Net utilization of roughage and concentrate diets by sheep

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1. Two diets, an all-roughage diet and a high-concentrate diet, were fed at two levels, a low level of estimated 1·5 times maintenance energy requirement and a higher level of estimated two times maintenance energy requirement, to South African Mutton Merino castrated male sheep, aged 13 months and in fairly lean condition at the start of the 93 d experimental period.

2. Body composition and energy retention were determined using the comparative slaughter technique and two series of digestibility and balance studies were done during the course of the experiment. Metabolizability of each diet was estimated and corrected for fermentation heat using the fermentation balance approach.

3. Although there were significantly different rates of energy gain on different diets and feeding levels, fat energy gained (% total energy gained) was similar for the four groups, i.e. 78–80.

4. Regression of energy gain *v*. corrected metabolizable energy (ME) intake indicated that the maintenance energy requirements of sheep used in this experiment were 310·2 and 302·3 kJ ME/kg body-weight$^{0.75}$ per d and the values for net utilization of ME for body energy gain were 0·411 and 0·479 with the roughage and concentrate diets respectively.

5. It was concluded that the estimated maintenance energy requirements of sheep obtained in this study are realistic values and that the efficiency of utilization of surplus ME for the two diets did not differ significantly.

It is generally accepted that, although the determination of apparent digestibility of a diet takes into account the faecal loss as the largest single and most variable loss of gross dietary energy, the energy losses incurred in excreted urine, and production of combustible gases in the digestive tract should be taken into account in order to obtain a more discriminating measure. Blaxter (1962) found that metabolizable energy (ME) corrected for fermentation heat is utilized with a fairly constant efficiency for maintenance (a view slightly modified in later publications, e.g. Agricultural Research Council, 1965), and also that for productive functions the efficiency of ME utilization is strongly dependent on the nature of the diet, whether it is roughage or concentrate. This is related to the nature of the end-products of rumen digestion, i.e. the molar ratio, acetic:propionic:butyric acids in the rumen fluid. However, results from subsequent studies by Elliot, Hogue, Myers & Loosli (1965), Ørskov & Allen (1966), Ørskov, Hovell & Allen (1966) and Bull, Reid & Johnson (1970) indicated that the difference in efficiency of utilization of volatile fatty acids (VFA) is far less marked, and that, in long-term experiments, acetic and propionic acids or their salts are used with similar efficiencies for production. The results of these studies seem to indicate that, if it can be accurately determined or estimated, the ME of diets differing widely in roughage:concentrate ratio and hence in the proportions of VFA produced, should be utilized with similar efficiencies for production.

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In the experiment reported here we studied the utilization of two diets, one of all roughage and the other containing a high proportion of concentrate, in an effort to determine whether the ME obtained from the two diets was utilized with similar efficiencies.

EXPERIMENTAL

Animals

Twenty-eight South African Mutton Merino castrated male sheep aged 13 months and in fairly thin condition, with a mean live weight of 43 kg, were used. They were housed in individual pens on slatted floors in an asbestos-roofed barn.

Design and treatment

After a period of 4 weeks, during which they were trained to individual penning, they were shorn and divided into two equal groups by stratified randomization based on live weights, and one group was given the roughage (R) diet and the other the concentrate (C) diet for a 3-week adaptation period at the maintenance level calculated at 359·8 kJ ME/kg body-weight $(W)^{0.75}$. Each group was subsequently divided into three subgroups, i.e. 'initial slaughter' group (control) consisting of four animals, 'low-level' group (L) and 'high-level' group (H), both consisting of five animals.

Composition and preparation of diets

The two experimental diets used in the study consisted of: (1) a coarsely milled mixture of equal parts oat hay and lucerne hay (R); (2) (g/kg) 500 diet R, 400 maize meal, 100 fish meal (C).

Feeding levels

Values obtained in recent feeding trials with similar diets by F. J. van der Merwe & C. L. van Wyk (unpublished results) were used to calculate digestibility and metabolizability of the two diets. Calculated values of ME were 7·8 MJ/kg for diet R and 12·5 MJ/kg for diet C. Under our experimental conditions, the highest attainable voluntary food intake on diet R at the 15% refusal level was about twice maintenance. Both diets were subsequently given at two levels of ME, 538·1 (L) and 717·6 (H) kJ/kg $W^{0.75}$ per d, representing 1·5 and two times the estimated maintenance energy requirements respectively.

Management of sheep

Daily rations were offered at 07.00 hours and uneaten food removed and dried to constant weight. The preliminary determination of voluntary intake of diet R, and subsequent adaptation of feeding levels to that level, limited food refusals to very small quantities. Water was offered *ad lib.* Initial live weight after 18 h starvation was used to calculate daily food requirements and, after 45 d of the experiment, the requirements for the remaining 48 d period was calculated, according to the adjusted live weight corrected for wool growth. None of the animals scoured during the experimental period and general health was good. All animals were treated against internal parasites before the adaptation period began.

Digestibility and energy balance trial

The sheep were equipped with faeces collection bags and urine funnels for two 10 d periods within the experimental period. Representative 10% samples of the collected faeces and urine were retained for analysis.

Analysis of food, faeces and urine

Moisture content was determined for all samples by oven drying at 103°, and crude fibre, diethyl ether extract, ash and nitrogen were determined according to the Assocation of Official Agricultural Chemists (1960) methods. Energy determinations were done using an adiabatic bomb calorimeter (A. Gallenkamp & Co. Ltd, London EC2). Lignin determinations were made according to the method of Van Soest & Wine (1968).

Comparative slaughter procedure

The feeding period of 93 d began on the day the control group was slaughtered and the remaining twenty animals were slaughtered at the end of the experiment. At slaughter the oesophagus was tied and blood collected quantitatively in a plastic container. Skinning took place in a high-humidity, closed room. The digestive tract was removed and emptied. The skinned carcass plus blood plus empty digestive tract were weighed and ground three times in succession in a carcass grinder (Wolfking, Slagelse, Denmark) through three sets of screens, of which the smallest had 5 mm die-holes. The skins were sampled separately and analysed.

Estimation of body tissue and energy gains

The mean weights of the digestive tract contents of the control groups were used to compute the initial empty-body-weight (EBW) of sheep in the experimental groups. The regression of body composition *v*. EBW was used to calculate mean gains of dry matter (DM), fat, ash and energy.

RESULTS

Chemical composition of the diets

Food samples were taken at regular intervals during the feeding period. The average chemical compositions of the diets are given in Table 1. The greater daily intake of diet R compensated for the lower crude-protein ($N \times 6.25$) content of this diet. The high crude-fibre content of diet R is in accordance with the object of comparing a roughage diet with a more concentrated diet.

Digestibility of the diets

Digestibility of gross energy (GE) and crude fibre and digestible energy concentrations of the two diets, as determined in the two digestibility trials, are given in Table 2.

It is interesting to note that in diet R the digestibility of crude fibre was reduced at the higher level of feeding but in diet C no such reduction was found.

Table 1. *Dry matter* (DM) *content* (*g/kg fresh wt*) *and chemical composition* (*g/kg*) *of the* DM *of the all-roughage* (*R*) *and high-concentrate* (*C*) *diets fed to sheep*

		Chemical composition of DM					
Diet*	DM content	Crude protein (nitrogen × 6·25)	Crude fibre	Crude fat	Ash	N-free extract	Lignin
R	874·8	96·6	308·9	24·9	62·1	507·5	66·3
C	884·7	145·1	170·9	40·1	47·3	596·6	38·9

* For details of diets, see p. 202.

Table 2. *Mean digestibility of gross energy* (*GE*), *amount of digestible energy* (DE) *and digestibility of crude fibre of the all-roughage* (*R*) *and high-concentrate* (*C*) *diets fed to sheep at two levels, high* (*H*) *and low* (*L*)

(Mean values for ten determinations)

	Dietary treatment*				
	LR	HR	LC	HC	SE
Digestibility of GE	0·578	0·568	0·767	0·758	0·005
DE (MJ/kg diet)	10·75	10·56	14·54	14·36	0·10
Digestibility of crude fibre	0·514	0·490	0·559	0·559	0·007

* For details of diets, see p. 202 and Table 1.

Table 3. *Molar proportions of volatile fatty acids* (*mmol/mol*) *in rumen fluid samples taken from rumen-fistulated and slaughtered sheep given the all-roughage* (*R*) *or high-concentrate* (*C*) *diets at two levels, high* (*H*) *and low* (*L*)

(Mean values for seven samples)

	Dietary treatment*				
	LR	HR	LC	HC	SE
Acetic acid	690	680	590	580	11·5
Propionic acid	190	220	280	270	14·8
Butyric acid	120	100	130	150	7·7

* For details of diets, see p. 202 and Table 1.

Rumen fermentation

During the feeding experiment the experimental diets were fed to four rumen-fistulated sheep that were not included in the comparative slaughter trial. Rumen fluid samples of large volume were taken twice by aspiration, as described by Van Niekerk (1965), 4 h after feeding on two occasions evenly spaced in the 93 d feeding period. Rumen fluid samples were also taken from the twenty-eight slaughtered animals and sampling coincided with slaughtering time, which varied from 2 to 5 h after feeding. All samples were treated as described by Erwin, Marco & Emery (1961) and VFA concentrations were determined by gas–liquid chromatography. The results are given in Table 3.

Table 4. *Mean values used to calculate metabolizable energy* (ME) *and corrected* ME *of the all-roughage (R) and high-concentrate (C) diets fed to sheep at two levels, high (H) and low (L)*

	Dietary treatment*				
	LR	HR	LC	HC	SE
DM intake (kg) for 93 d period	90·41	122·66	70·30	79·13	2·73
Digestible crude-fibre intake (kg)	14·37	18·55	6·72	9·29	0·33
Corrected NFE (NFE − lignin) intake (kg)	39·89	54·12	39·21	54·17	1·40
Digestible carbohydrate intake:					
kg	54·26	72·67	45·93	63·46	1·72
mol	334·91	448·55	283·50	391·71	10·61
GE intake − ($E_f + E_u$) (MJ)	906·82	1207·54	964·50	1308·32	33·48
Methane production (MJ)	115·18	148·82	62·27	81·12	2·76
ME intake (MJ)	791·64	1058·71	903·13	1227·20	30·89
ME concentration (MJ/kg DM)	8·757	8·632	12·832	12·636	
Residual heat of fermentation (MJ)	37·32	48·97	25·22	33·96	1·01
Corrected ME intake (MJ)†	754·32	1009·74	876·91	1193·24	29·97
Corrected ME concentration (MJ/kg)†	8·343	8·238	12·477	12·284	

DM, dry matter; NFE, nitrogen-free extract; GE, gross energy; E_f, E_u, faecal and urinary energy respectively.

* For details of diets, see p. 202 and Table 1.

† Corrected for heat of fermentation, see below.

The results in Table 3 clearly indicate different patterns of rumen VFA with the two diets. The molar proportion of acetic acid in rumen fluid was subsequently used in the calculations of methane and fermentation heat losses.

ME *concentrations of the diets and* ME *intake*

The energy in faeces and excreted urine was determined directly but values for methane production and fermentation heat were calculated using the stoichiometrical approach described by Ørskov, Flatt & Moe (1968). From their results (Table 1 of Ørskov *et al.* (1968)) the regression equation, $Y = 0{\cdot}498X - 20{\cdot}6$ could be obtained, where Y is the total methane energy (MJ/40 mol digestible carbohydrate); X is the acetic acid concentration in rumen fluid (mmol/mol VFA) (r 0·985, $P < 0{\cdot}01$).

The digested carbohydrate (digested crude fibre + N-free extract − lignin) was assumed to be $C_6H_{10}O_5$ with a molecular weight of 162. Dividing the amount of digested carbohydrate (g) by 162 gave the amount of hexose consumed (mol).

For the estimation of corrected ME the fermentation heat had to be calculated. The regression equation, $Y = 0{\cdot}090X - 1{\cdot}75$, where Y is the residual fermentation heat (MJ/40 mol digestible carbohydrate) and X is the acetic acid present (mmol/mol VFA) (r 0·945, $P < 0{\cdot}01$), was derived from the results of Ørskov *et al.* (1968) and used for the estimation of fermentation heat. However, it should be pointed out that Ørskov *et al.* (1968) used dairy cows, and these values were used because we lacked facilities for the direct determination of methane and residual heat of fermentation. By giving one prediction equation (methane production) for both cattle and sheep the Agricultural Research Council (1965) implied that results obtained with one species should be applicable to the other.

Table 5. *Mean gains in empty-body-weight (EBW), dry matter (DM), fat and energy of sheep given the all-roughage (R) or high-concentrate (C) diets at two levels, high (H) and low (L)*

(Mean values for five estimations)

	Dietary treatment*				
	LR	HR	LC	HC	SE
Initial EBW (kg)†	32·7	33·0	32·4	32·4	1·59
Final EBW (kg)	38·0	43·0	41·6	48·6	1·51
Mean total gain in EBW (kg)	5·3	10·0	9·2	16·2	0·58
Mean daily gain in EBW (g)	57	107	99	174	
Mean gain in: DM (kg)	3·9	7·1	6·8	10·4	
Fat (kg)	2·1	4·0	3·7	6·6	0·23
Energy (MJ)	105·2	200·4	184·4	324·4	11·30
Energy gained as fat (MJ)‡	82·3	156·8	145·0	258·7	
Ratio, fat gain: total energy gain	0·782	0·782	0·786	0·799	

* For details of diets, see p. 202 and Table 1.
† Calculated from the EBW of the 'initial slaughter' group (for details, see p. 202).
‡ kg fat × 39·2.

The values used in the calculation of ME concentration and corrected ME concentration are given in Table 4.

The corrected values for N-free extract intakes at corresponding feeding levels were very similar. This fraction, together with the digested crude fibre, formed the substrate for methane formation. Methane production (as calculated) differed markedly between groups but when expressed as J/kJ energy consumed was 67, 65, 47 and 44 for groups LR, HR, LC and HC respectively.

The residual fermentation heat for diet R was considerably greater than that for diet C at corresponding feeding levels. This would indicate that more carbohydrate was fermented in the instance of diet R because according to Ørskov *et al.* (1968) the residual fermentation heat is a fixed proportion of the fermented carbohydrate (0·064) irrespective of the type of diet.

Gains in EBW, body tissue and energy

Mean gains in EBW, DM, fat and energy of the four groups of sheep are given in Table 5.

Significant differences in EBW gains were found. Within both diet types, feeding level had a statistically significant effect on mean total gain in EBW. Between diet types EBW gains of sheep on diets HR and LC did not differ significantly, which is to be expected in view of the nearly equal ME intakes of sheep in these two groups. Mean gains in EBW, energy and DM followed the same pattern. Although different rates of gain were obtained in all four groups, the ratio, fat gained: energy gained was virtually the same.

Maintenance energy requirements and energy utilization

Regressions of energy gain *v.* corrected ME intake gave the following equations for diets R and C respectively:

$$Y = 0{\cdot}411X - 127{\cdot}5 \quad (\text{SE(b) } 0{\cdot}064),$$
$$Y = 0{\cdot}479X - 144{\cdot}8 \quad (\text{SE(b) } 0{\cdot}112),$$

where Y is the energy retention (kJ/kg $W^{0\cdot75}$ per d); X is the corrected ME intake (kJ/kg $W^{0\cdot75}$ per d). The slopes of the two lines did not differ significantly. In effect these two regressions indicate that: (1) maintenance energy requirements of the sheep used in this experiment were 310·2 and 302·3 kJ ME/kg $W^{0\cdot75}$ per d on diets R and C respectively; (2) net utilization of corrected ME for energy retention (of which 80% is in the form of fat) was 411 and 479 J/kJ on diets R and C respectively, a difference which was not statistically significant.

The regressions of energy gains *v.* DM intakes gave the following equations for diets R and C respectively:

$$Y = 3{\cdot}24X - 116{\cdot}9 \ (\text{SE(b) } 0{\cdot}503),$$
$$Y = 5{\cdot}59X - 128{\cdot}1 \ (\text{SE(b) } 0{\cdot}897),$$

where Y is the energy retention (kJ/kg $W^{0\cdot75}$ per d); X is the DM intake (g/kg $W^{0\cdot75}$ per d). The slopes of the two lines differed significantly ($P < 0{\cdot}05$). These two regressions indicate that the amounts of net energy for production (NE_p) are 3·24 and 5·59 MJ/kg DM for diets R and C respectively. If the NE_p values obtained from these regression equations are related to corrected ME values for the two diets (Table 4), NE_p is 39 and 46% corrected ME respectively for diets R and C, which are of the same order as the values of 41·1 and 47·9 obtained from the regression of energy retention *v.* corrected ME intake.

DISCUSSION

In this study the molar proportions of VFA in rumen fluid as well as the faecal and urinary losses of dietary energy were determined directly. However, to obtain values for ME and corrected ME intakes, values for methane production and residual heat of fermentation had to be estimated and these estimations were based on a number of assumptions. The use for this purpose of some of the results of Ørskov *et al.* (1968) obtained with dairy cows is open to criticism. These were the only results we knew of which allowed methane production and residual heat of fermentation to be related to molar proportions of VFA in rumen fluid.

In order to put the results obtained in this study into some perspective a comparison of these with Blaxter & Wainman's (1964) results, obtained using two diets fed at the production level, is given in Table 6.

In chemical composition, apparent digestibility and metabolizability of gross energy (GE), diet HR (high-level, all-roughage) of the present study, and the all-hay diet used by Blaxter & Wainman (1964) are remarkably similar. Although the results are not given, it can be stated that the molar proportions of VFA in rumen fluid were

Table 6. *The average composition, metabolizability and net utilization of metabolizable energy* (ME) *for energy retention of diets used by Blaxter & Wainman* (1964) *and those used in the present study*

Composition of diet	Blaxter & Wainman (1964)		Present study HR	Present study HC
Ingredients				
Hay (g/kg)	1000	400	1000	500
Maize meal (g/kg)	—	600	—	400
Fish meal (g/kg)	—	—	—	100
Chemical composition				
Crude protein (g/kg)	85·4	93·3	96·6	145·1
Crude fibre (g/kg)	338	148	309	171
Nitrogen-free extract (g/kg)	503	714	508	597
GE (MJ/kg diet)	18·41	18·41	18·41	18·83
GE intake (MJ/d)	22·50*	19·51*	24·90	19·72
Apparent digestibility	0·589	0·738	0·578	0·757
Urine energy (J/kJ)	35·6	23·8	26·8	41·3
Methane loss (J/kJ)	64·8	62·4	65·4	44·1
Metabolizability of GE	0·488	0·638	0·465	0·667
Net utilization of ME (J/kJ) for retention	275	471	400·8	475·6
Net utilization of corrected ME† (J/kJ) for retention	—	—	418·8	488·8

GE, gross energy; HR, all-roughage diet given at a high level; HC, high-concentrate diet given at a high level (for details of diets, see p. 202 and Table 1).
* Average intake at the production level of sheep Y, Ry and St.
† Corrected for heat of fermentation, see p. 205.

also comparable in the two studies. The two high-concentrate diets (our HC diet and Blaxter & Wainman's hay–maize diet) differ more widely in chemical composition, although digestibility and metabolizability again can be considered to be of the same order. The most striking difference between these two high-concentrate diets is in protein concentration, and the considerably higher urinary energy losses of sheep on our diet HC must be ascribed to an over-supply of protein in this instance. In the planning of our experiment it was argued that we should strive at a comparable protein:energy ratio in the two diets. Eventually the values for the ratio, crude protein (g):corrected ME (MJ) were 11·7:1 (97 g, 8·3 MJ/kg; 145 g, 12·4 MJ/kg) in both instances, an exact correspondence which occurred incidentally and not by design.

In the present study the net utilization of ME and corrected ME for energy retention were estimated from results obtained in the comparative slaughter experiment, for a 93 d feeding period. In the instance of diet HC used in the present study this was 475·6 J/kJ ME, which compares favourably with the 471 J/kJ obtained by Blaxter & Wainman (1964). However, for the all-hay diets the value of 400·8 J/kJ ME obtained in the present study is much higher than the 275 J/kJ ME obtained by Blaxter & Wainman (1964), even though the metabolizability of GE was slightly lower for diet HR of the present study.

As these values reflect efficiencies of utilization of surplus ME, the maintenance energy requirements of the sheep as estimated in the present study should also be put into perspective. The estimated maintenance requirements of 310 and 302 kJ

ME/kg $W^{0.75}$ for sheep on diets R and C respectively are much lower than Rattray, Garret, Hinman & East's (1974) mean estimate of 519 kJ/kg $W^{0.75}$ obtained from regressions of energy gain *v.* ME intake. However, if the Agricultural Research Council (1965) preferred value for fasting metabolism of 12-month-old sheep ($W^{0.75}$ 18 kg) of 255 kJ/kg $W^{0.75}$ is converted to corrected ME on the assumption that efficiency of utilization of corrected ME for maintenance $= 74.1 + 0.16 \dfrac{\text{corrected ME}}{\text{GE}}$ (Agricultural Research Council, 1965), the estimated maintenance requirements are 314 and 301 kJ ME/kg $W^{0.75}$ on diets R and C respectively. These are of the same order as the values obtained in the present study from regressions of energy gain *v.* corrected ME intake.

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