British Journal of Nutrition (1983), **50**, 173–187

Basal urinary nitrogen excretion and growth response to supplemental protein by lambs close to energy equilibrium

BY F. D. DEB. HOVELL, E. R. ØRSKOV, D. A. GRUBB AND N. A. MACLEOD

Rowett Research Institute, Bucksburn, Aberdeen AB2 9SB

(*Received 23 July 1982 – Accepted 10 March 1983*)

1. Two experiments are reported. In Expt 1, five male lambs of 26–33 kg were used to measure basal nitrogen excretion when the lambs were entirely sustained by an intraruminal infusion of 450 kJ/kg body-weight$^{0.75}$ per d of volatile fatty acid (VFA) and were receiving no protein. In Expt 2, which was a conventional growth trial, the response to fish meal (66 or 132 g dry matter/d) of lambs given a control diet of sodium-hydroxide-treated barley straw was measured.

2. In Expt 1 the mean basal N excretion of the lambs was 429 (SE 21) mg N/kg body-weight$^{0.75}$ per d. This exceeds current UK standards for the amino acid N of microbial origin which would be made available to the normally-fed host animal at a maintenance level of metabolizable energy intake.

3. In Expt 2 there was a clear growth response to the fish meal, which was greater ($P < 0.05$, single-tailed test) than that to be predicted from the energy content of the fish meal. There was no effect of fish meal on the voluntary intake of the basal diet, but there was a suggestion that the digestibility of the basal diet was improved.

4. It is concluded from Expt 1 that the basal requirement for amino acid N by lambs is three- to fourfold that currently recommended in the UK. This higher basal N requirement should have resulted in a marked response to supplemental protein in Expt 2. The fact that the growth response in Expt 2 was less than anticipated may have been due to a combination of a slightly lower basal N excretion than that found in Expt 1, a higher yield of amino acids of microbial origin than current UK standards predict, and possibly to a change in the body composition of the lambs.

It is now well understood that the requirement for protein by ruminant animals is a combination of the needs of the rumen micro-organisms and of the host animal. The host animal's requirement for amino acids is met from the microbial protein synthesized in the rumen, together with dietary protein which escapes degradation in the rumen and is digested in the small intestine. The limitations of existing systems for the evaluation of protein sources for ruminant nutrition have been discussed by Roy *et al.* (1977) who then proposed a system which is the basis of the new Agricultural Research Council (ARC; 1980) system for protein rationing. The ARC system attempts to arrive at estimates of the separate needs of the host animal and its rumen micro-organisms, and to integrate the contributions made by dietary protein and non-protein nitrogen towards these requirements.

The host animal's requirement for amino acids (tissue N; TN), is defined as the sum of the N needed to maintain N equilibrium by offsetting endogenous losses in the urine, the losses from the body pool as hair and shed epithelial cells, and the amino acids retained in the body, the fetus, and secreted as milk (Roy *et al.* 1977). When dietary energy is supplied at a level close to that needed to maintain the energy equilibrium of the host animal (maintenance), Roy *et al.* (1977) concluded that for an animal neither lactating, nor pregnant, TN would be met and even exceeded by the protein synthesized in the rumen by the micro-organisms.

At energy intakes close to maintenance, the main component of TN will be the N needed to offset the endogenous losses in the urine (endogenous urinary N, UN(E)). This is difficult to measure in ruminants, due to the fact that N has to be supplied to satisfy the requirements of the rumen micro-organisms, and therefore the technique of using N-free diets (as with single-stomached animals) cannot be applied. A further complication with ruminants is that

endogenous losses may be partitioned between the urine and faeces, dependent on the amount of fermentation taking place in the hind gut, and the consequent excretion of N in the debris of the micro-organisms participating in that fermentation (Ørskov *et al.* 1970). This faecal N will be in addition to the undigested microbial debris originating from the rumen which can also contain recycled N of endogenous origin. The fact that recycled N of endogenous origin may be lost in the faeces has long been recognized, as was discussed by Blaxter (1964) who referred to obligatory faecal losses associated with food intake. The ARC (1965) recommendations took *de facto* account of this route of N loss by including a faecal component in their estimation of protein requirement which was related to dry matter (DM) intake, but that did not allow for the increase in the urinary component which will occur at low DM intakes. At high DM and protein intakes, faecal N of microbial origin will contain N of exogenous origin. Thus, the current ARC (1980) recommendations do not include a faecal component in the estimation of host animal requirements. However, the ARC (1980) estimates use values for UN(E) derived from experiments in which microbial debris in the faeces would have contained N of endogenous origin, and which therefore underestimate true endogenous losses. All these problems stem from the difficulty of measuring endogenous losses of N in the normally-fed ruminant, when these losses are partitioned between the urine and the faeces.

The development of a technique whereby ruminants may be wholly maintained by intragastric infusion (Ørskov *et al.* 1979) has provided a means to circumvent these problems, and a number of measurements of N excretion from sheep maintained at about energy equilibrium by an intraruminal infusion of volatile fatty acid (VFA) have been made in this laboratory. As will be shown, these measurements gave values considerably in excess of current estimates (ARC, 1965, 1980) of UN(E). Indeed, the values were so great, that the implication was that microbial N would not be able to supply sufficient amino acids for tissue maintenance at energy equilibrium, and therefore a feeding trial was undertaken to test whether animals given a diet supplying a maintenance level of energy intake would respond to an increase in the amino acid supply to the tissues.

Two experiments are reported. In the first the basal N excretion of lambs wholly maintained by intragastric infusion was measured. A provisional account of this experiment has already been given (Ørskov & Grubb, 1979). In the second, growing lambs were given a diet based on barley straw treated with sodium hydroxide and the growth response to additions of a protein of low degradability in the rumen (fish meal) was determined. A provisional report of this experiment has also been given (Hovell & Ørskov, 1981).

EXPERIMENTAL

Expt 1

Animals, treatments and design. Five male lambs of between 26 and 33 kg live weight, which had been fitted with permanent rumen cannulas and abomasal catheters, were maintained by an intraruminal infusion of VFA and an intra-abomasal infusion of casein as described by Ørskov *et al.* (1979). The lambs were housed in metabolism cages, and a total collection of urine made. Urine N was determined on the 24 h excretion of each individual lamb. Methods were those described by Ørskov *et al.* (1979).

The trial to be described here was carried out after the animals had been on an infusion experiment in which they had been maintained in positive N balance by the infusion of casein into the abomasum. The casein infusion was then stopped, but the infusion of VFA was maintained at a rate of 450 kJ/body-weight$^{0.75}$ per d (with acetic, propionic and butyric acids in molar proportions of 55:35:10).

Expt 2

Animals, treatments and design. Twenty-four entire male lambs, initially between 24 and 40 kg live weight and 4–5 months old, were ranked according to live weight and divided into four groups each of six animals. Lambs within each group were allocated at random to one of six treatment groups. These were: OO, basal diet of NaOH-treated straw plus urea throughout the experiment. This control treatment was conducted in duplicate to give two groups of four animals; LL, basal diet as for group OO, but supplemented with 66 g white fish meal DM/d throughout the experiment; HH, basal diet as for group OO, but suplemented with 132 g white fish meal DM/d throughout the experiment; OL, basal diet as for group OO for 69 d (period 1), and then supplemented with 66 g white fish meal DM/d from day 70 until the end of the experiment (period 2); OH, basal diet as for group OO for 69 d (period 1), and then supplemented with 132 g white fish meal DM/d from day 70 until the end of the experiment (period 2). Half the lambs within each treatment group were slaughtered after 119 d. The remaining twelve lambs were continued on the treatments for a further 43 d during which time the digestibilities of the diets were measured. These lambs were then slaughtered.

Housing and management. The lambs were penned in individual slatted floor pens in the institute's sheep house. After approximately 2 weeks they were moved to slatted floor pens in a controlled environment ewe house, where they remained until the first batch of lambs was slaughtered. The remaining lambs were transferred back to the sheep house for the digestibility trial, where they remained until they too were slaughtered. The lambs were individually fed, the basal diet of NaOH-treated straw being offered *ad lib.* The protein supplement was given once daily. The feed troughs were completely cleaned out every 2 or 3 d. A fresh batch of straw was prepared approximately every 10 d, all animals being changed to the new batch at the same time. Food residues were bulked within batches for each animal. Residues thought to contain fish meal were analysed for N and the amount of fish meal in the refusal calculated. All lambs were given an injection of vitamins (Duphofral multivit; Philips-Duphor B.V. Amsterdam, Holland) at the start, and again approximately half-way through the experiment.

Diet preparation. The straw was coarsely ground through a 40 mm screen using a hammer mill (Alvan Blanch bale grinder) into a mixer-trailer (Oswalt Ensilmixer). NaOH (approximately 60 g/kg DM) was sprayed on to the straw (while mixing) as a solution of approximately 160 g/l. Following this, a solution of urea and sodium sulphate was sprayed on (and the hoses and spray lines washed through with water). Dicalcium phosphate and a trace mineral–vitamin mixture were then sprinkled on to the straw, and the whole thoroughly mixed. The mixed, treated straw was sampled for DM determination, and weighed into individual plastic dustbins used to store each lamb's straw. The amounts of materials added to the straw were (kg/tonne DM) NaOH 60, dicalcium phosphate 6·0, urea 1·8, sodium sulphate 0·18, trace mineral–vitamin supplement (Norvite, Kennethmont, Aberdeenshire) 1·0, calcium chloride 1·0.

The supplement mixture was prepared by mixing the white fish meal with some of the NaOH-treated straw and molasses. A small amount of water was added to the molasses to facilitate mixing. The supplement mixture was prepared weekly, an individual mixture being made for each group of four lambs within each treatment group. All lambs (including the unsupplemented animals) were given the same amount of molasses, the only variable being the amount of fish meal.

Digestibility trial. Twelve lambs were used, two from each treatment group. The digestibility trial was carried out from days 127 to 149 of the experiment, and there were

therefore four lambs at each protein level, O, L and H. The lambs were kept in metabolism cages, and a total collection of faeces made during the last 9 d.

Measurements. Straw intake was measured on a weekly basis. The lambs were weighed twice weekly. Dietary DM and organic matter digestibility were determined during the digestibility trial. At slaughter the hot carcass, abdominal fat (excluding the perirenal fat) and rumen contents were weighed and the backfat thickness was measured on both sides of the carcass above the tenth rib and approximately 55 mm from the centre-line of the carcass.

RESULTS

Expt 1 (infusion trial)

The N excretion in the urine of the five lambs during the period of protein-free infusion is shown by Fig. 1. It can be seen that N excretion fell rapidly until approximately 2 d after the cessation of the casein infusion and thereafter remained relatively constant. The mean (with SEM of between animal means) of the 9 d averages of urine N excretion from day 2 to day 10 was 429, 21 mg N/kg body-weight$^{0.75}$ per d.

There was considerable day-to-day variation in the N excretion of the lambs. Examination of the results showed that within animals a day of relatively high N excretion was frequently followed by a day of relatively low N excretion, suggesting that much of the variation was simply due to end of collection errors.

Expt 2 (growth trial)

Health and management. The health of the lambs remained good throughout the experiment. There was initially some difficulty in persuading all the lambs offered fish meal to eat the fish meal. The fish meal was first offered as a meal and then as pellets. Some lambs continued to refuse some of their fish meal which was then offered in the supplement mix as described

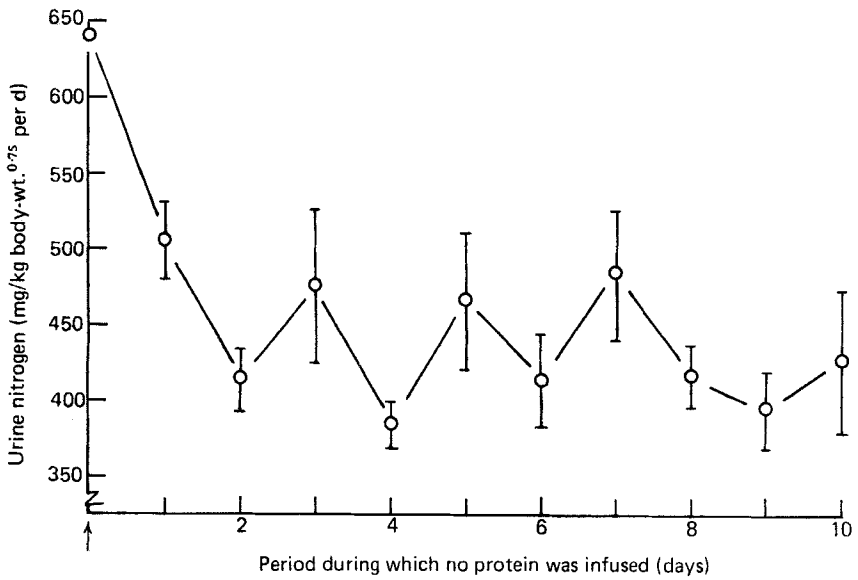

Fig. 1. Expt 1. Daily excretion of endogenous urinary nitrogen by five wether lambs of 26 to 33 kg live-weight given an intraruminal infusion of volatile fatty acids (450 kJ/kg body-weight$^{0.75}$ per d) and no protein (mean values with their standard errors represented by vertical bars). ↑, Last day of protein infusion.

Table 1. *Expt 2. Growth and food intake of lambs given sodium-hydroxide-treated straw with urea and supplemented with nil (O), 66 (L) or 132 (H) g/d white fish meal dry matter (DM)*

(Mean values for four lambs)

	Control groups (no fish meal)		Fish meal in second period only		Fish meal in both periods			Significance of the effect of:	
Treatment groups...	OO	OO	OL	OH	LL	HH	SEM	Protein	Protein level
Period 1 (0–69 d)									
Initial wt (kg)	34·4	34·9	33·2	34·2	35·1	35·6	1·2	NS	NS
Final wt (kg)	36·4	37·1	37·6	37·3	42·0	40·3	1·3	**	NS
Daily gain (g/d)	28	32	63	44	100	68	14	**	NS
DM intake (g/d)									
Treated straw†	795	853	950	910	911	855	52	NS	NS
Fish meal	—	—	—	—	66	132	—	—	—
Molasses	66	66	66	66	66	66	—	—	—
Daily intake (kg body-weight$^{0·75}$)									
Straw DM (g)	55	59	65	63	59	56	3	NS	NS
Total ME (kJ)†	505	538	590	569	629	638	25	**	NS
Period 2 (70–119 or 162 d)									
Initial wt (kg)	36·4	37·1	37·6	37·3	42·0	40·3	1·3	*	NS
Final wt (kg)	38·5	39·9	47·2	49·3	48·0	49·0	1·8	***	NS
Daily gain (g)	24	40	132	176	89	136	10	***	***
DM intake (g/d)									
Treated straw†	836	880	1044	1108	1081	986	42	***	NS
Fish meal	—	—	66	132	66	132	—	—	
Molasses	66	66	66	66	66	66	—	—	
Daily intake (kg body-weight$^{0·75}$)									
Straw DM (g)	56	57	63	66	61	57	2	**	NS
Total ME (kJ)	509	520	660	706	633	622	20	***	NS
Hot carcass: final live wt	0·419	0·412	0·434	0·435	0·432	0·469	0·010	NS	NS

ME, metabolizable energy; NS, not significant.

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

† DM of straw plus sodium-hydroxide, urea and added minerals.

‡ Fish meal taken as 11·20 MJ/kg DM, molasses as 10·05 MJ/kg DM and straw as 15·58 MJ/kg digestible organic matter calculated from treatment means (Table 2).

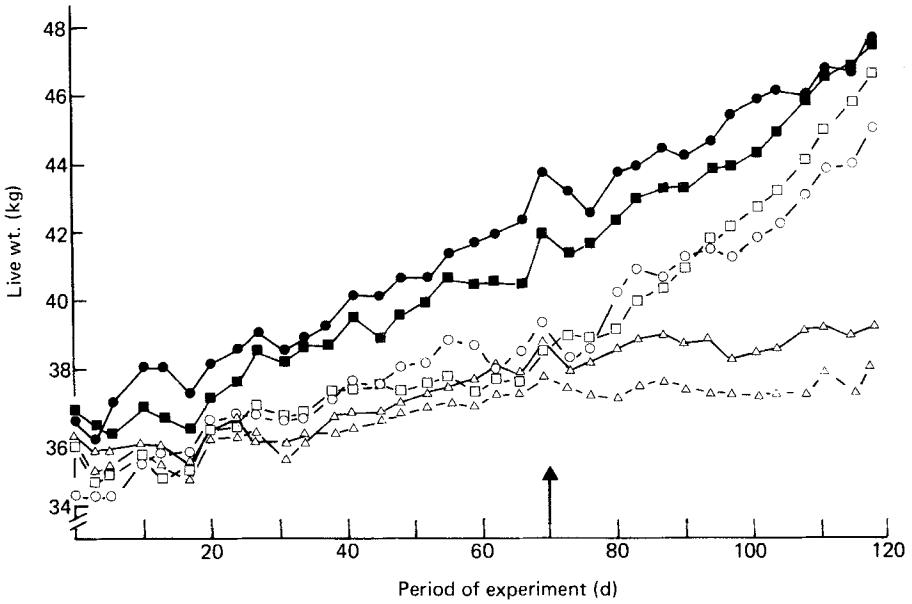

Fig. 2. Expt 2. Growth of lambs given sodium-hydroxide-treated barley straw with urea and supplemented with nil (△), 66 (○, ●) or 132 (□, ■) g white fish meal dry matter daily throughout the experiment (●, ■) or after 69 (↑) days (○, □). Mean values for four lambs.

previously. This was done from day 21 of the trial. The fish meal was readily eaten in this form. Any earlier refusals (calculated from the N content of the total refusal) were then fed back during the next 3–4 weeks (by slightly increasing the total amount offered).

Straw intake. There were no effects of protein supplementation on the voluntary intake of treated straw, for although supplementation did have a statistically significant effect on straw intake in period 2, this was due to the OL and OH groups maintaining the same high intakes in period 2 (when given protein) that they had achieved in period 1 (when not given protein). The comparison is clearer when intake is expressed on a metabolic body-weight basis (Table 1). This is in contrast to the findings of Kempton & Leng (1979) who reported an increase in the intake of an oat hull–wood cellulose–urea diet when supplemented with formaldehyde-treated casein. Examination of the intake values from the twelve lambs (two in each group) slaughtered at 162 d did, however, show a very clear increase in straw intake (and growth) during the period from 120 to 162 d. Thus, the mean straw DM intakes (g/kg body-weight$^{0.75}$ per d) for the four lambs on the O, L and H treatments (OL and LL, and OH and HH lambs were grouped together) respectively were 50, 58 and 53 (SE 0·9) from 70 to 119 d, and 63, 63 and 60 (SE 2·0) from 120 to 162 d. Corresponding growth rates (g/d) were 4, 110 and 116 (SE 16), and 81, 130 and 168 (SE 17). This increase in intake occurred right throughout the last 43 d of period 2. It coincided with the removal of the lambs from a controlled environment ewe house to the sheep house which was open to the natural daylight at a time of year (mid-February to the end of March) when the day length was increasing rapidly (by approximately 4 min/d) and it is tempting to suggest that the increased intake of straw was a day length response similar to that reported by Forbes *et al.* (1979).

Growth and energy intake. There was a clear growth response to the fish meal as is shown by Fig. 2 which indicates the live-weight gain of all lambs to 119 d. Those lambs given fish meal starting from day 70 also showed a growth response to the supplement.

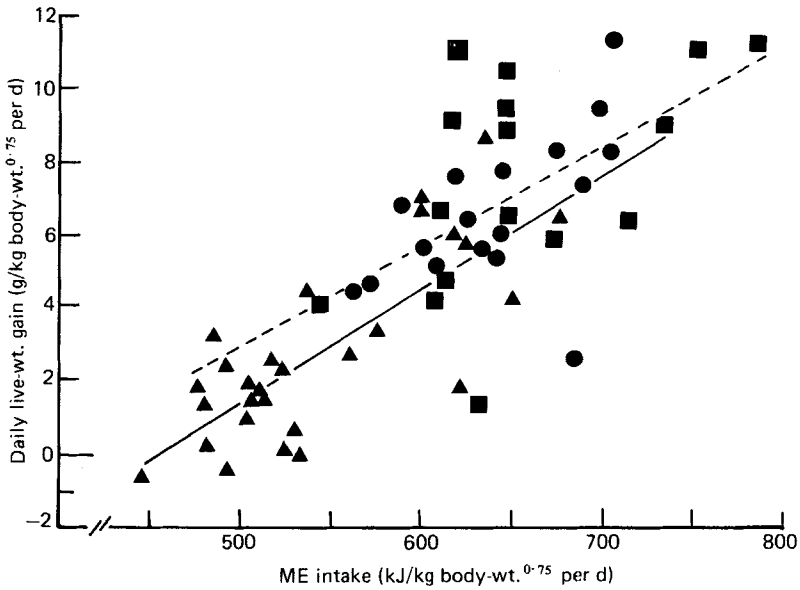

Fig. 3. Expt 2. Live-weight gain (g/kg body-weight$^{0.75}$ per d) *v.* metabolizable energy (ME) intake (kJ/kg body-weight$^{0.75}$ per d) of twenty-four lambs given sodium-hydroxide-treated barley straw with urea and nil (▲), 66 (●) or 132 (■) g/d of white fish meal dry matter. Values plotted for individual lambs for each of two or three growth periods. Regression lines relate to supplemented (----) and unsupplemented (——) lambs.

Average growth rates and energy intakes are given in Table 1. During period 1 (0–69 d), the growth response to protein only reached statistical significance ($P < 0{\cdot}01$) in the case of the LL group (when compared with all lambs not given protein during this period (OO, OL and OH)). However, the lambs of the HH group made better growth than those of the OO groups which had consumed similar amounts of straw, and similar growth to the OL and OH groups which had consumed more straw (when straw intakes were compared on a metabolic body-weight basis). Taken as a whole, the supplemented animals made better growth ($P < 0{\cdot}01$) than did the unsupplemented animals at similar intakes of straw. In period 2 (70–119 or 162 d) the LL and HH groups continued to make better growth than the OO (unsupplemented groups, and the OL and OH groups made better growth during period 2 when they received fish meal than they had during period 1 when they did not receive fish meal. In this period (period 2) there was an effect of protein level on growth rate ($P < 0{\cdot}001$; Table 1).

Table 1 also shows the energy intake of the lambs. The contribution of the straw was calculated from the measured digestibility (Table 2) as 15·58 MJ/kg digestible organic matter (ARC, 1980), that of the molasses from its organic matter content (with the assumption that this was completely digested) and that of the fish meal from published values ((US) National Research Council, 1969). Daily live-weight gain has been plotted *v.* daily energy intake (both on a metabolic body-weight basis) in Fig. 3. The individual values for each lamb during each period (0–69, 70–119 and 120–162 d) have been plotted. There are, therefore, two plots for each of the twelve lambs killed after 119 d, and three for those killed after 162 d. The treatments are defined as those given during the period in question. As can be seen from Fig. 3, the response to additional energy of the supplemented and unsupplemented lambs was very similar, the slopes of the two regressions of live-weight gain on energy intake being 27·8 (SE 6·8) and 31·7 (SE 4·9) g gain/MJ metabolizable energy

Table 2. *Expt. 2. Voluntary intake and digestibility of diets by lambs given sodium-hydroxide-treated straw supplemented with nil (O), 66 (L) or 132 (H) g/d of white fish meal dry matter (DM)*

(Mean values for four lambs)

Treatment group...	O	L	H	SEM
Daily intake of DM (g)				
Straw	837	1128	1026	62
White fish meal	—	66	132	—
Molasses	66	66	66	—
Straw (g/kg body-weight$^{0.75}$ per d)	59	66	57	3·1
Digestibility (g/kg):				
Total organic matter	632	696	691	6
Straw organic matter*	612	668	645	13
Metabolizable energy (ME) of straw† (MJ/kg DM)	8·35	9·12	8·80	

* Calculated with the assumption that the organic matter of the fish meal and molasses was completely digestible.

† Calculated from total organic matter above. ME = 15·58 MJ/kg digestible organic matter (Agricultural Research Council, 1980).

(ME) for the supplemented and unsupplemented groups respectively. The slopes were therefore combined to give a growth response of 29·9 (SE 4·2) g gain/MJ ME. The intercepts of the regressions when using the combined slope were −12·27 and −13·48 g/kg body-weight$^{0.75}$ per d for the supplemented and unsupplemented groups respectively. The difference of 1·21 (SE 0·65) was not significant statistically ($0·05 < P < 0·10$). If, however, it is assumed that the response to protein could only be positive, then a single-tailed test can be applied, and the difference between the intercepts becomes significant statistically ($P < 0·05$).

Slaughter results. Hot carcass weights, abdominal fat and backfat thickness and weight of rumen contents were measured. In general, heavier carcasses tended to be associated with more fat, although the high level of variation made most of the comparisons statistically non-significant and no clear conclusions could be drawn. Rumen contents tended to be greatest with the animals with the highest intakes of straw, and the correlation coefficient of average intake of straw during period 2 with rumen contents at slaughter was 0·62 ($P < 0·01$). There was a good correlation (r 0·92, $P < 0·001$) between hot carcass weight and final live weight. However, since the supplemented animals were heavier, it is difficult to relate carcass weight to a true treatment effect. The hot carcass expressed as a proportion of final live weight tended to be greater with the supplemented groups (OL, OH, LL and HH), although the effect was not statistically significant (Table 1).

Digestibility of diets. Table 2 shows the digestibility of the diets. There is the suggestion that the straw was more digestible when given in conjunction with the fish meal, for even when the organic matter of the fish meal and molasses was assumed to be 100% digestible, the comparison with the unsupplemented lambs (O) was statistically significant ($P < 0·05$) when the L and H groups were combined. The ME values given to the straw for the calculation of energy intake (Table 1 and Fig. 3) were therefore taken from Table 2; thus even if the difference in digestibility was real, it is allowed for in the estimates of energy intake.

DISCUSSION

The basal excretion of urinary N found in the infusion trial (Expt 1) was very considerably in excess of the generally-accepted level. The current recommendation of the ARC (1980) is that UN(E) excretion of sheep is estimated from the relationship UN(E) = 0·02348 W + 0·54 g/d where W is the live weight (kg) of the animal. Using this relationship, UN(E) of the 26–33 kg lambs used in Expt 1 was calculated to be 95–100 mg N/kg body-weight$^{0.75}$ per d, less than one-quarter of the 429 mg N/kg body-weight$^{0.75}$ per d actually measured. Since the ARC (1980) estimate of the requirement for maintenance is assumed to be simply UN(E) together with losses in hair and scurf, this difference in the estimation of UN(E) is important.

As Fig. 1 demonstrates, the basal excretion of N by the lambs showed no clear trend with time, and remained relatively constant during the 10 d when there was no infusion of casein. Therefore the high UN(E) value was not transient. The much lower estimates of UN(E) published in the literature can largely be explained by the difficulty of adequately describing the components of faecal N loss. Of the microbial N originating from rumen fermentation, approximately 15% will be voided in the faeces (assuming microbial N to be approximately 85% digested (Storm, 1982), and microbial N originating from hind-gut fermentation will probably be almost entirely voided in the faeces. If the N intake of the host animal is below the requirements of the rumen micro-organisms, or the digesta presented to the micro-organisms of the hind gut is deficient in N relative to fermentable substrate, or both, there will be a net faecal excretion as microbial debris of N that is of endogenous origin, and that has been recylced to the gastrointestinal tract rather than excreted in the urine. For these reasons UN(E) will often be underestimated due to this diversion of N of endogenous origin to microbial debris in the faeces, a fact not allowed for by the ARC (1980) and which accounts for their low estimate of basal N excretion. This has been fully discussed by Ørskov & MacLeod (1982) who showed the UN(E) of cattle measured by the intragastric infusion technique used here to be 300–400 mg N/kg body-weight$^{0.75}$ per d and that the addition of faecal N to UN(E), as measured with normally-fed animals, gave a total N excretion of the same order. A further source of N loss from the animals is in the gastrointestinal secretions and epithelial debris not reabsorbed. This faecal N is truly of metabolic origin and will be additional to the UN(E) loss discussed previously. Provisional estimations of the true metabolic faecal N (E. R. Ørskov, N. S. MacLeod & E. Storm, personal communication) suggest that it is small relative to UN(E) and estimates of basal N metabolism will not be grossly in error if equated with UN(E) as measured with animals nourished by VFA infusion, as here.

Expt 2 was conceived on the basis of the estimates of UN(E) derived from Expt 1. The effect of an upwards revision of UN(E) on the protein requirement of a 35 kg lamb is shown in Fig. 4. In Fig. 4 the ARC (1980) estimates of protein deposition as wool and lean tissue have been added to the estimates of UN(E) derived from ARC (100 mg/kg body-weight$^{0.75}$ per d (A)) and Expt 1 (429 mg/kg body-weight$^{0.75}$ per d (B)) to give values for the total requirement for TN by the host animal (shown by the two solid lines). These requirements are for available amino acid N (AAN). Also plotted are three estimates of the AAN contributed by microbial protein. That of 526 mg AAN/MJ ME is that proposed by the ARC (1980). The value of 758 mg AAN/MJ ME was calculated from the values of Storm (1982), who measured a higher availability (0·85) and better utilization (0·81) of microbial amino acids than that adopted by the ARC (1980), and the value of Hart & Ørskov (1979), who measured a yield of microbial N from alkali-treated straw of 33 g/kg fermented organic matter, higher than that of 30 g/kg adopted by the ARC (1980). The value of 638 mg AAN/MJ ME was recalculated from the ARC (1980) values with the assumption of a true

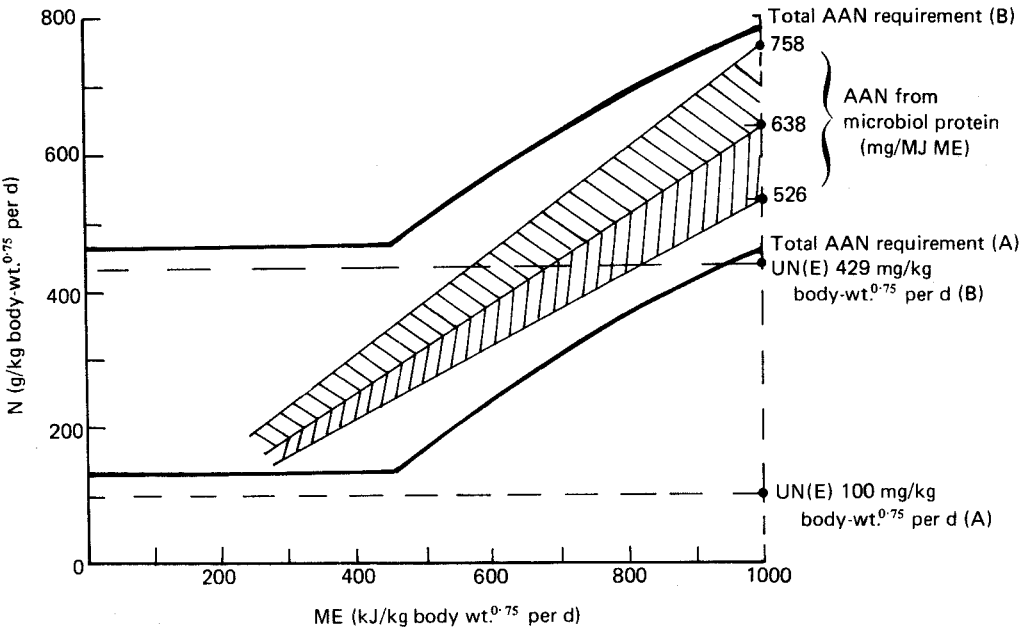

Fig. 4. Diagrammatic representation of the effect of metabolizable energy (ME) intake by a 35 kg lamb on the available amino acid nitrogen (AAN) requirement for wool and tissue growth (Agricultural Research Council, 1980) based on a maintenance requirement of (A) 100 (Agricultural Research Council, 1980) or (B) 429 (Expt 1) mg N/kg body-weight$^{0.75}$ per d and related to AAN provided from microbial protein (▨) (for details, see p. 181). UN(E), endogenous urinary N.

digestibility for microbial N of 0·85 rather than the apparent digestibility of 0·70 adopted by the ARC (1980). The value of 638 mg is thus more strictly comparable with that of 758 mg AAN/MJ ME which is also based on true digestibility. The intake of 1000 kJ/kg live weight$^{0.7}$ would correspond to a growth rate of about 200 g/d.

As can be seen from Fig. 4, the consequence of a higher UN(E) as an estimate of the animal's basal need is that, even with the greater estimates of the contribution of microbial protein, the host animal would suffer a net protein deficiency, and that this would be particularly pronounced at levels of ME close to maintenance. The results from Expt 2 do indicate a response to the supplemental protein. However, as Fig. 3 shows, it is difficult to distinguish this from a response to the additional energy, although the regression analysis of growth on energy intake did provide evidence that there was a true response to the protein.

On the basis of our previous experience with NaOH-treated barley straw (Ørskov & Grubb, 1978) we had anticipated lower intakes than those actually achieved. (The best intakes achieved by Ørskov & Grubb (1978) were approximately 40 g/kg body-weight$^{0.75}$ per d of a treated straw (70 g NaOH/kg) of digestibility 0·628.) A consequence of the relatively high intakes of straw achieved in Expt 2 would be that there would also be an increase in the amount of microbial protein made available to the host animal. If the provision of microbial AAN is better described by the higher levels shown by Fig. 4, then the effect of the higher straw intakes may have been to reduce the area of response to supplemental protein, for with more efficient microbial synthesis, the area of response to supplemental AAN becomes reduced when ME intake is much above maintenance.

If the basal requirement for AAN was in the order of 350 mg/kg body-weight$^{0.75}$ per d

Table 3. *Summary of values from the literature on the effect of supplementation of high-roughage diets with a protein of low rumen degradability on the growth of cattle and sheep*

Reference	Animals: IW	Animals: *n*	Period of experiment (d)	Basal diet	Supplement*	Daily DMI (kg): Basal	Daily DMI (kg): Supplement	Supplement (g nitrogen/d)	LWG
				CATTLE					
Garstang (1981)	< 200	8	—	Silage	—	2·64		—	100
					SBM	2·45	0·40	32	240
					FM	2·52	0·28	31	460
Smith *et al.* (1980)	282	4	75	Barley straw + barley (70:30, w/w)	U	4·93		13	212
					U	5·01		47	175
					FM	4·87	0·07	8	428
					FM	4·66	0·36	41	650
									SEM 79
	223	5	75	Barley straw + barley (19:81, w/w)	—	3·30		—	282
					U	3·30	0·06	31	239
					FM	3·09	0·27	30	421
				Barley straw + barley (53:47, w/w)	—	4·24		—	245
					U	4·24	0·07	31	295
					US	4·27	0·07	31	231
					FM	4·01	0·30	33	400
					FM	3·79	0·58	65	460
									SEM 43
	286	7	75	Barley straw + barley (56:44, w/w)	—	4·88		—	360
					SBM	4·55	0·32	26	373
					SBM	4·23	0·65	52	492
					FM	4·66	0·27	30	633
					FM	4·45	0·53	59	642
									SEM 31
Redman *et al.* (1980)†	288	8	57	Oaten chaff + concentrate	—	5·51	0·62	—	356
					U	6·72	0·69	54	798
					C	6·70	0·62	50	843
					C + TC	6·96	0·67	59	842
					TC	6·69	0·72	62	805
									SEM 69

Table 3. (*cont.*)

Reference	Animals: IW	Animals: *n*	Period of experiment (d)	Basal diet	Supplement*	Daily DMI (kg): Basal	Daily DMI (kg): Supplement	Supplement (g nitrogen/d)	LWG
Oltjen *et al.* (1977)‡	221	8	140	Cottonseed hulls+concentrate	—	4·71	0·39	—	−190
					U/Bi	7·97	0·58	90	540
					SBM+U/Bi	8·14	0·69	88+22	600
					FM+U/Bi	8·48	0·68	88+22	680
									SEM 100
	216	8	140	Cottonseed hulls	U	7·92	0·36	56	510
					U+SBM	8·44	0·96	123+31	710
					U+TSBM	8·33	0·63	81+20	580
					U+FM	7·94	0·48	61+15	590
									SEM 30
Leibholz & Kellaway (1981)	166	8	—	Paspalum hay	U	3·62		35	471
					U+MM	3·73	0·29	35+30	474
				NaOH-treated paspalum hay	U	4·18		35	547
					U+MM	3·93	0·29	35+30	524
						(0·17)			SEM 76
Sriskandarajeh *et al.* (1981)	209	8	—	Wheat straw	U	2·83		37	−189
					U+C	3·00	0·25	37+38	−108
					U+C+TC	2·65	0·26	37+27+14	−82
					U+C+TC	3·31	0·28	37+11+33	102
					U+TC	3·32	0·30	37+47	42
						(0·16)			SEM 57
Spragg *et al.* (1981)	250	9	—	NaOH-treated wheat straw	U+CSM	7·35	0·61	98+49	891
					U+EB	7·52	0·54	101+12	784
					U+CB	7·41	0·50	99+11	761
									SEM 45
Macdearmid *et al.* (1983)	360	8	84	NH_4OH-treated barley straw	—	6·30		—	390
					BM	6·35	0·25	38	600
						(0·28)			SEM 72

				SHEEP					
Kempton (1981)	—	—	56	Oaten chaff	—	493			10
					U	525		5	33
					U+C	463	46	4+7	23
					U+TC	553	55	5+9	50
					U+C+TC	509	51	5+8	59
						(41)			SEM 13
Barry (1981)§	16	13	84	Ryegrass clover herbage+	—	745		—	79
				abomasal infusion C	C	703	44	7	99

IW, initial weight; *n*, number per treatment. DMI, dry matter intake, LWG, daily live-weight change (g/d).

* SBM, soya-bean meal; FM fish meal; B, barley; U, urea; US, urea+sulphur; C, casein; TC, formaldehyde-treated casein; Bi, Biuret; TSBM, formaldehyde-treated SBM; MM, meat meal; CSM, cottonseed meal; BM, blood meal; EB, extruded barley; CB, crushed barley.

Where necessary, N contribution of supplement calculated as (proportion of N): SBM 0·08, FM 0·11, CSM 0·08, C 0·156, MM 0·105, B 0·022.

† Concentrate supplement of molasses, oat chaff, maize flour and appropriate N supplement proportioned to give similar energy and (where supplemented) similar N contents.

‡ Treatments shown with more animals than the control represent mean values of several treatments in which non-protein-N was added as urea or Biuret or mixtures of urea and Biuret (SE is that of *n*).

§ Forage intake calculated from presented values which are expressed on a kg body-weight$^{0·75}$ basis.

then, at the higher estimate of microbial contribution, there would be sufficient or nearly sufficient AAN of microbial origin to sustain slight growth. More recent measurements of UN(E) made in our laboratory have given values for UN(E) of 329 (SE 64) mg N/kg body-weight$^{0.75}$ per d (eight lambs of 29 kg; E. Storm, personal communication) and 279 mg N/kg body-weight$^{0.75}$ per d (one lamb of 42 kg; F. D. DeB Hovell, unpublished observations). The number of observations made using the intragastric infusion technique on sheep is still relatively small, and the normal variation in values and the effect of age and of other factors on UN(E) is unknown. Therefore, it may be that 429 mg N/kg body-weight$^{0.75}$ per d represents a high value and the fact that the unsupplemented animals in Expt 2 made slight growth implies that basal needs were met.

However, even if a lower value for UN(E) of 356 mg N/kg body-weight$^{0.75}$ per d (the mean of all the observations cited) is taken, it can still be demonstrated on the basis of the ARC (1980) estimates of requirements for growth, that the growth made by lambs given supplementary protein on Expt 2 would have required AAN over and above that provided by the rumen micro-organisms (Fig. 4). Even so, a substantial proportion (one-half to two-thirds) of the fish meal would have been available as an energy source, thus partially masking any growth response attributable to the protein as a source of amino acids. There is evidence that lambs will respond to an increased amino acid supply by increasing N retention even when in negative energy balance (Hovell *et al.* 1981). Small differences in live weight can be associated with large differences in body composition (Hovell *et al.* 1976) and the fact that the fish-meal-supplemented animals which were heavier had a greater proportion of their growth as carcass (Table 1) may have been associated with important compositional differences. Barry (1981) showed that herbage-fed lambs supplemented with an intra-abomasal infusion of casein + methionine made a 25% improvement in rate of live-weight gain (Table 3). However, chemical analysis showed that the rate of protein deposition was increased by 64%, and that of fat deposition was reduced by 12%.

There is considerable evidence in the literature which shows that ruminants making slight growth on high-roughage diets will respond to supplemental protein of a low rumen degradability. The experiments summarized in Table 3 were selected on the basis of there having to be sufficient N in the basal diet to satisfy the requirements of the rumen micro-organisms for rumen degradable N (RDN; ARC, 1980), or there being a comparison between proteins of a high and low rumen-degradability (e.g. soya-bean and fish meal). Of the eleven cattle experiments cited, a positive response was shown in eight. Of five sheep experiments identified, three were also associated with an increase in DM intake which complicates interpretation and have therefore been excluded. The two sheep experiments cited in Table 3 both suggest a positive response to protein, although not of statistical significance.

It is concluded therefore, that the information on basal N metabolism determined by total infusion has shown UN(E) truly to be three- to fourfold that predicted by the ARC (1980). These greater values for UN(E) are not transient and, as has been discussed by Ørskov & MacLeod (1982), agree well with previously published values (determined with animals with a rumen fermentation) if the bulk of faecal N on low N intakes is assumed to be diverted from UN(E).

The fact that in the growth trial the control animals made slight growth and that the growth response to supplemental protein was less than anticipated, can be reconciled with the concept of a basal N requirement greater than that adoped by the ARC (1980), if the current estimates of the provision of AAN by the rumen micro-organisms are revised upwards (Fig. 4). Even so, the actual growth made by the supplemented animals in Expt 2 would still have required more AAN than would have been supplied by the rumen micro-organisms.

REFERENCES

Agricultural Research Council (1965). *The Nutrient Requirements of Farm Livestock No. 2, Ruminants*. London: HM Stationery Office.

Agricultural Research Council. (1980). *The Nutrient Requirements of Ruminant Livestock*. Slough: Commonwealth Agricultural Bureaux.

Barry, T. N. (1981). *British Journal of Nutrition* **46**, 521–532.

Blaxter, K. L. (1964). In *The Role of the Gastrointestinal Tract in Protein Metabolism*, pp. 143–154 [H. N. Munro, editor]. Oxford: Blackwell.

Forbes, J. M., El Shahas, A. A., Jones, R., Duncan, J. G. S. & Boaz, T. G. (1979). *Animal Production* **29**, 33–42.

Garstang, J. R. (1981). *Animal Production* **32**, 355.

Hart, F. J. & Ørskov, E. R. (1979). *Proceedings of the Nutrition Society* **38**, 130A.

Hovell, F. D. DeB., Greenhalgh, J. F. D. & Wainman, F. W. (1976). *British Journal of Nutrition* **35**, 343–363.

Hovell, F. D. DeB., MacLeod, N. A., Stirton, R. A. & Ørskov, E. R. (1981). *Proceedings of the Nutrition Society* **41**, 27A.

Hovell, F. D. DeB. & Ørskov, E. R. (1981). *Animal Production* **32**, 374.

Kellaway, R. C. & Leibholz, J. (1981). In *Recent Advances in Animal Nutrition in Australia 1981*, pp. 66–73 [D. J. Farrell, editor]. Armidale: University of New England Publishing Unit.

Kempton, T. J. (1981). In *Recent Advances in Animal Nutrition in Australia 1981*, pp. 52–65 [D. J. Farrell, editor]. Armidale: University of New England Publishing Unit.

Kempton, T. J. & Leng, R. A. (1979). *British Journal of Nutrition* **42**, 289–302.

Leibholz, J. & Kellaway, R. C. (1981). Cited by Kellaway & Leibholz (1981).

Macdearmid, A., Williams, P. E. V. & Innes, G. M. (1983). *Animal Production*. (In the Press.)

National Research Council. (1969). *United States – Canadian Tables of Feed Composition*. Washington, DC: National Academy of Sciences.

Oltjen, R. R., Dinius, D. A. & Goering, H. K. (1977). *Journal of Animal Science* **45**, 1442–1452.

Ørskov, E. R., Fraser, C., Mason, V. C. & Mann, S. O. (1970). *British Journal of Nutrition* **24**, 671–682.

Ørskov, E. R. & Grubb, D. A. (1978). *Journal of Agricultural Science, Cambridge*, **91**, 483–486.

Ørskov, E. R. & Grubb, D. A. (1979). *Proceedings of the Nutrition Society* **38**, 24A.

Ørskov, E. R., Grubb, D. A., Wenham, G. & Corrigall, W. (1979). *British Journal of Nutrition* **41**, 553–558.

Ørskov, E. R. & MacLeod, N. A. (1982). *British Journal of Nutrition* **47**, 625–636.

Redman, R. G., Kellaway, R. C. & Leibholz, J. (1980). *British Journal of Nutrition* **44**, 343–354.

Roy, J. H. B., Balch, C. C., Miller, E. R., Ørskov, E. R. & Smith, R. H. (1977). *Proceedings of 2nd EAAP Symposium on Protein Nutrition and Metabolism*, pp. 126–129. European Association for Animal Production Publication no. 22. Wageningen: Pudoc.

Smith, T., Broster, V. J. & Hill, R. E. (1980). *Journal of Agricultural Science, Cambridge*, **95**, 687–695.

Spragg, J., Kellaway, R. C., Kempton, T. J., Leng, R. A. & Leibholz, J. (1981). Cited by Kellaway & Leibholz (1981).

Sriskandarajeh, N., Kellaway, R. C. & Leibholz, J. (1981). Cited by Kellaway & Leibholz (1981).

Storm, E. (1982). Isolation and nutritive value of rumen micro-organisms and their limiting amino acids for growing sheep. PhD Thesis, University of Aberdeen.

Printed in Great Britain