cases. This illustrates the care with which apparent effects of feeding frequency upon live weight or any other characteristic measured once daily must be interpreted.

General effects on food utilization

Zero, positive or negative responses in the digestibility of the diet to increased frequency of feeding have all been reported. No responses were obtained by Blaxter, Graham & Wainman (1956) when sheep were fed equal amounts of dried grass at 24, 12 or 6 hourly intervals or by Satter & Baumgardt (1962) or Rhodes & Woods (1962).

Rakes *et al.* (1957) reported that feeding ten times daily significantly depressed the digestibility of the dry matter, nitrogen, crude fibre and nitrogen-free extract by 1–4% compared with twice daily feeding of mixed hay. McGuire, Bradley & Little (1966) obtained a similar result for nitrogen in steers fed six times instead of once daily, but found slight, though not significant increases in the digestibility of crude fibre, NFE and gross energy. Moir & Somers (1957) obtained a significant increase in dry-matter and N digestibility when sheep were fed concentrates, oat and lucerne chaff twice or four times daily instead of once. Mohrman *et al.* (1959) obtained increases in the digestibility of nitrogen and energy by more frequent feeding and Gordon & Tribe (1952) also found a response for nitrogen in lambs fed eight times instead of once daily.

Dependence of the response upon the diet used is indicated by Sutherland, Gupta, Reid & Murray (1963), who found that continuous feeding over the 24 h improved the digestibility of cubed hay, but not of dried grass, compared with feeding twice or four times daily.

Feeding more frequently evens out fluctuations in the concentration of total steam volatile fatty acids and ammonia in rumen liquor (cf. Rakes *et al.* 1957;

Satter & Baumgardt, 1962; Moir & Somers, 1957). Several experiments have shown slightly lower mean pH levels (Rakes *et al.* 1957; Knox & Ward, 1960). Increased proportions of propionic acid in total steam volatile fatty acids have been reported in samples taken hourly over 24 h from cattle fed a maintenance ration eight times instead of twice daily (Knox & Ward, 1960). Sutherland *et al.* (1963) found that continuous feeding did not alter the total production of steam volatile fatty acids per unit organic matter digested in the rumen of sheep, but increased the percentage of propionic acid in the steam volatile fatty acids. Concrete evidence that completely regular feeding of equal amounts at hourly intervals to sheep kept at a constant temperature, at constant illumination and at a constant level of noise eliminates diurnal variation of faecal dry-matter output and concentration, of flow, specific gravity and nitrogen concentration of urine, and of total nitrogen excretion in urine, has recently been provided by Minson & Cowper (1966). More even concentrations of ammonia in rumen liquor would be expected to increase the efficiency of nitrogen utilization, by reducing losses by absorption at peak levels, and improvements in nitrogen retention have been reported by Gordon & Tribe (1952), Moir & Somers (1957), Rakes *et al.* (1961) and Satter & Baumgardt (1962).

Brody (1945) suggested that heat losses might be reduced by more frequent feeding to prevent substantial peaks of heat production and more recently Payne (1966) has suggested that high-producing animals in the tropics should be fed as frequently as possible through the 24 h to spread heat increment and give less likelihood of overloading heat dissipation mechanisms. However, Blaxter *et al.* (1956) found that increased feeding frequency had no significant effect upon total heat production, but increased methane production significantly by about 1 kcal/100 kcal ingested energy. Rakes *et al.* (1961) also found little difference in the total heat production of sheep fed once, four or eight times daily, but found a considerable diurnal fluctuation related to feeding frequency. Sheep fed once daily adjacent to frequently fed sheep also produced more heat during the hours of feeding than when housed at a distance, but the difference was compensated during the night in the absence of food.

In two experiments counts of rumen protozoa have been shown to be increased by feeding more than once daily. Putnam *et al.* (1961) found that feeding ten times daily almost doubled counts of *Entodinium* after 8 weeks of experiment, and Moir & Somers (1957) reported an increase in ciliate protozoa from 1.15×10^6/ml in animals fed once daily to $2.26–2.34 \times 10^6$/ml in animals fed twice daily to 3.14×10^6/ml in animals fed four times daily.

These results may be related to the rate of flow of digesta from the rumen. Sutherland *et al.* (1963) found that continuous feeding reduced the volume of rumen contents, the quantity of dry matter in the rumen and the rate of outflow to the abomasum but increased the fractional hourly clearance of rumen contents. Blaxter *et al.* (1956) and Rakes *et al.* (1957) found no effect of increased feeding frequency on overall rates of passage. Harrison & Hill (1962) reported that the rate of flow of digesta from the abomasum increased almost threefold when sheep were fed three times instead of once daily, but their observations did not cover the whole 24 h.

Compensatory lower flows during the night in animals previously fed more frequently might result in higher concentrations of protozoa being present at counts taken the following morning (Moir & Somers, 1957), while the counts of Putnam *et al.* (1961) were taken after the first one-tenth feed for more frequently fed animals and therefore fewer protozoa may have been 'flushed out' of the rumen by the flow stimulated by feeding than in animals receiving the whole of their daily ration before the counts were taken.

The possible importance of the protozoal population should not be underrated in view of the observations of Abou Akkada & El-Shazly (1964) and Christiansen, Kawashima & Burroughs (1965) of increased live-weight gain, higher rumen liquor contents of reducing sugars, ammonia and steam volatile fatty acids and higher acetic to propionic ratios in faunated than in defaunated lambs.

It should be noted, however, that the effects on protozoa noted by Putnam *et al.* and Moir & Somers applied only to part of the protozoal population, other species were present in fluctuating but often great numbers in the experiment of Moir & Somers and failed to respond significantly to treatment.

Several conclusions may be drawn from this review:

Growing ruminants will often respond to increasing the feeding frequency from once to twice daily, and further response to further increases in feeding frequency may occur on low-energy diets consisting mainly of roughage, or if substantial amounts of urea are included. The concept of an interaction of diet with frequency of feeding is clearly substantiated by the observations of Sutherland *et al.* (1963) and Raleigh & Wallace (1965).

These responses appear to be related to changes in the ratio of solids to liquor in the rumen, to protozoal population, and possibly to rates of saliva addition so that the utilization of nitrogen and energy is enhanced, but the precise limiting conditions for such responses to occur are not yet well defined.

There appears to be no benefit to be gained by feeding the dairy cow more frequently or more evenly than is commonly recommended, namely two to three meals of concentrates and two meals of roughage daily.

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