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Effect of concentrate type and distribution method on milk fat content and milk production in dairy cows

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Summary – Twenty-one Holstein dairy cows in mid lactation were included in a 3 × 3 Latin square design study over three successive 4-week periods. Throughout the trial, the animals were fed an isoenergetic diet composed of 55% grass silage and 45% concentrate. Silage was offered twice a day (9:00 and 16:00). In the first treatment (GW) the concentrate was ground wheat given in two meals per day 1 h before silage distribution. In the second treatment (RW), the concentrate was rolled wheat given three times a day 2 h after silage distribution. In the third treatment (PHM), the concentrate was a mixture of beet pulp (40%), soybean hulls (40%) and maize (20%) given under the same conditions as treatment RW. Milk yield was higher (+ 2 kg/day) for PHM treatment than for the GW and RW treatments ($P < 0.01$). In the PHM treatment milk contained more fat (+2 g/kg, $P < 0.01$) and less protein (–1.7 g/kg, $P < 0.01$) than in the GW and RW treatments. These results were associated with changes in rumen fluid parameters (higher pH and higher proportions of acetic acid for PHM treatment). There was little difference between the GW and RW treatment groups, probably because of slower intake and marked concentrate refusal in the GW group, which may have affected the effects of that treatment on rumen fermentation.

dairy cow / fat content / concentrate / milk yield

Résumé – Effet de la nature et des modalités de distribution du concentré sur le taux butyreux du lait. Vingt et une vaches Holstein en pleine lactation ont été utilisées dans un schéma en carré latin 3 × 3 avec trois périodes successives de 4 semaines. Durant tout l'essai, les animaux ont reçu une ration isoénergétique constituée de 55 % d'ensilage d'herbe et de 45 % de concentré. Dans le premier traitement (GW), le concentré était du blé broyé distribué en deux repas par jour, 1 h avant la distri-

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bution de l'ensilage. Dans le deuxième traitement (RW), le concentré était du blé aplati, distribué en trois repas par jour, 2 h après la distribution d'ensilage. Dans le 3[e] traitement (PHM) le concentré était un mélange de pulpes de betteraves (40 %), de coques de soja (40 %) et de maïs (20 %) distribué dans les mêmes conditions que le traitement RW. Les animaux du traitement PHM ont produit 2 kg/jour de lait de plus que ceux des traitements GW et RW ($p < 0,01$). Leur lait a été plus riche en matières grasses (+ 2 g/kg, $p < 0,01$) et moins riche en protéines (– 1,7 g/kg, $p < 0,01$). Ces résultats sont à mettre en relation avec un pH et une proportion d'acide acétique dans le jus du rumen supérieurs avec le traitement PHM. Les différences entre les lots GW et RW ont été faibles, vraisemblablement en raison d'une ingestion moins rapide et de refus importants du concentré dans le lot GW qui ont pu limiter les effets de ce traitement sur les fermentations dans le rumen.

vache laitière / taux butyreux / concentré / production laitière

INTRODUCTION

A number of factors may affect milk fat content, especially dietary factors linked to the type of forage and to the proportion of concentrate in the diet (Journet and Chilliard, 1985; Sutton, 1989; Hoden and Coulon, 1991). When the proportion of concentrate is high, the concentrate type and distribution methods (mixed with forage, number of meals, presentation) may play a considerable role (Gibson, 1984; Sutton et al, 1985; Grant et al, 1990; Aaes, 1993), although opposite results have been published (Yang and Varga, 1989; McLeod et al, 1994). Most of these studies, however, were conducted under extreme conditions (very high proportion of concentrate in the diet, totally ground diet) hardly reflecting the feeding practices routinely applied in France. Observations at the farm level, however, suggested that concentrate presentation and feed distribution sequence could be associated with significant changes in milk fat content (Coulon et al, 1994). Recent trials on the effect of concentrate presentation (Coulon and Agabriel, 1995), feeding sequence (Chassaing et al, 1996), type of concentrate and number of meals (Jackson et al, 1991; Agnew et al, 1996) have not confirmed these observations. It is possible that these practices are effective only when combined together. The aim of this study was to test that hypothesis by comparing the effect of associating several dietary factors under realistic feeding conditions, such as the number of feeds and the order in which they were distributed, and the type and processing form of the concentrates.

MATERIALS AND METHODS

Experimental design and feeding

Twenty-one Holstein dairy cows (five primiparous and 16 multiparous) in their decreasing lactation phase (85th lactation day at the beginning of the experiment, on average) were used in a 3 × 3 Latin square experimental design, with seven cows in each cell of the Latin square. They were managed in loose housing with boxes and troughs fitted with electronically controlled gates for individual rationing. Cows were milked at 7:00 and 17:00 in the milking pen. At the beginning of lactation, all the cows were given ad libitum a complete diet based on grass silage. During a 2-week pre-experimental period, the cows were given a diet composed of 10 kg DM/day of second cycle cocksfoot silage mixed with 4.5 kg/day ground wheat and 4.5 kg/day pelleted concentrate composed of 40% beet pulp, 40% soybean hulls and 20% ground maize, in two meals per day.

The trial started on 11 March 1996 and unfolded over three 4-week periods. Three groups of seven cows each were formed according to the date of calving, parity, and milk yield performances recorded during the pre-experimental period. In the first treatment (GW), the concentrate was ground wheat given in two equal meals 1 h before silage distribution (8:00 and 15:00). In the second treatment (RW), the concentrate was rolled wheat distributed as three equal meals (11:00, 15:00 and 18:00); the first and third of these meals were given 2 h after silage distribution. In the third treatment (PHM), the concentrate was pelleted and composed of 40% beet pulp, 40% soybean hulls and 20% ground maize. The distribution was as in the RW treatment group. Maize incorporation in that mixture maintained a relatively high energy value (1.06 UFL/kg DM) while sustaining a degradation rate in the rumen twice as low as that obtained with wheat (table I). Silage was given in two meals to all treatment groups (9:00 and 16:00). The silage (55% of total DM in the diet) and concentrate (45% of total DM in the diet) amounts were given in a controlled and restricted manner. They were set for the whole duration of the trial and adapted so as to cover 95% of each animal's maintenance and production requirements throughout the pre-experimental period. The animals' nitrogen requirements were always met. Practically, for the GW and RW treatment groups and for a milk yield of 30 kg/day, the amounts of silage and concentrate given were 10.5 kg DM/day and 9.5 kg/day, respectively. In the PHM treatment group, these amounts were 11 kg DM/day and 10 kg/day, respectively, to take into account the lower energy value of the concentrate. The cows were maintained at the trough for 30 min after concentrate distribution when it was given before silage and for 2.5 h in the morning and 2 h in the evening after grass distribution. They only had access to drinking water once freed. Throughout the duration of the trial, the cows were given 250 kg/day mineral supplement (type 7P-21Ca in the GW and RW treatment groups and type 14P-16Ca in the PHM group). Treatment changeovers between experimental periods were sudden, occurring in a single day.

Measurements

Milk yield was measured individually at each milking. For each animal, milk fat, protein and lactose contents, together with somatic cell count, were measured at each milking, for 4 days of each of the last 2 weeks of each period and 2 days each week from a mixed sample of two daily milkings the other weeks. The animals were weighed in the first and last week of each experimental period. Their body condition score was assessed by handling at the beginning and end of the experiment, according to the notation scale (1–5) proposed by Bazin (1985). During the last week of each period, rumen fluid was sampled by abdominal puncture between 14:00 and 15:00. The pH was directly measured and a sample was made up and frozen for volatile fatty acid (VFA) composition analysis (Jouany, 1982). The amounts of silage and concentrate ingested were measured individually every day. The DM matter content of feeds was measured four times a week in silage and once a week for each concentrate, by oven-drying. In the PHM and RW treatment groups, the amount of silage eaten before each concentrate distribution was measured once during the third and fourth week of each period. One day during the same weeks, each animal's feeding behaviour was monitored between 8:00 and 12:00 and between 15:00 and 19:00 by recording their activity every 5 min (forage and/or concentrate intake).

The crude fibre (Weende method), crude protein (Kjeldahl technique) and organic matter contents were analysed once in each period for silage and once during the whole trial duration for concentrates. The quality of silage preservation (pH, VFA, soluble nitrogen, ammoniacal nitrogen, alcohol) was assessed once in each experimental period according to Dulphy and Demarquilly (1981). Particle size distribution was measured once in the ground wheat and in the rolled wheat. For RW, 96 and 18% of the particles were larger than 1 and 4 mm, respectively. Corresponding values for the GW were 40 and 0%. The characteristics of the feeds are shown in table I.

Energy and nitrogen balances were computed from the differences between nutritional supplies and the animals' requirements according to Inra recommendations (Andrieu and Demarquilly, 1987; Vermorel, 1989; Vérité and Peyraud, 1989). Milk energy was computed from the fat, protein and lactose contents according to the Sjaunja formula (1989).

The effect of the experimental treatments on the variables studied was processed by analysis of variance (SAS, 1987) from the measurements performed in the last two weeks of each experimental period (except for rumen fluid characteristics, which were available only in the last week). The factors introduced in the analysis were the treatment, the period and the animal. One cow was excluded from data processing because it became ill (foreign body).

RESULTS

At the beginning of the experiment, the animals' mean live weight was 652 kg and their

Table I. Composition of foods and diets.

	Foods			*Diets*		
	Grass silage[1]	*Wheat*	*Concentrate PHM*	*GW*	*RW*	*PHM*
Dry matter (DM) (%)	30.9	86.4	85.4			
Organic matter (% DM)	87.4	98.2	93.4	92.3	92.3	90.1
Crude protein (g/kg DM)	192	120	129	162	162	166
Crude fibre (g/kg DM)	317	26	221	191	191	279
Starch (g/kg DM)	0	670	144	302	302	65
Energy value (UFL[2]/kg DM)	0.75	1.19	1.06	0.95	0.95	0.89
PDIN[3] value (g/kg DM)	118	86	77	104	104	100
PDIE[4] value (g/kg DM)	83	110	111	95	95	96
DM4h[5] (g/kg)	450	800	400	607	607	427

[1]Silage pH 4.35; N-NH 3 content 8.7%; soluble N content 50.1%; acetic, butyric, propionic and lactic acid content, respectively 16.7, 1.0, 2.0, et 45.7 g/kg DM; and alcohol content 3.1 g/kg DM.
[2]UFL, feed unit for lactation (Vermorel, 1989).
[3]PDIN, true protein truly digestible in the small intestine when energy in the rumen is not limiting (Vérité and Peyraud, 1989).
[4]PDIE, true protein truly digestible in the small intestine when degraded N in the rumen is not limiting (Vérité and Peyraud, 1989).
[5]Dry matter fermented in the rumen during a 4-h period (Peyraud et al, not published).

body condition score was 2.3. During the trial, their live weight remained almost unchanged (+2 kg on average) and the body score increased slightly (+0.4). Over the course of the trial, five cows suffered from mastitis but there were no real repercussions on their milk yield. One cow presented a pulmonary disorder. No acidosis was recorded.

Feed intake

Energy supplied to the cows was lower than designed in the protocol because of an overestimation of the grass silage energy value used when preparing the diet, so that the animals were in negative energy balance under the three treatments (table II). Energy supply was slightly lower in the GW treatment because of a slightly lower concentrate intake. Under that treatment, three cows significantly refused concentrate (in excess of 2 kg/day). It was also under that treatment that the duration of concentrate intake was the longest (twice as long as under PHM treatment where larger quantities were offered), even for cows that did not refuse much. When the cows were given the concentrate in three meals a day (RW and PHM treatments), the amount of silage eaten during the 2 h preceding the first concentrate distribution was high, 4.4 and 5.1 kg DM for RW and PHM treatments, respectively, ie, about half of the total daily intake of silage.

Milk yield and composition

Milk yield and fat content were significantly higher (+2.0 kg/day and +2.1 g/kg, respectively, $P < 0.01$) for the PHM treatment than for the GW and RW treatments (table II). In contrast, protein content was lower for the PHM treatment than for the GW and RW treatments (–1.6 g/kg, $P < 0.01$). With the same type of concentrate (GW and RW

Table II. Feed intake, milk yield and composition and ruminal fluid characteristics.

Treatment	*GW*	*RW*	*PHM*	*RSD*[1]
Feed intake				
Grass silage (kg DM/d)	9.4a	9.3a	10.1b	0.6
Concentrate (kg DM/d)	7.5a	7.8a	8.2b	0.6
Energy supply (UFL/d)	14.5	14.7	14.8	0.7
Protein supply (g PDI/d)	1606a	1630a	1754b	74
Energy balance (UFL/d)	–1.9a	–1.7a	–2.7b	0.7
Protein balance (g PDI/d)	–32	–8	–19	86
Feeding behaviour				
Grass silage intake before the first distribution of the concentrate (kg DM/d)		4.4a	5.1b	0.4
Time spent eating the concentrate (min)[2]	72a	39b	36b	11
Time spent eating the silage (min)[2]	134a	113b	120b	17
Milk yield				
Milk (kg/day)	25.7a	25.3a	27.5b	1.6
Fat content (g/kg)	39.4a	40.3a	41.9b	2.2
Protein content (g/kg)	31.8a	32.5b	30.6c	1.2
Fat yield (g/day)	1005a	1008a	1143b	68
Protein yield (g/day)	807	814	831	57
Lactose content (g/kg)	48.5ab	48.2a	48.9b	0.7
Somatic cell count (log/mL)	5.10	5.24	5.23	0.27
Live weight change (g/day)[3]	0ab	257a	–211b	552
Ruminal fluid				
pH	6.08a	6.17a	6.36b	0.19
VFA (mol/100 mol)				
Acetic acid	61.2a	63.8b	64.8b	3.0
Propionic acid	21.2	19.8	19.5	3.7
Butyric acid	12.7	11.6	11.8	2.0

[1]Residual standard deviation.
[2]During the 8 h of observation.
[3]Calculated between the last and the first week of each experimental period.

treatments), distribution practices slightly altered the fat content (+0.9 g/kg in favour of RW treatment, $P > 0.05$) and the protein content (+0.7 g/kg in favour of the RW treatment, $P < 0.05$). When restricting the analysis to the 17 cows that refused less than 2 kg/day concentrate under GW treatment, the difference in fat content between the GW and RW treatments increased (+1.8 g/kg in favour of the RW treatment, $P < 0.05$), whereas the difference in protein content disappeared (+0.3 g/kg in favour of the RW treatment, $P > 0.05$). In the cows under RW and PHM treatments, individual fat content variability was not linked to silage intake before concentrate distribution. The amounts of protein produced were the same in all three treatments, whereas fat amounts were higher under PHM treatment (+137 g/day, ie, +13% relative to GW and

RW treatments, $P < 0.01$). The lactose content was slightly but significantly higher in the PHM than in the RW treatment (+0.7 g/kg, $P < 0.05$).

Rumen fluid characteristics

The rumen fluid pH was significantly higher under PHM treatment (6.36) than under the GW (6.08) and RW (6.17) treatments (table II). The acetic acid (C2) proportion was significantly lower ($P < 0.01$) under the GW treatment than under the RW or PHM treatments, whereas the propionic acid (C3) and butyric acid (C4) contents were slightly higher, although not significantly so. The fat content increased in parallel with the rumen juice pH and the (C2+C4)/C3 ratio ($P < 0.01$). However, taken together, these two variables only accounted for 23% of the fat content variability.

Animal performance changes induced by feeding transition

The intake of silage and concentrate, on the day of diet changeover, did not vary from GW to RW treatment but increased between RW and PHM treatments and decreased between PHM and GW treatments, as expected in the protocol. Three days after changing the diet, a marked decrease in concentrate intake (–2 kg DM/day) occurred in the cows that changed to the GW treatment. All animals on this treatment exhibited a lower concentrate intake, but its extent varied in intensity and duration: four cows refused large amounts (> 4 kg/day for 10 days) and three almost maintained the intake previous to the change in diet. The effect of diet changeover on milk yield occurred quickly with the transition involving the PHM treatment: milk decreased on the first day of diet change when changing from PHM to GW. When changing from RW to PHM, the milk yield increase was spread over 3 days.

DISCUSSION

The experimental design of this trial made it possible to compare: a) the association of different feeding practices known to favour fat content (number of meals, feed distribution sequence, presentation of the concentrate) with the same type of concentrate (GW/RW comparison); and b) the effect of the composition of concentrate distributed under the most favourable conditions for milk fat content (RW/PHM comparison). As described in the protocol, these comparisons were made with the same level of nutritional supplies and the same proportion of concentrate in the diet (45%).

Under these conditions, significant performance changes were noted, although they were moderate, in particular for fat content. In the treatment which was thought to be the most unfavourable (GW), with 30% of rapidly degradable starch, fat content remained high, close to 40 g/kg. It was therefore logical that the RW and PHM treatments had relatively little effect on fat content. Indeed, the effects of feeding methods were only important when applied to a diet which induced very low fat contents (Gibson, 1984; Robinson, 1989). This trial showed that, with grass-based diets, incorporating 40 to 50% cereal-based concentrate did not induce any sharp drop in fat content, even in the absence of any special precautions in its distribution. This confirmed the results of Jackson et al (1991) and Coulon and Agabriel (1995). It is likely, however, that the deleterious effect expected from the GW treatment was partially inhibited by the slow intake rate of the concentrate in the cows subjected to the GW treatment and the high levels of refusal by some of those cows, as demonstrated by the results obtained when those cows were excluded from the analysis. It is also possible that the negative energy balance observed in this treatment contributed to the maintenance of a high milk fat content due to a higher body lipid mobilisation (Journet and Chilliard, 1985). The fact that refusals were only observed after the third day of animals being introduced to the GW treatment suggests that refusals might be the result of rejection due to rumen dysfunction rather than palatability. The decrease in concentrate intake rate could then be considered as an animal adaptation to restrict the drop in pH associated with the intake of very fermentable feeds.

The main differences in performance resulted from the type of concentrate, as it is classically reported in the literature, when the proportion of concentrate in the diet is high (Coulon et al, 1989; De Visser et al, 1990). The PHM treatment induced higher milk yield, higher milk fat content and lower protein content than the GW and RW treatments. Several factors can account for that result. The highest milk yield can be related to a better digestibility of the diet under PHM treatment because of slower degradation in the rumen, which reduces digestive interactions (Vérité and Dulphy, 1981; Michalet-Doreau and Sauvant, 1989). Such a higher milk yield can also be due to the slightly higher nitrogen supplementation of the PHM diet, which may have improved the diet digestibility and/or stimulated milk yield (Journet et al, 1983). The differences in milk chemical composition could be due both to matter dilution effects (protein content) and/or to changes in the fermenting orientations in the rumen. Diets inducing a high C2/C3 ratio in the rumen are usually favourable to milk yield and detrimental to

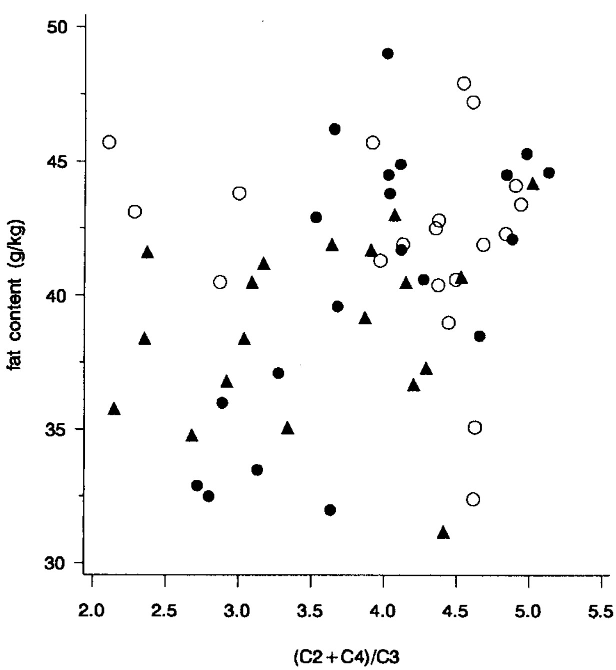

Fig 1. Relationship between milk fat content and the ratio of (C2 + C4) to C3 in the ruminal fluid. GW treatment (▲), RW treatment (●), PHM treatment (O).

live weight gain and protein content (Vérité and Journet, 1971; Thomas, 1984; De Visser et al, 1990). This is consistent with our observations, even if estimating live weight changes over short periods is delicate. Diets leading to a high (C2+C4)/C3 ratio usually improve fat content (Journet and Chilliard, 1985). However, the weak correlation between fat content and the (C2+C4)/C3 ratio (fig 1) demonstrates the failure of that indicator to account for the fat content variations, especially because it only reflects an instant measurement of the rumen status which itself only partially reflects the production of the main VFA on a daily scale. Other mechanisms, either metabolic or hormone-related, should therefore be taken into consideration (Sutton and Morant, 1989) to explain the individual variations in fat content.

In conclusion, this trial showed that significant differences in milk yield and composition can be induced by jointly modifying the type and mode of distribution of concentrates. For concentrate proportions in the diet between 40 and 50% of total DM, however, the changes in fat content remain moderate, much lower than observed with higher concentrate proportions. Results obtained with the GW diet, in particular the high protein/fat milk ratio, should be viewed with caution. The behaviour of the cows observed in this study would indicate that that treatment may increase the risk of rumen dysfunction.

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RÉFÉRENCES

Agnew KW, Mayne CS, Doherty JG (1996) An examination of the effect of method and level of concentrate feeding on milk production in dairy cows offered a grass silage-based diet. *Anim Sci* 63, 21–31

Aaes O (1993) Total mixed rations versus separate feeding of concentrate rich rations fed restrictively or ad libitum to dairy cows. Report No 16/1993 from the National Institute of Animal Science, Foulum, Denmark.

Andrieu J, Demarquilly C (1987) Valeur nutritive des fourrages: tables et prévision. *Bull Techn CRZV Theix, Inra* 70, 61–74

Bazin S (1985) *Grille de notation de l'état d'engraissement des vaches Pies Noires.* Iteb Éditions, 31 p

Coulon JB, Faverdin P, Laurent F, Cotto G (1989). Influence de la nature de l'aliment concentré sur les performances des vaches laitières. *Inra Prod Anim* 2, 47–53

Coulon JB, Agabriel C, Brunschwig G, Muller C, Bonaïti B (1994) Effects of feeding practices on milk fat concentration for dairy cows. *J Dairy Sci* 77, 2614–2620

Coulon JB, Agabriel C (1995) Effet de la forme de présentation de l'orge sur la production et la composition du lait de vache. *Ann Zootech* 44, 247–253

Chassaing C, Coulon JB, Agabriel C, Garel JP (1996) The effect of feeding sequence on fat concentration in milk. *Ann Zootech* 45, 151–157

De Visser H, Van Der Togt PL, Tamminga S (1990) Structural and non-structural carbohydrates in concentrate supplements of silage-based dairy cows rations. 1. feed intake and milk production. *Neth J Agric Sci* 38, 487–498

Dulphy JP, Demarquilly C (1981) Problèmes particuliers aux ensilages. *In*: *Prévision de la valeur nutritive des aliments des ruminants* (Demarquilly C, ed), Inra Publications, Paris, 81–104

Hoden A, Coulon JB (1991) Maîtrise de la composition du lait: influence des facteurs nutritionnels sur la quantité et les taux de matières grasses et protéiques. *Inra Prod Anim* 4, 361–367

Gibson JP (1984). The effect of frequency of feeding on milk production of dairy cattle: analysis of published results. *Anim Prod* 38, 181–191

Grant RJ, Colenbrander VF, Albright JL (1990) Effect of particule size and rumen cannulation upon chewing activity and laterality in dairy cows. *J Dairy Sci* 73, 3158–3164

Jouany JP (1982) Volatile fatty acid and alcohol determination in digestive contents, silage juices, bacterial cultures and anaerobic fermentor contents. *Sci Alim* 2, 131–144

Jackson DA, Johnson CL, Forbes JM (1991) The effect of compound composition and silage characteristics on silage intake, feeding behaviour, production of milk and live-weight change in lactating dairy cows. *Anim Prod* 52, 11–19

Journet M, Faverdin P, Rémond B, Vérité R (1983) Niveau et qualité des apports azotés en début de lactation. *Bull Tech CRZV Theix, Inra* 51, 7–17

Journet M, Chilliard Y (1985) Influence de l'alimentation sur la composition du lait. 1. Taux butyreux: facteurs généraux. *Bull Tech CRZV Theix, Inra* 60, 13–23

Macleod GK, Colucci PE, Moore AD, Grieve DG, Lewis N (1994) The effects of feeding frequency of concentrates and feeding sequence of hay on eating behavior, ruminal environment and milk production in dairy cows. *Can J Anim Sci* 74, 103–113

Michalet-Doreau B, Sauvant D (1989) Influence de la nature du concentré, céréales ou pulpe de betteraves, sur la digestion chez les ruminants. *Inra Prod Anim* 2, 235–244

Robinson PH (1989) Dynamic aspects of feeding management for dairy cows. *J Dairy Sci* 72, 1197–1209

Sjaunja LO (1989) *Methods for calculation of the energy content of milk. International commission for recording the productivity of milk animal,* ICRPMA, Brussels.

Statistical Analysis System Institute (1987) *SAS user's guide: statistics.* SAS Institute Inc, Cary NC.

Sutton JD (1989) Altering milk composition by feeding. *J Dairy Sci* 72, 2801–2814

Sutton JD, Broster WH, Napper DJ, Siviter JW (1985) Feeding frequency for lactating cows. Effects on digestion, milk production and energy utilization. *Br J Nutr* 53, 117–130

Sutton JD, Morant SV (1989) A review of the potential of nutrition to modify milk fat and protein. *Livest Prod Sci* 23, 219–237

Thomas PC (1984) Feeding and milk production. *In: Milk Compositional Quality and its Importance in Future Markets* (Castle ME, Gunn RG, eds), Occ Publ Br Soc Anim Prod, UK, 9, 53–67

Vérité R, Journet M (1971) Utilisation comparée de l'ensilage de maïs et de l'ensilage d'herbe pour la production laitière. *Ann Zootech* 20, 153–167

Vérité R, Dulphy JP (1981) Effet de la nature de l'aliment concentré sur l'ingestion et les performances des vaches laitières. *Bull Tech CRZV Theix, Inra* 45, 15–21

Vérité R, Peyraud JL (1989) Protein: the PDI system. *In: Ruminant Nutrition. Recommended allowances and feed tables* (Jarrige R, ed), Inra-John Libbey Eurotext, London, 33–47

Vermorel M (1989) Energy: the feed unit systems. *In: Ruminant Nutrition. Recommended allowances and feed tables* (Jarrige R, ed), Inra-John Libbey Eurotext, London, 23–30.

Yang CMJ, Varga GA (1989) Effect of three concentrate feeding frequencies on rumen protozoa, rumen digesta kinetics and milk yield in dairy cows. *J Dairy Sci* 72, 950–957