Ann. Zootech., 1980, **29,** n° h. s., 127-143.

Utilisation of feed energy by growing ruminants

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Abstract

As the energy value of feeds for growing ruminants is generally calculated from the data obtained from adult sheep, the various factors which can alter the utilisation of feed energy are considered :

- effects of species, age, diet composition and feeding level on energy digestibility and metabolisability, methane and urinary energy losses ;
- effects of age, breed, diet composition and feeding level on partial efficiency of metabolisable energy (ME) for maintenance or tissue gain and on overall efficiency of ME for growth.

Résumé

Utilisation de l'énergie par les ruminants en croissance

La valeur énergétique des aliments destinés aux ruminants en croissance étant généralement calculée à partir des données obtenues sur des moutons adultes, les auteurs examinent les facteurs susceptibles de modifier l'utilisation de l'énergie des aliments :

- effets de l'espèce, de l'âge, de la composition de la ration et du niveau d'alimentation sur la digestibilité de l'énergie, les pertes sous forme de méthane et dans l'urine et la teneur en énergie métabolisable (EM) de la ration ;
- effets de l'âge, de la race, du sexe, de la composition de la ration et du niveau d'alimentation sur l'utilisation partielle de l'EM pour l'entretien ou le gain d'énergie et sur l'utilisation globale de l'EM pour la croissance.

Introduction

The energy value of feeds for growing ruminants is generally calculated from the data on digestive and metabolic energy utilization obtained on adult ruminants, mainly sheep. Due to the likely variations of ME efficiency with body gain composition, each feed is supposed to have several net energy values. However, if one assumes that these variations are similar for the various feeds, their energy values related to that of a reference feed (e.g. barley, as used in the Feed Unit system) are the same whatever the body gain composition. This assumption is open to discussion and, therefore, it is important to compare the digestive and metabolic utilization of feed energy in growing and adult ruminants and to analyse the effects of the various factors which can affect it. For practical purposes, the total efficiency of ME utilisation for growth must also be considered, in order to explain the variation in the feed conversion ratio with breed, sex, diet composition and feeding level.

1. — Energy digestibility and metabolisability

A) Energy digestibility

Only a few direct comparisons have been made of the energy digestibility (dE) of the same feeds or diets fed to growing and adult ruminants. Furthermore, the results have not always been published in detail and part of the information is not available. Therefore, precise and definitive conclusions still cannot be drawn. However, energy digestibility seems to be somewhat lower in growing ruminants than in adults, for the same feeding level, but the differences seem to depend on animal species (adult sheep versus lamb or growing cattle) and diet composition.

In growing lambs, dE is lower than in adult sheep (Figure 1A). The difference is only 1 or 2 per cent units for green forage or hays, but it amounts to 3 or 5 per cent units for concentrate diets (RAYMOND *et al.*, 1954 ; BOUVIER and VERMOREL, 1975 ; VERMOREL *et al.*, 1980). In growing cattle, dE seems to be similar to or slightly higher than in adult sheep in the case of green forages, grass silages, hays and low concentrate diets (Figure 1B) (VAN DER NOOT, 1954 ; PRESTON *et al.*, 1957 ; GEAY *et al.*, 1976 ; LE NEINDRE, 1980), but generally lower in the case of maize silage and high concentrate diets (VAN DER NOOT, 1954 ; COLOVOS *et al.*, 1970 ; GEAY *et al.*, 1978 ; CARLE *et al.*, 1980). According to JENTSCH *et al.* (1976), the discrepancy was on average 4.6 per cent units (that is about 3 per cent units after correction for the difference in feeding level) in the case of 44 diets containing about 70 per cent concentrate (dE = .78 in adult sheep) fed to growing cattle and adult sheep and it did not vary significantly with cattle age.

In growing as in adult ruminants, dE decreases when the feeding level (L) increases, but the variations are not known accurately as the differences in feeding level (Δ L) are often small. The reduction in dE is about from 0 to 2 per cent units per multiple of the maintenance requirement (Δ L = 1) for long grass or hays (THOMSON and CAMMELL, 1979 ; CARLE *et al.*, 1980) but from 4 to 8 per cent units for pelleted forages (BOUVIER and VERMOREL, 1975 ; THOMSON and CAMMELL, 1979 ; 1980 ; VERMOREL *et al.*, 1980) (Figure 2). It

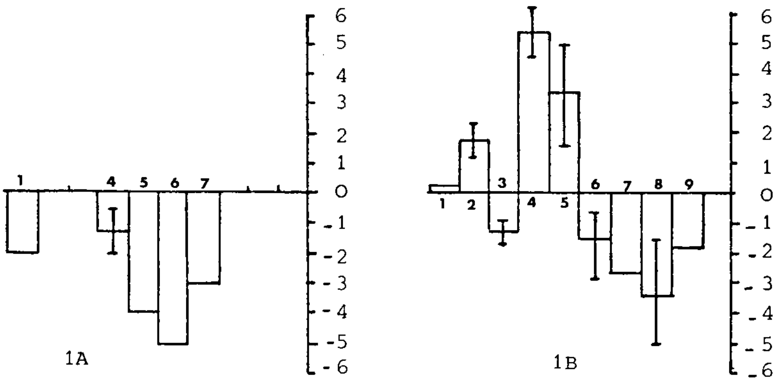

FIG. 1. — *Difference in energy digestibility* (percent units *d*E) *between lamb and adult sheep* (1A) *and growing cattle and adult sheep* (1B)

1 = grass; 2 = grass silage;
3 = grass silage + 30 p. 100 concentrate
4 = hay (chopped or pelleted);
5 = hay + 30 p. 100 concentrate;
6 = hay + 50 p. 100 concentrate;
7 = hay + 85 p. 100 concentrate;
8 = maize silage;
9 = maize silage + 30 p. 100 concentrate
10 = maize silage + 50 p. 100 concentrate.

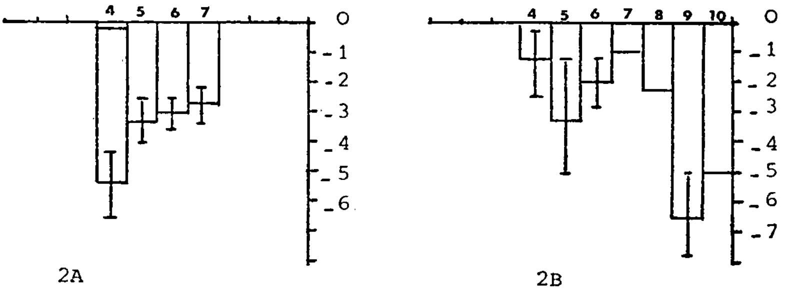

FIG. 2. — *Variation in energy digestibility with feeding level* (percent units *d*E for L = 1) *in lambs* (2A) *and growing cattle* (2B) (same legend as in fig. 1 above).

decreases from 4 to 2.5 per cent units in lambs and from 3 to 1 per cent units in growing cattle fed mixed diets containing from 20 to 80 per cent concentrate. This can explain why BLAXTER *et al.* (1966) did not observe any significant variation in dE with L in growing steers fed a 50 per cent concentrate diet. However, the reduction in dE amounts to about 5 per cent units for diets based on maize silage and concentrates (TYRRELL *et al.*, 1974).

B) Methane production

Methane energy losses (GE), expressed in per cent of gross energy intake (IE), are generally lower in growing ruminants than in adult sheep and they increase with age (Figure 3) (DEMCHENKO, 1969 ; GRAHAM and SEARLE, 1972 ; NEERGAARD, 1974 ; JENTSCH *et al.*, 1976 ; WEBSTER *et al.*, 1977 ; VERMOREL *et al.*, 1980). In addition, GE decreases by about 1 per cent unit when the feeding level increases (L = 1) (BOUVIER and VERMOREL, 1975 ; VERMOREL *et al.*, 1980). The decrease is even greater in the case of compensatory growth in lambs

(THOMSON, 1979). However, BLAXTER *et al.* (1966) did not observe significant variations in GE with age and feeding level, in growing steers between 15 and 81 weeks of age and the values equalled those expected for adult sheep. Similar results were obtained between 5 month-old lambs and adult sheep by BOUVIER and VERMOREL (1975).

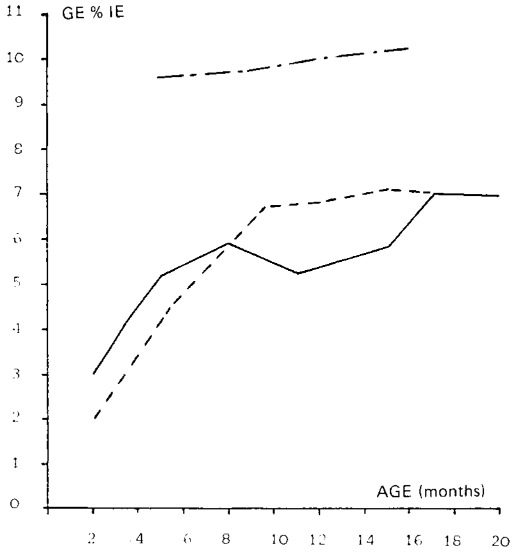

FIG. 3. — *Variations of methane energy losses* (GE % IE) *in growing cattle with age:* DEMCHENKO, 1969) (——); JENTSCH *et al.*, 1976 *in growing bulls* (- - - -) *and adult sheep* (— · —) *fed the same diets.*

The GE variations can be related to rumen development and to rumen fermentations, as well as to the molar proportions of volatile fatty acids in the rumen liquor : the normal working of the rumen seems to be reached in 175 kg bulls when fed diets with 22 per cent crude fibre but at more than 250 kg liveweight when the animals are fed diets with only 10 per cent crude fibre (SCHIEMANN *et al.*, 1976).

Urinary energy depends mostly on urea excretion. Therefore, on the one hand, urinary energy losses (UE) increase with the protein level of the diet and, on the other hand, they are lower in growing than in adult ruminants : 3.3 versus 4.8 per cent of IE in growing bulls and adult sheep respectively for 44 diets (JENTSCH *et al.*, 1976). Furthermore, UE increases with age : 2.9 and 3.7 per cent of IE in 10 week — and 8 month old bulls respectively (VERMOREL *et al.*, 1980). However, when the protein gain of the growing animals is low, urinary energy losses are not significantly less than in adult ruminants (BLAXTER *et al.*, 1966 ; BOUVIER and VERMOREL, 1975). In addition, UE decreases when the feeding level increases ; it amounted to 4.2 and 3.1 per cent of IE in lambs for L = 1.3 and 2.1 respectively (VERMOREL *et al.*, 1980).

Energy metabolisability

Due to smaller methane and urinary energy losses, the ratio between metabolisable and digestible energy (ME/DE) is generally much higher in

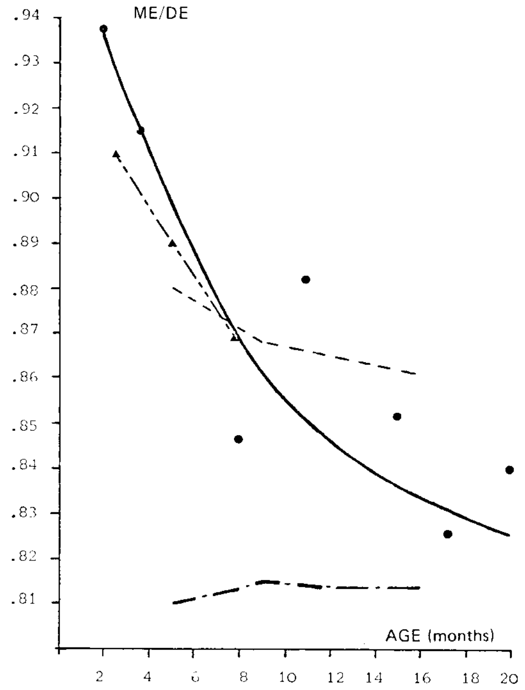

FIG. 4. — *Variations of the ratio ME/DE with age in growing cattle* (DEMCHENKO, 1969 ● ——; VERMOREL *et al.*, 1980 ● - - —— - - ——; JENTSCH *et al.*, 1976, in growing bulls - - - - - and adult sheep —·—· fed the same diets).

growing (about 0.87 ; i.e. from 0.82 to 0.93) than in adult ruminants (0.81) (DEMCHENKO, 1969 ; TYRRELL *et al.*, 1974 ; SCHIEMANN *et al.*, 1976 ; WEBSTER *et al.*, 1976 ; VERMOREL *et al.*, 1976, 1980), but the reduction still cannot be given accurately when the growing ruminants get older (Figure 4). The ratio ME/DE also depends on the chemical and physical composition of the diet and on the feeding level (Figure 5) (VERMOREL *et al.*, 1980).

Therefore, to estimate the ME intake of growing ruminants from their DE intake measured at any feeding level, the mean coefficient 0.81 determined in adult ruminants at the maintenance feeding level should be avoided. The resulting error can reach 10 or 15 per cent and lead to large over-estimation of ME efficiency for growth in experiments using the slaughter technique. When necessary, it is better to estimate the ME intake of growing ruminants from the energy metabolisability of the diet determined in adult sheep. The data available show indeed that there is no significant difference in the feed energy metabolisability (q) between growing and adult ruminants, at least for the same feeding level (JENTSCH *et al.*, 1976 ; VERMOREL *et al.*, 1980). In the Rostock data obtained on 44 diets, the lower energy digestibility is compensated for by lower methane and urinary energy losses ; however q is slightly higher in young bulls than in adult sheep (Figure 6). Furthermore, as shown by SCHIEMANN *et al.*, (1971) in the dairy cow, q seems to decrease (by 1.9 per cent units) when L increases by one unit (VERMOREL *et al.*, 1980). WEBSTER *et al.*, (1976) however, did not observe any significant variation in q with L.

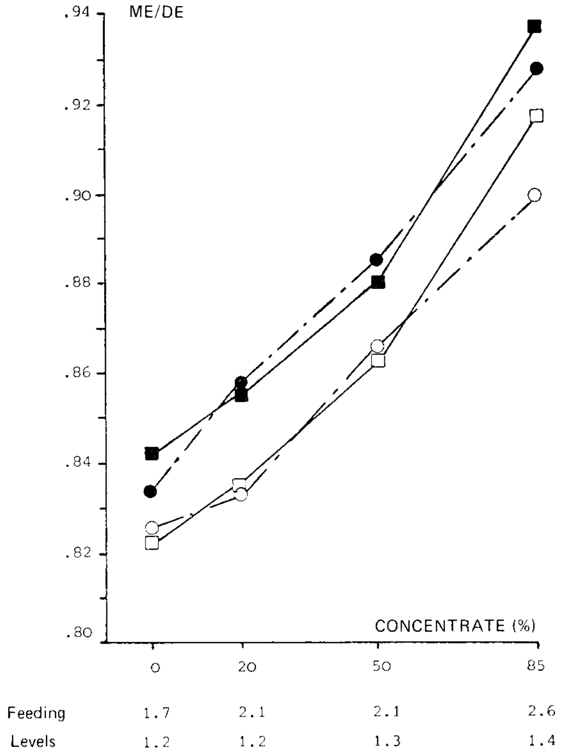

FIG. 5. — *Variations of the ratio ME/DE with diet composition and feeding level in growing lambs*

——— chopped hay;
— — pelleted hay;

● ■ *ad libitum*
○ □ restricted

(VERMOREL *et al.*, 1980).

So, in spite of the variability of the results obtained for digestibility, methane and urinary energy losses, it seems that the ME values of feeds determined in adult sheep can be used to calculate rations for growing ruminants, at least for the same feeding level.

2. — Utilisation of metabolisable energy for maintenance and growth

To determine feeding standards, the factorial approach is often employed. However, in doing this, one must be aware that requirements can hardly be separated, especially in the case of growing animals, as stressed by VAN ES (1980). Nevertheless, partial efficiencies of ME utilisation are most commonly computed separately using linear regression analysis for both maintenance (k_m) and growth (k_g) respectively (VAN ES, 1980).

A. — *Utilisation of ME for maintenance*

From the early experiments of KELLNER (1908) with adult steers it can be demonstrated that the efficiency of utilisation of digested starch is about

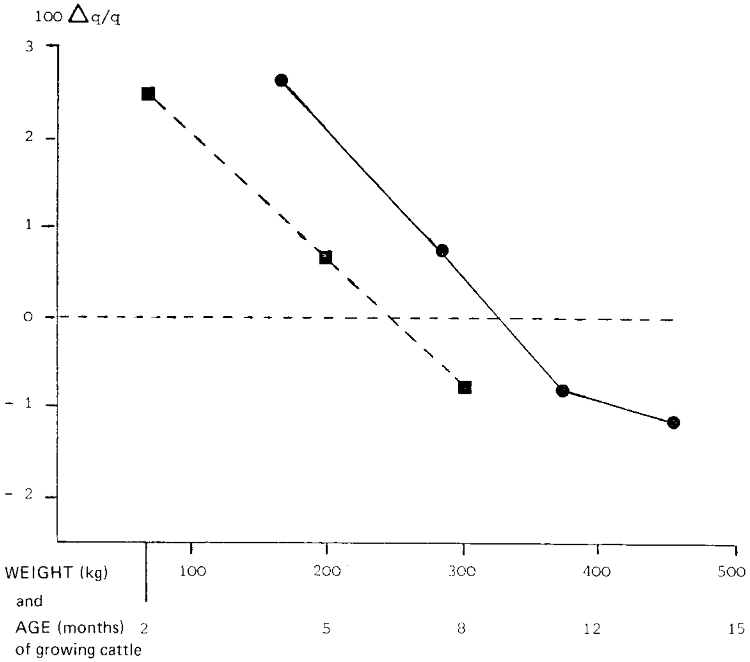

FIG. 6. — *Difference in energy metabolisability* (100 Δ *q/q*) *between growing cattle and adult sheep; variations with age*

——— JENTSCH *et al.*, 1976.

- - - - - VERMOREL *et al.*, 1980.

20 per cent higher for maintenance than for fattening. In the "Starch Equivalent" system for feed evaluation and feeding standards this result is extended to all feeds used in practical feeding. The principe of a better utilisation of energy for maintenance than for fattening was confirmed by BLAXTER (1962) and generally accepted, e.g. in the different new proposals for energy evaluation of feed and feeding standards (ARC, 1965 ; LOFGREEN and GARRETT, 1968 ; VAN ES *et al.*, 1978).

Calculation of k_m stems from energy balances obtained by calorimetry with animals at maintenance or far below maintenance, including at fasting. Under these conditions growth is retarded and metabolism may change from the previous period of positive energy balance. However positive protein balance can be obtained in spite of a zero or slight negative energy balance and at the cost of negative fat balance (GINGINS, 1978; THOMSON, 1979).

Retarding the growth by underfeeding the animals showed a substantial reduction in maintenance heat production (MHP) or ME requirement (ME*m*) of growing calves (THORBEK and HENCKEL, 1976) growing steers (CRABTREE *et al.*, 1976 ; SCHNYDER, 1979) growing heifers (TYRRELL and MOE, 1980) and growing bulls (VERMOREL *et al.*, 1980), as of growing pigs (GRAY and MC CRACKEN, 1980). In these experiments, MHP was reduced by 60 to 100 kJ/kg $W^{\frac{3}{4}}$. Similar results were obtained with adult sheep when the feeding level was altered from the maintenance level to an underfed level (Table 1 and Figure 7) (GINGINS, 1978).

TABLE 1

FASTING HEAT PRODUCTION (FHP), ME REQUIREMENT FOR MAINTENANCE (MEm) AND PARTIAL EFFICIENCY OF ME UTILISATION FOR MAINTENANCE (k_m) AT MAINTENANCE OR DURING UNDERFEEDING AND REALIMENTATION OF ADULT SHEEP (GINGINS, 1978)

Feeding level	FHP (1) ($kJ/W^{3/4}$)	MEm ($kJ/W^{3/4}$)	k_m (3)	'True' k_m (3)
Maintenance	279	381 (1)	0.73	
Underfeeding	249	275 (2)	0.91	0.75
Realimentation	293	374 (2)	0.78	

(1) Measured FHP or MEm

(2) MEm estimated by regression analysis

(3) k_m calculated as FHP/MEm

(4) 'True' k_m, estimated by regression analysis

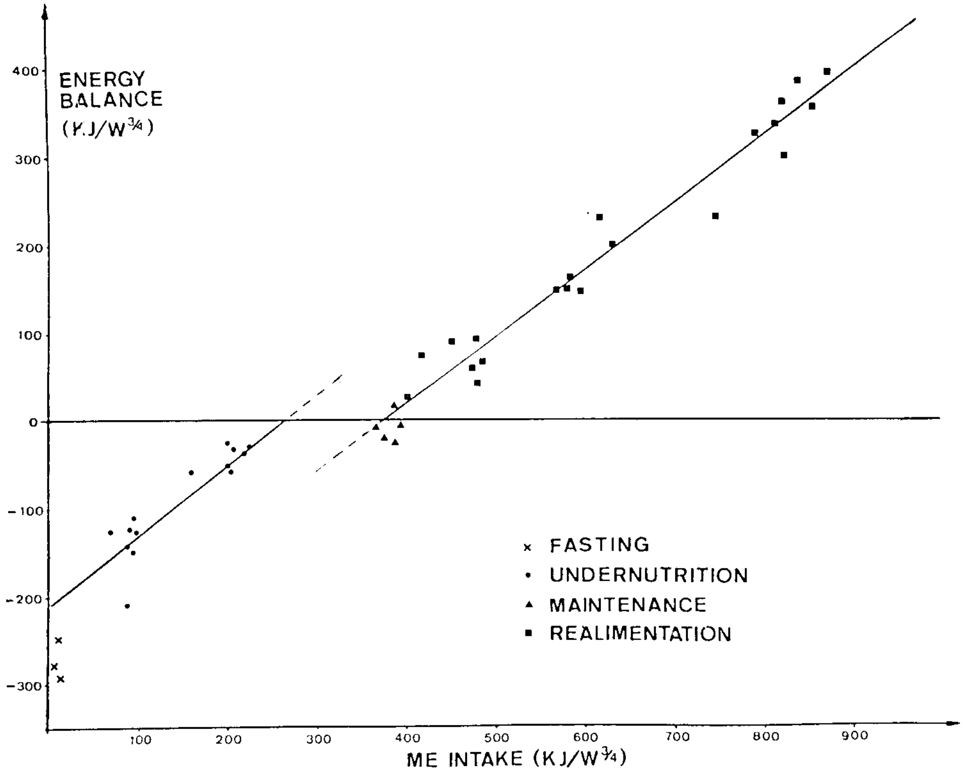

FIG. 7. — *Energy balances of adult sheep at fast or maintenance, during undernutrition or realimentation* (GINGINS, 1978).

Undernutrition: EB = — 206 + 0.75 ME $R^2 = 0.80$

Realimentation: EB = — 273 + 0.73 ME $R^2 = 0.95$

From these results, it appears that not only FHP and ME*m*, but also k_m could be influenced by the feeding level. However, if statistical regression analysis is used to determine " true " k_m for the underfed animals, without including the FHP, the value (0.75) is comparable to those given by ARC (1965), MAFF (1975) and VAN ES (1978) (fig. 7). Yet, if FHP is included in the regression computation, a non-linear regression line would better suit the results than a linear regression line. This suggests that a drastic change in the energy metabolism takes place at fasting.

Steers of various breeds are able to maintain different liveweights at the same feed intake (VERCOE, 1970). The discrepancy is not necessarily and only due to differences in fasting metabolism; it may also come from a better efficiency of ME utilisation for maintenance (VERCOE, 1970). Between Hereford × Shorthorn (HS) and Brahman × HS steers, the difference may amount to 10 per cent (VERCOE, 1970; VERCOE and FRISCH, 1974; FRISCH and VERCOE, 1976). According to these authors, the higher k_m in Brahman × HS steers could be due to a lower methane production and smaller proportion of acetic and butyric acids in the rumen volatile fatty acids, but probably not to differences in body composition.

B. — *Energy utilisation for growth*

Knowledge of the efficiency of ME utilisation by growing ruminants is still poor compared to that obtained on monogastric animals. The number of studies is limited and the results are often conflicting. The discrepancies may originate, on the one hand, in the variability of feeds and rations used and, on the other hand, in the diversity of genetic types and physiological stages of experimental animals. They are likely to come from poor estimates of ME intake and maintenance requirements, which sometimes are not determined in these experiments. The main reason, however, is probably the lack of accuracy in measuring energy retention (especially by calorimetry) which amounts only to 10 or 25 per cent of energy intake in lambs and 5 to 15 per cent in growing bulls. Therefore, the results obtained with very low weight gains are hardly reliable.

ME utilisation for protein and lipid deposition

The studies carried out on growing monogastric animals have shown that the efficiency of ME utilisation is lower for growth (k_g) than for fattening (k_f) (cf. reviews by KIELANOWSKI, 1976, and THORBEK, 1977). The difference comes from the higher energy expenditure associated with protein deposition. In the statistical models mentioned and criticised by VAN ES (1980) this is expressed as a lower efficiency of ME utilisation for protein (k_{pr}) than for lipid (k_{lp}) deposition (about 45 and 75 per cent respectively), mainly due to different biochemical pathways and to a high protein turnover (EDMUNDS *et al.*, 1980).

A similar trend was obtained in growing ruminants but the data are scarce and very variable. Some figures derived for k_{pr} and k_{lp} are irrelevant for the reasons indicated above and because protein gain and lipid gain are not independent variates and the variation range of protein gain is not large enough to allow an accurate estimate of k_{pr}. The results obtained on growing lambs seem to indicate that k_{pr} is about 33 per cent and k_{lp} 70 per cent (from 55 to 99 per cent, ØRSKOV and MCDONALD, 1970, 1976; BICKEL and DURRER, 1974; THOMSON, 1979; THERIEZ *et al.*, 1980). However, much lower values were obtained for k_{pr} by FERRELL *et al.*

(1979) and RATTRAY and JOYCE (1976) but in this case, the weight gains of the lambs were very low.

Furthermore, from a large number of balances carried out on growing bulls, by indirect calorimetry, SCHIEMANN *et al.* (1976) concluded that k_{pr}/k_{lp} was about 1/1.9, that is, a figure similar to that obtained in monogastric animals. Using the comparative slaughter technique in growing Limousin bulls, ROBELIN and GEAY (1976) showed that k_g increased with the proportion of energy retained as fat. Finally, in feeding trials on growing finishing bulls of different French breeds and cross-breeds, COLLEAU (1978), using the slaughter technique, obtained figures of 33 per cent for k_{pr} and 55 per cent for k_{lp}.

So, in ruminants as in monogastric animals, the efficiency of ME utilisation for growth seems to depend on the proportions of energy retained as protein and lipids. It is, therefore, important to examine the effect on k_g of factors which can influence the composition of body gain.

Effect of age

Several experiments carried out on lambs and growing bulls or steers have shown that k_g was lower than the k_f value expected for adult ruminants (WEBSTER *et al.*, 1974; GEAY *et al.*, 1976; ROBELIN and GEAY, 1976; FERRELL *et al.*, 1979; GEAY *et al.*, 1980; THOMSON and CAMMELL, 1979, 1980). However, for a wide range of diets, HOFFMANN *et al.* (1977) obtained, on average, the same maintenance requirements and similar ME efficiencies for growth ($k_g = 58$ per cent) in bulls and for fattening ($k_f = 55$ per cent) in adult steers. In the same way, BOUVIER and VERMOREL (1975) did not observe any significant difference in ME efficiency for the same diet fed to 4 month-old lambs and adult sheep, whereas the proportion of energy retained as fat (FE) amounted to 70 and 85 per cent of energy gain respectively, but the maintenance requirement was much higher in the lambs. WEBSTER *et al.* (1972) concluded likewise from an experiment on lambs only.

As the animals get older, the proportion of energy retained as fat increases and consequently k_g should rise. However, it did not vary significantly in growing steers between 15 and 81 weeks of age, but FE increased only from 70 to 75 per cent (BLAXTER *et al.*, 1966). In the same way, k_g determined by the comparative slaughter technique in Limousin bulls did not increase significantly over 3 growth periods (9-13, 13-16 and 16-19 months of age), although FE increase from 46 to 70 per cent, but the results were very variable ($0.29 \leqslant k_g \leqslant 0.48$) (ROBELIN and GEAY, 1976). So, the actual phenomena can be masked by the lack of accuracy in the measurements, the variability of the results and inadequate estimates of maintenance requirements.

Effect of breed

Available data are also scarce. In growing steers the efficiency of ME utilisation for body gain was better in Herefords, which had a higher fat gain, than in Holsteins (GARRETT, 1971). In experiments on growing fattening bulls of different French breeds and crossbreeds, COLLEAU (1978) obtained only small variations in k_g (49.8 per cent for the Holstein × Friesian and 46.8 per cent for the Charolais) in spite of rather large variations in FE (74.5 and 62.3 per cent respectively). There were, however, large differences in maintenance requirements (636 kJ/kg $W^{0.75}$ for the HF and 552 for the Charolais bulls). In the same way, VERMOREL *et al.* (1976) did not observe significant differences in k_g between Friesian and Charolais calves or bulls, in spite of large variations in FE, but a 13 per cent lower maintenance requirement for the Charolais bulls.

Effect of sex

The efficiency of ME utilisation for growth seems to be higher (by about 5 to 8 per cent units) in females than in intact males, which may be connected with the higher proportion of energy retained as fat, in sheep (BULL *et al.*, 1976; FERRELL *et al.*, 1979; THERIEZ *et al.*, 1980) and in cattle (GEAY *et al.*, 1980) (Table 2). However, k_g seems to be similar in heifers and in castrated steers (GARRETT, 1970, 1980).

TABLE 2

EFFICIENCY OF ME UTILISATION FOR GROWTH. EFFECT OF SEX IN CONNECTION WITH THE PROPORTION OF ENERGY RETAINED AS FAT (FE)

Animals		k_g		FE		References
		♂	♀	♂	♀	
Lambs		.58	.66	82%	89%	Bull, Tyrrell and Reid, 1976
Lambs		.31	.36	74%	82%	Ferrell et al., 1979
Lambs	(1)	.27	.33	64%	75%	Theriez, Houssin and Castillo Gonzales, 1980
	(2)	.42	.48	67%	79%	
Cattle	(3)	.24	.31	50%	62%	Geay, Robelin and Vermorel, 1980
	(4)	.32	.42	62%	79%	

Diet composition: dehydrated lucerne: (1) 70%; (2) 30%; (3) 80%;
(4) 20% and concentrate

Effects of feeding level and diet composition

In the experiments carried out on different feeding levels (L), the efficiency of ME utilisation for growth did not vary significantly with L (THORBEK and HENCKEL, 1976; GEAY *et al.*, 1976; THERIEZ *et al.*, 1980; VERMOREL *et al.*, 1980).

From the energy balances obtained on adult ruminants, BLAXTER (1974) showed that k_f increased with the metabolisability of the diet (q) and he obtained several equations for different types of diets. In growing ruminants, k_g seems to vary also with q, although WEBSTER (1976) obtained the same value (62 per cent) for 2 diets with different q values (0.55 and 0.67). However, the slope of the regression line of k_g over q seems to be lower in growing ruminants than in adults (FERRELL *et al.*, 1979; GEAY *et al.*, 1980; THOMSON and CAMMELL, 1980; VERMOREL *et al.*, 1980).

Furthermore, some data obtained on growing heifers and steers by GARRETT

(1980) and on growing bulls and heifers by GEAY *et al.* (1980) seem to show that the ratio between k_g and k_f (according to BLAXTER (1974) equation) is almost constant for a given type of growing cattle for $0.50 \leqslant q \leqslant 0.70$ (Table 3). These results must be confirmed. However, as feeds have about the same ME content in growing and adult ruminants, this would mean that, if their net energy values for growth or fattening are different, the relative energy values of feeds are similar. So, k_f could be used instead of k_g, with little error, to calculate the energy value (expressed in Feed Units) of feeds for growing ruminants. This assumption was adopted in the new Dutch, French and Swiss energy systems for beef cattle (VAN ES *et al.*, 1978).

TABLE 3

COMPARISON OF ME UTILISATION FOR FATTENING (k_f) IN ADULT RUMINANTS AND FOR GROWTH (k_g) IN CATTLE. VARIATIONS WITH THE METABOLISABILITY (q) OF THE DIET

Animals		k_f or k_g (%)			k_f/k_g			References
q		.50	.60	.70	.50	.60	.70	
Adult ruminants		39.6	47.4	55.2	-	-	-	Blaxter, 1974
Cattle	♂ ♀	32.8	41.1	46.4	1.20	1.15	1.19	Garrett, 1980
Cattle	♀	31.2	36.9	43.1	1.27	1.28	1.29	Geay, Robelin and Vermorel, 1980
	♂	25.3	31.0	36.6	1.56	1.53	1.51	

3. — Total efficiency of energy utilisation for growth

From a practical point of view, the total efficiency of energy utilisation for growth (k_t) is an important criterion because it is the main factor of feed efficiency. k_t is defined as the ratio of retained energy (RE) over the total intake of gross energy (IE) or ME. It depends on the feeding level (L) and on the partial efficiency of energy utilisation for growth (k_g. if referred to ME), with the following relationship (BICKEL, 1977).

$$\mathrm{RE} = k_g\,(\mathrm{ME} - \mathrm{ME}m) \qquad \mathrm{RE} = k_g\left(1 - \frac{1}{\mathrm{L}}\right)\mathrm{ME} \qquad k_t = k_g\left(1 - \frac{1}{\mathrm{L}}\right)$$

This hyperbolic function shows the diminishing increase in k_t as L rises. If k_g is assumed to increase linearly (as FE increases) or asymptotically with L, k_t is maximum and reaches k_g when L is infinite (fig. 8). However, if k_g varies curvilinearly and decreases with high feeding levels, then k_t reaches a maximum value in the finite range of L (fig. 8).

The feed conversion ratio (FCR) is also theoretically a hyperbolic function of L. If c_g and c_f are the energy concentrations of gain and feed (expressed by ME), FCR can be expressed with the following relationship:

$$\mathrm{FCR} = \frac{\mathrm{ME}/c_f}{\mathrm{RE}/c_g} = \frac{c_g}{c_f} \times \frac{\mathrm{ME}}{k_g\left(1 - \frac{1}{\mathrm{L}}\right)\mathrm{ME}} \qquad \mathrm{FCR} = \frac{1}{k_g} \times \frac{c_g}{c_f} \times \frac{\mathrm{L}}{\mathrm{L} - 1}$$

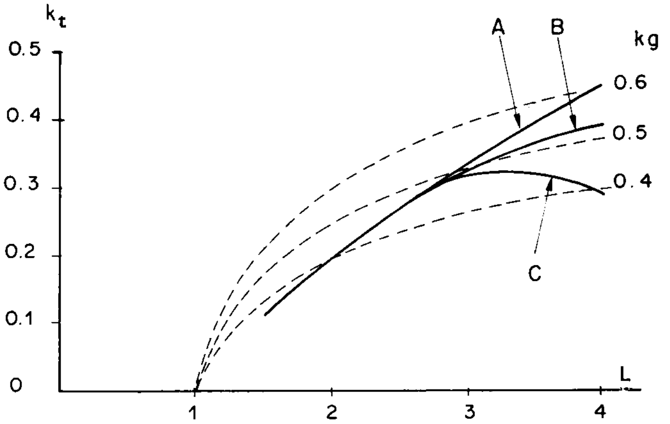

FIG. 8. — *Relationship between total efficiency* (k_t), *partial efficiency* (k_g) *of energy utilisation for growth and feeding level* (L.).

- - - - - - variation of k_t for a given value of k_g.

——— variation of k_t when k_g increases linearly (A) or asymptotically (B) with L or varies curvilinearly and decreases for high feeding levels (C).

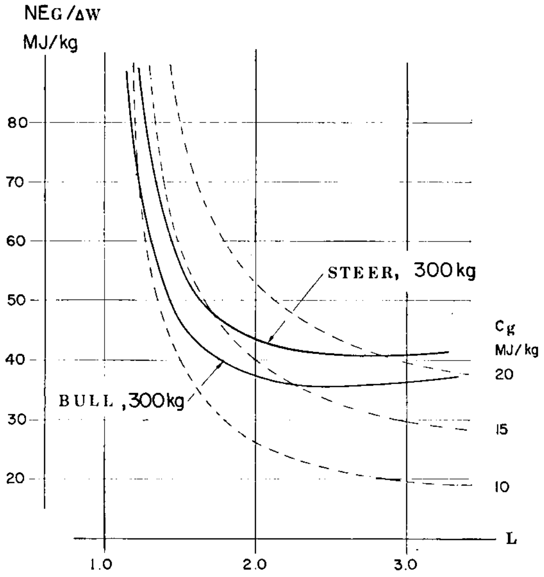

FIG. 9. — *Relationship between energy conversion ratio, feeding level* (L) *and energy value of gain* (c_g). *Example for fattening bull and steer* (Swiss dual purpose breed) (cf text).

(Energy conversion ratio: net energy for growth per kg weight gain)

- - - - - - when c_g is constant.

——— when c_g increases with L.

However, c_g is not a constant, but it increases with L. Therefore, FCR reaches a minimum value in the finite range of L. This holds true also for the energy conversion ratio (ECR), defined as the requirement of net energy for growth (NEG) per kg liveweight gain. Figure 9 shows an example of the variations of NEG with L for bulls and steers at 300 kg liveweight. The dotted lines represent the theoretical hyperbolic functions for 3 different values of c_g. The calculation is based on the estimation of c_g from experimental results with Swiss dual purpose cattle (LEHMANN, 1979). No correction of k_g was made for the influence of the protein level. It is suggested that this influence is of minor importance compared to the influence of L and c_g.

The example shows that FCR may be optimised for any specific case, if the relationship between level of feeding and energy value of gain is known.

Conclusion

In growing ruminants, ME intake and the ME content of feeds can be estimated accurately, in spite of variations in energy digestibility, in methane and urinary energy losses. The estimates of energy, protein and fat gain are less accurate, especially when using calorimetry. However, the partition of the total heat production (H = ME — RE) into its various components is tricky.

H amounts to about 50 per cent of IE and ranges from 60 to 90 per cent ME intake ; it depends firstly on the breed, sex, age, physical activity and body gain composition of the animals, and secondly, on the diet composition and ME intake. The heat production arises from numerous interrelated phenomena which set the metabolic rate in different tissues and organs : maintenance of the cellular structure and activity, protein and lipid synthesis associated with different turn-over rates. Therefore, the partition of this energy expenditure between maintenance and tissue gains leads to various conclusions depending on the methods used, the accuracy of the estimates and the statistical model used to analyse the data.

These phenomena can be analysed properly only if ME and RE are determined very accurately, if the variations in protein gain and fat gain are large and if the other factors which can influence the metabolic rate are mastered. With such an analysis the energy allowances which promote the best efficiency for each kind of ruminant and a given production type can be defined.

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