Protein metabolism in growing lambs fed on fresh ryegrass (*Lolium perenne*)–clover (*Trifolium repens*) pasture *ad lib.*

1. Protein and energy deposition in response to abomasal infusion of casein and methionine

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1. Male lambs that had been born in autumn and wintered on forage diets were cannulated in the abomasum, confined indoors in individual pens, and fed on fresh primary growth ryegrass (*Lolium perenne*)–clover (*Trifolium repens*) pasture *ad lib.* for a 12-week period during spring. Mean diet organic matter digestibility (OMD) was 0·76, nitrogen content 29 g/kg dry matter (DM) and metabolizable energy (ME) content 11·1 MJ/kg DM. Thirteen lambs were infused into the abomasum with 44 g sodium caseinate +0·5 g L-methionine/d and 12 lambs were similarly infused with equivalent amounts of inorganic sodium and phosphorus. Initial live weight was 16·5 kg.

2. The twenty-five treatment lambs were slaughtered at the end of the experiment, and thirteen similar lambs were slaughtered when the experiment commenced. Body composition was determined and rates of protein, fat and energy deposition were calculated using comparative slaughter procedures.

3. Voluntary herbage DOM intakes tended to be slightly greater for control than protein-infused lambs, but calculated ME intakes including that infused as amino acids were similar for the two groups. Live-weight gains were 79 and 99 g/d for control and protein-infused lambs respectively ($P < 0·05$) and corresponding values for carcass gain:live-weight gain were 0·44 and 0·50 ($P < 0·01$). Wool growth was markedly increased by the amino acid infusion.

4. Carcass and whole body protein content was increased 10 g/kg by the protein infusion ($P < 0·01$) and fat content depressed approximately 25 g/kg ($P < 0·05$). Rates of protein deposition in both carcass and wool-free whole body were markedly increased by protein infusion, and total deposition including wool was 12·6 and 21·0 g/d for control and protein-infused lambs ($P < 0·001$). Energy deposited in protein as a proportion of total energy deposition was 0·27 and 0·41 for control and protein-infused lambs ($P < 0·001$), but total energy retention and the efficiency of utilization of ME for growth did not differ between the two groups of lambs.

5. It was estimated that 60 and 100 g total amino acids/d were absorbed from the small intestine in the control and protein-infused lambs respectively, corresponding to 0·16 and 0·25 of total ME intake. It was concluded that absorption of protein from the small intestine was limiting protein deposition in the growing lambs fed on fresh ryegrass-based spring pasture in this study. Absorption of cystine+methionine was specifically shown to be limiting. However, the protein deficiency was not a major factor in the low value for the efficiency of utilization of ME for growth for this diet (0·30).

Recent work in New Zealand has shown that with sheep given diets of fresh ryegrasses (*Lolium* spp.) and white clover (*Trifolium repens*) approximately 70% of the dietary protein is degraded by micro-organisms in the reticulorumen (Ulyatt *et al.* 1975). In the same experiments the quantity of protein arriving at the duodenum was much less than the protein intake, with the difference (i.e., net nitrogen loss across the rumen) enlarging as N intake increased; live-weight gain of young sheep grazing swards of pure species was shown to be positively related to the amount of protein absorbed from the intestines (MacRae & Ulyatt 1974). This suggets that, contrary to generally-accepted views, ruminants fed *ad lib.* fresh herbages of high digestibility and protein content may nevertheless have a deficiency in the quantities of one or more essential amino acids absorbed from the small intestine. Barry (1981) tested this hypothesis by infusing casein into the abomasum of twin-bearing lactating ewes given fresh New Zealand spring pasture *ad lib.*, with the result that lactation persistency (especially for net protein secretion) of the treated ewes was improved compared with ewes that did not receive the infusion. To examine further the hypothesis that absorption of amino acids from the small intestine could be limiting the performance of ruminants given fresh spring pasture *ad lib*., young growing ruminant lambs were infused into the abomasum with casein + methionine in the present work and their performance compared with control lambs. The considerable responses obtained indicated that the digestion products from this diet were deficient in the supply of essential amino acids relative to that of ME.

In New Zealand, lambs are normally suckled by their dams during the period of spring pasture growth and are weaned onto summer or autumn pasture. However, both the feeding and nutritive value of summer and autumn pasture are inferior to that of spring pasture (Scott *et al.* 1976), and as the objective of this work was to evaluate spring pasture a method had to be found for having reasonably-sized ruminant lambs and spring pasture available at the same time. Deep-freezing large quantities of spring pasture and feeding this at a later date was discarded as a possibility, because deep-freezing reduces herbage protein solubility (MacRae *et al.* 1975). The method selected was to produce autumn-born lambs, and have them weaned and functional as ruminants before spring pasture growth commenced.

EXPERIMENTAL

Experimental design

Twenty-five growing ruminant lambs were all cannulated in the abomasum and individually fed cut fresh ryegrass (*Lolium perenne*)–clover pasture *ad lib.* for 12 weeks. Thirteen of the lambs received continuous abomasal infusions of sodium caseinate + methionine, whilst the twelve control lambs received a continuous abomasal infusion of inorganic salts supplying the same volume daily. The animals were slaughtered at the end of the experiment and effects of the protein infusion on body growth and composition, wool growth, and the efficiency of protein and energy deposition were studied. An additional group of twelve lambs was slaughtered at the start of the experiment, designated initial slaughter (IS) group and their data used to predict body composition of the twenty-five test lambs.

Animals

Romney lambs were born in the autumn, approximately 7 months out of season, using hormone therapy upon their dams and were weaned at 10 weeks of age. They were grazed throughout the 2 months of early winter on autumn-saved ryegrass–clover pasture with some hay supplementation. In mid-winter, when the lambs were 4 months old, thirty-nine castrated male lambs were selected from the group and brought indoors and fed in individual pens. They were divided into lots of three, in descending order of live-weight, and within each lot the lambs were allocated at random to either the control, protein infusion or IS groups. Animals designated either control or protein infusion were then fistulated in the abomasum. During this 3 week pre-experimental period all animals were fed *ad lib.* fresh 'Tama' annual ryegrass (*Lolium multiflorum* Lam) until the experiment commenced in mid September 1978. During the pre-experimental period one lamb died from each of the control and IS groups. Mean live-weight at the commencement of the experiment for the remaining thirty-seven lambs was 16·5 kg (SD 1·65).

Mid-side wool patches of 122·5 mm × 122·5 mm were clipped on the left side of the twenty-five test animals at the start of the experiment, and thereafter wool was clipped from these areas to skin level at 4-week intervals. The lambs were weighed after a 24 h fast at the beginning and end of the experiment. All lambs were drenched with a broad-spectrum anthelmintic (Valbazen manufacturer; Smith, Kline and French Ltd) + 1 mg selenium as sodium selanate at monthly intervals during both the pre-experimental and experimental periods. Retinol (30000 μg), cholecalciferol (1250 μg) and vitamin E (40 mg) were administered on days 1, 30 and 60.

Diets and infusion procedures

Ryegrass–clover pasture in the leafy vegetative state was cut and fed fresh each day. Average botanical composition was 700 g perennial ryegrass and 100 g white clover/kg, with the remainder being other grass species. This is typical of spring pasture fed to grazing sheep in New Zealand. Food was offered at 15% in excess of the previous day's consumption to ensure *ad lib.* intake, with equal portions being given at 09.00 and 16.00 hours each day. Representative samples of food offered and residues were pooled on a weekly basis for laboratory analyses.

Thirteen lambs were continuously infused with 1 l/d of a solution supplying 44 g sodium caseinate and 0·5 g L-methionine. The remaining twelve lambs were infused with an equivalent volume of solution containing sodium chloride and sodium monohydrogen-phosphate, which supplied the same amounts of sodium and phosphorus as the sodium caseinate.

Voluntary herbage dry matter (DM) intakes were calculated on a weekly basis, and digestible organic matter (DOM) intakes computed by applying weekly values of in vitro digestibility from both food offered and residue samples. Metabolizable energy (ME) intakes were calculated assuming 16·3 MJ ME/kg DOM for the basal diet (Ulyatt *et al.* 1980) and the metabolizability of abomasally-infused casein as found by Blaxter (1962). ME used for growth was calculated by subtracting a maintenance requirement of 0·473 MJ ME/kg body-weight $(W)^{0.75}$ per d from the total ME intake, determined from comparative slaughter experiments in New Zealand with lambs given spring pasture (Rattray & Joyce 1976).

Slaughter procedures

All lambs were shorn before slaughter, and in all instances the wool-free empty body was divided into carcass, liver, intestines, hide and remainder, with each component being weighed and triple-minced ready for laboratory analysis.

Results were calculated as follows using standard comparative slaughter procedures (Thomson & Cammell, 1979). Using the IS group lambs, regression relationships were derived of empty-body-weight (EBW) and clean dry fleece weight (FW) on fasted live-weight (W). Further relationships were then derived of body protein, fat and energy on EBW. In the IS group, all these criteria (including EBW) were actually measured (i.e., none of the variables were transformed before the regressions were calculated). These relationships were then used first to predict the initial EBW and FW of the twenty-five test lambs from their W at the start of the experiment, and then to predict the weights of various body components at this time. Rates of gain in all these measurements were then derived by subtracting the predicted initial value for the twenty-five test lambs from the values obtained at final slaughter. In both IS group and 'final slaughter' lambs, total body energy was calculated from body composition assuming 23·65 MJ/kg protein and 39·09 MJ/kg fat (Drew & Reid, 1975).

Laboratory methods

Chemical composition and in vitro digestibility of food offered and residue samples were determined as described by Barry (1981). Mid-side wool clippings and samples of entire fleece were cleaned by scouring with non-ionic detergent in a four-bowl system. They were then dried at 105° for 4 min, brought to constant moisture content by leaving in a standard atmosphere room at 20 ± 2° and 65 ± 2% relative humidity for 48 h, and then weighed. Dry weight was calculated by applying a standard factor to correct for moisture content. In minced body components, water was determined as loss in weight after freeze-drying for

48 h, fat by Soxhlet extraction with diethyl ether, ash by ignition at 500° overnight, and protein by difference.

Statistical methods

Analysis of variance was used, and analyses of covariance where indicated.

RESULTS

Herbage composition

The herbage fed was of high organic matter digestibility (OMD) and N content (Table 1), and showed little variation over the 12-week feeding period. Mean estimated ME content was 11·1 MJ/kg DM.

Voluntary intake

Averaged over the entire experimental period, mean herbage voluntary intakes of DM (g/kg $W^{0.75}$ per d) and DOM (g/kg $W^{0.75}$ per d) tended to be slightly lower for protein-infused than for control lambs (Table 2). However, when the amount of ME supplied by the infused amino acids was taken into account, (0·853 MJ/d), mean ME intakes (MJ/kg $W^{0.75}$ per d) were similar for the two groups.

Effects of time were studied by comparing voluntary DOM intake over weeks 2+3 with that over weeks 9+10, using a split-plot procedure with lambs as main plots and time as sub-plots. Herbage OMD was practically indentical over both periods (0·78). There was no significant effect due to time and no significant time × infusion interaction ($P > 0.05$), the effects produced by the protein infusions (Table 2) being apparent by week 2 and remaining at this magnitude throughout the experiment.

ISG lambs

Regression equations derived from the IS group, and used to predict values for the twenty-five test lambs at the start of the experiment, are shown in Table 3. All relationships showed similar precision to those calculated by Thomson & Cammell (1979) from their IS animals.

Equations 1 and 2 were used to predict the initial EBW and clean dry fleece weight (FW) of the twenty-five test animals from their fasted live weight (W) at the start of the experiment. The twenty-five predicted initial EBW values (i.e., linear transformations of initial W) were then used in equations 3–8 to predict initial body contents of protein, fat and energy. The range in initial fasted W for control and protein-infused lambs (13–19 kg) was similar to that for IS lambs (11–19 kg); likewise the range in predicted initial EBW of control and protein-infused lambs (12-17 kg) was similar to that actually measured for IS lambs (10–17 kg). Thus the range of independent variable over which equations 1 to 8 were applied was within the range from which the equations were derived. Relationships between initial EBW and the weight of protein in both the wool-free whole body and carcass are shown in Fig. 1.

Weight gains

Rates of live-weight gain ($P < 0.05$), EBW gain and carcass gain ($P < 0.01$) were greater for the protein-infused than for control lambs (Table 4). Carcass weight gained as a proportion of live-weight gain was also greater for the protein-infused lambs.

Wool production

Wool growth rate on the mid-side areas progressively increased with time in both groups of lambs (Table 5). These increases corresponded to increases in daylength and ambient temperature and are normal for Romney sheep in New Zealand. Mid-side wool growth rate was increased by 16 mg/10^4 mm^2 per d by the protein infusion during the first 4 weeks

Table 1. *Chemical composition (g/kg DM) of the herbage fed.*

(Mean values and standard deviations from twelve samples taken at weekly intervals)

	Mean	SD
Total nitrogen	29·1	5·25
Protein (proportion of total N)	0·89	0·033
OM	889	13·3
Digestible organic matter:		
Proportion of OM	0·76	0·039
Proportion of DM	0·68	0·034
Soluble carbohydrates	160	15·6
Sulphur	3·0	0·26
Calcium	5·3	0·79
Phosphorus	3·9	0·41
Magnesium	1·89	0·220
Sodium	1·82	0·827

DM, dry matter; OM, organic matter.

Table 2. *Mean daily intakes of dry matter (DM) and digestible organic matter (DOM) and metabolizable energy (ME) in lambs fed on ryegrass* (Lolium perenne)*–clover* (Trifolium repens) *pasture* ad lib. *(g/kg fasted live weight* $(W)^{0.75}$)

(Mean values with their standard errors)

Treatment…	Control lambs		Protein-infused lambs		Statistical significance of difference between diets
	Mean	SE	Mean	SE	
DM	79·3	2·51	72·5	2·41	*
DOM	56·6	1·64	52·4	1·58	*
ME (MJ/kg $W^{0.75}$):					
Basal diet	0·923	0·0267	0·854	0·0258	*
Total	0·923	0·0269	0·940	0·0259	NS

NS, not significant. * $0.05 < P < 0.10$.

Table 3. *Regression equations derived from the initial slaughter group of thirteen lambs*

Equation	Correlation coefficient	Residual standard deviation	Mean dependent variable	Equation number
EBW = 0·861 W + 0·451	0·984***	0·52	14·4	1
FW = 34·9 W + 77·7	0·618*	122·7	676	2
CW = 0·582 EBW − 0·941	0·996***	0·115	7·40	3
CP = 0·115 EBW − 0·280	0·980***	0·051	1·36	4
CF = 0·088 EBW − 0·695	0·678*	0·210	0·56	5
WBP = 0·190 EBW − 0·205	0·985***	0·074	2·52	6
WBF = 0·126 EBW − 0·873	0·750**	0·245	0·93	7
WBE = 9·410 EBW − 38·953	0.921***	8·828	96·06	8

W, fasted live weight (kg); EBW, wool-free empty-body-weight (kg); FW, clean dry fleece weight (g): CW, carcass weight (kg); CP, carcass protein (kg); CF, carcass fat (kg); WBP, wool-free whole-body protein (kg); WBF, whole-body fat (kg); WBE, wool-free whole-body energy (MJ).

* $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$.

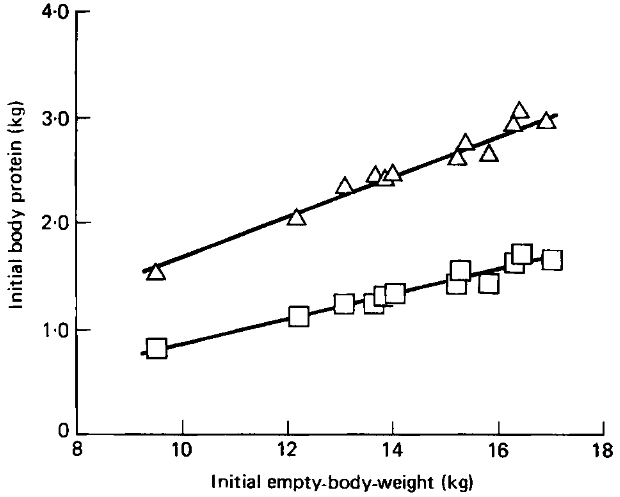

Fig. 1. Relationships between initial empty-body-weight and the weight of total protein in the whole body (△) and in the carcass (□).

Table 4. *Rates of gain in live-weight, empty-body-weight and carcass (g/d)*

(Mean values with their standard errors)

Treatment	Control lambs		Protein-infused lambs		Statistical significance of difference between diets
	Mean	SE	Mean	SE	
Live-weight (LW) gain	79·3	5·80	99·2	5·57	*
Empty-body-weight (EBW) gain	62·0	5·06	82·4	4·86	**
Carcass-weight (CW) gain	35·4	3·01	49·2	2·89	**
CW:EBW	0·53	0·003	0·54	0·003	*
CW gain/LW gain	0·44	0·013	0·50	0·012	**

* $P < 0.05$, ** $P < 0.01$.

($P < 0.05$) and thereafter by 47 mg/10^4 mm^2 per d ($P < 0.001$). Total fleece growth over the full 12 weeks was 2·7 g/d greater for protein-infused than for control lambs ($P < 0.05$). Averaged over all three measurement periods, the wool growth response to protein infusion tended to be proportionately lower when calculated from mid-side (+45%) than from entire fleece (+70%) wool production. Greater reliability is placed on the mid-side values because this was an actual measurement as opposed to fleece growth being an estimate. For this reason mid-side growth was also recorded with greater precision (coefficient of variance 22) than fleece growth (coefficient of variance 54).

Body composition

Total body protein of lambs slaughtered at the end of the experiment was positively related to EBW for both groups ($P < 0.001$), and as the slopes did not differ ($P > 0.05$) the common slope was used to adjust total protein to values corresponding to the over-all mean EBW of 20·1 kg (Fig. 2). It is recognized that the co-variate (EBW) was also affected by the nutritional treatment imposed, but from the graphical data the adjustment seems reasonable.

Table 5. *Wool growth from mid-side areas* ($mg/10^4\ mm^2/d$) *and from the entire fleece* (g/d)

(Mean values with their standard errors)

Treatment...	Period of experiment (weeks)	Control lambs		Protein-infused lambs		Statistical significance of difference between diets
		Mean	SE	Mean	SE	
Mid-side wool growth	1–4	66	5·7	82	5·5	*
	5–8	83	6·5	129	6·3	***
	9–12	88	6·2	137	5·9	***
Clean fleece growth	1–12	3·9	0·84	6·6	0·81	*

* $P < 0.05$, *** $P < 0.001$.

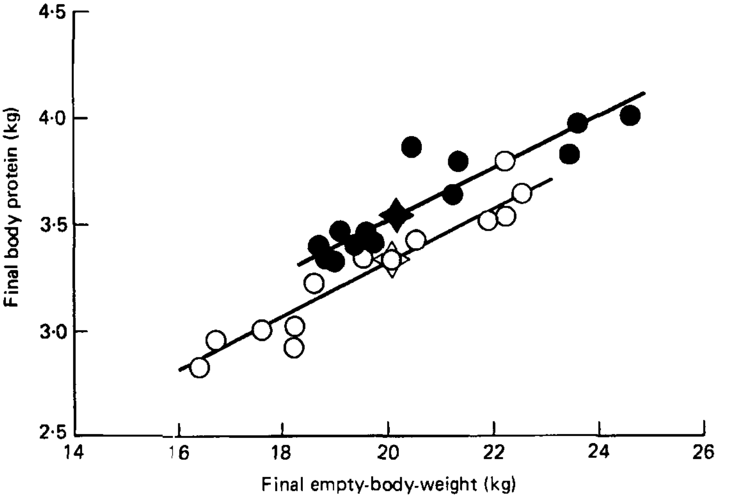

Fig. 2. The relationship between final empty-body-weight and weight of total protein in the whole body of control (○) and protein-infused lambs (●). Regression slopes were significant ($P < 0.001$) for both groups and did not significantly differ. Regression lines shown are for the common slope of 0·126 (SE 0·0103), with protein content adjusted to the mean EBW (20·1 kg) shown for control lambs (◇) and protein-infused lambs (◆).

Adjusted total body protein contents were 3·34 and 3·53 kg respectively for control and protein-infused lambs ($P < 0.001$), corresponding to 0·166 and 0·176 of EBW. Carcass protein comprized 0·556 of total body protein and the ratio was unaffected by nutritional treatment.

Final total body fat (kg) was not related to final EBW and likewise final carcass fat (kg) was not related to final carcass weight ($P > 0.05$) over the range of independent variables studied. Consequently, nutritional effects were assessed using unadjusted body composition data. Fat comprized 0·113 and 0·132 of EBW for control and protein-infused lambs ($P < 0.10$) and respectively 0·147 and 0·175 of carcass ($P < 0.05$).

Rates of fat, protein and energy deposition

Rates of protein deposition in both the carcass and the wool-free whole body (Table 6) were markedly greater for protein–infused than for control lambs ($P < 0.01$). Total protein deposition including wool was 12·6 g/d for control lambs and 21·0 g/d for lambs receiving

Table 6. *Rates of gain of fat and protein in the carcass and wool-free whole body and total protein deposition (g/d)*

(Mean values with their standard errors)

Treatment...	Control lambs		Protein-infused lambs		Statistical significance of difference between diets
	Mean	SE	Mean	SE	
Carcass:					
Fat	15·5	1·56	13·5	1·50	NS
Protein	4·9	0·47	8·6	0·46	***
Whole body (wool-free):					
Fat	21·2	2·06	18·5	1·98	NS
Protein	8·7	0·73	14·3	0·70	***
Total protein deposition	12·6	0·94	21·0	0·91	***

NS, not significant. *** $P < 0.001$.

Table 7. *Total energy retention (MJ/d), the efficiency of utilization of metabolizable energy for growth* (k_g), *and the proportion of energy retention as protein*

(Mean values with their standard errors)

Treatment...	Control lambs		Protein-infused lambs		Statistical significance of difference between diets
	Mean	SE	Mean	SE	
Total energy retention	1·13	0·109	1·29	0·105	NS
k_g	0·260	0·0167	0·276	0·0160	NS
Energy retained as protein:					
†	0·202	0·0199	0·338	0·0192	***
‡	0·272	0·0243	0·410	0·0233	***

NS, not significant. *** $P < 0.001$.

† Rate of protein energy deposition in wool-free whole body/rate of energy deposition in wool-free whole body.

‡ Rate of total protein energy deposition/rate of total energy deposition.

protein infusion ($P < 0.001$). Although fat deposition tended to be lower for protein-infused than for control lambs the difference was not significant.

Total energy retention (Table 7) and the efficiency of utilization of ME for growth (k_g) were similar for the two groups of lambs. However, protein energy as a proportion of total energy deposition was markedly greater for protein-infused than for control lambs ($P < 0.001$).

DISCUSSION

Efficiency of protein deposition

Previous abomasal protein infusion studies with lactating animals fed on fresh pasture diets in New Zealand have indicated that a deficiency in protein supply was restricting production, both for dairy cows (Rogers *et al.* 1979) and for ewes (Barry, 1981). Such studies with lactating animals can be insensitive, due to body tissue storage or mobilization of protein and fat. However, the design of the present experiment overcame this problem and demonstrated quite clearly that the digestion products of the basal ryegrass-dominant diet were deficient in protein relative to ME.

From a balance sheet for total amino acids (Table 8), approximately one-third of the total N consumed is predicted to have been lost across the rumen. Also, in the control lambs, the predicted absorption of amino acids from the small intestine (60 g/d) is used to meet amino acid requirements with the relatively high efficiency of 0·73. This is consistent with further increases in protein deposition being restricted by a shortage in amino acid supply, and corresponding calculations for protein-infused lambs (Table 8) show that this was the situation.

These calculations suggest a deficiency of specific amino acids, and a similar balance sheet (Table 9) was therefore drawn up for sulphur-containing amino acids (SAA), as cystine + methionine were considered as the most likely to be in limited supply. As predicted SAA absorption for control lambs was similar to the estimated SAA requirement, it seemed that further deposition of some proteins was limited by SAA supply, and this was confirmed when the same calculation was done for the protein-infused lambs. It has been well established that wool growth of sheep fed on forage diets at the maintenance level of energy intake is restricted by SAA supply (Reis & Schinckel 1964; Reis 1970). The present experiment shows that with fresh ryegrass-dominant pasture this can be extended to *ad lib.* intake, and that protein deposition in the wool-free body is also restricted.

Efficiency of energy deposition

Casein + methionine infusion increased ME in the form of amino acids absorbed from the small intestine from 0·16 to 0·25 (Table 8), and the principal effect of this was markedly to increase protein as a proportion of total energy deposited, with only very small and non-significant increases in the rate of total energy deposition and in k_g. Rates of whole-body protein synthesis in these lambs were in the order of 600 g/d, or approximately forty times the rates of protein deposition reported in the present paper, with the techniques used not showing any difference between the two groups of lambs (Davis *et al.* 1981). As heat production is related to protein synthesis rather than to protein deposition, this explains why there was little difference in k_g between the two diets used in this study, despite the efficiency of protein deposition being much greater in the lambs infused with casein + methionine.

The low k_g values found in this investigation are similar to those found by other authors for primary spring growths fed to growing lambs; i.e., 0·33 for fresh ryegrass (Rattray & Joyce, 1974), 0·29 for fresh lucerne and fresh ryegrass–clover pasture (Fennessy *et al.* 1972) and 0·28 for dried chopped lucerne (*Medicago sativa*) (Thomson & Cammell, 1979). The low values found here are not likely to result from the method of calculating results, as the ME subtracted for maintenance (0·473 MJ/kg $W^{0.75}$ per d) is similar to that derived by respiration calorimetry (0·45 MJ/kg $W^{0.75}$ per d) for lambs maintained on rumen infusions of volatile fatty acids (VFA) (Ørskov *et al.* 1979). In lambs receiving intra-gastric infusions of VFA as the sole energy source Ørskov *et al.* (1979) found no effect upon k_g when the acetate:propionate value was changed over a wide range. The high heat increment of these forage diets does not therefore appear to be related to the proportion of ME absorbed as either protein or as individual VFA, and is an area that requires further investigation.

Body composition

The reduction in body fat content and the somewhat smaller increase in protein content induced by increasing protein absorption from 0·16 to 0·25 of ME are in accord with the conclusions of computer modelling studies for lambs weighing 15–20 kg (Black, 1974). Similar changes are predicted to occur at higher rates of body growth in lambs of this weight range as protein absorption is increased from 0·15 to 0·25 of ME. This is supported by results of practical feeding trials with barley–fish-meal diets fed to lambs growing at 200–300 g/d from 14–20 kg (Ørskov *et al.* 1971), where increments in dietary crude protein (N × 6·25)

Table 8. *Comparison of predicted absorption of total amino acids from digestion of the diets (g/d), with the requirement for total amino acids (g/d) calculated from values obtained in the present study*

Treatment...	Control lambs	Protein-infused lambs
Herbage nitrogen consumed (g/d)*	24·3	22·7
NAN at duodenum (g/d)†	16·3	15·4
Amino acids absorbed from small intestine:		
Basal diet†	59·8	55·9
Infusion	—	43·4
Total	59·8	99·3
Proportion of ME	0·156	0·252
Amino acid requirement:		
Metabolic faecal N*	24·4	22·5
Endogenous urinary N*	6·9	7·0
Wool†	3·9	6·6
Body deposition†	8·7	14·3
Total	43·9	50·4
Efficiency of amino acid utilization	0·73	0·51

NAN, non-amonia-N; ME, metabolizable energy.

* Calculated from present experiment, assuming Agricultural Research Council (1965) values for endogenous losses.

† Calculated through applying equations of MacRae & Ulyatt (1974) to the mean herbage N intake recorded in the present experiment.

Table 9. *Comparison of predicted absorption of amino acid sulphur from the small intestine with the requirement for amino acid-S (mg S/d)*

Treatment...	Control lambs	Protein-infused lambs
Amino acid-S (mg) absorbed from small intestine:		
Basal diet*	418	392
Casein†	—	301
Methionine	—	99
Total	418	792
Amino acid-S requirement‡		
Metabolic faecal	212	195
Endogenous urinary	60	60
Wool	117	198
Body deposition	76	124
Total	465	577

* Assuming 20g methionine + 10 g cystine/kg amino acids, equivalent to 7·0 g S.

† From FAO (1970); 28·0 g methionine + 3·6 g cystine/kg amino acids, equivalent to 7·0 g S.

‡ Calculated through applying factors derived by Barry (1976) to requirement for total amino acids shown in Table 8.

concentration from 111 to 160 to 190 g/kg DM produced an over-all change in protein deposition as a proportion of total energy deposition from 0·25 to 0·38, similar to the increase found in this study. Dietary crude protein concentration in this study (182 g/kg DM) was close to the maximum fed by Ørskov *et al.* (1971), and the responses in body composition and protein deposition to abomasal infusion of casein+methionine offer a convincing demonstration that protein requirements of ruminants fed on fresh herbages of high protein solubility should be based upon protein absorption from the small intestine.

Manipulation of amino acid supply in ruminants fed on fresh herbages

In environments such as New Zealand where grazed forages comprise the only diet of ruminants for almost the entire annual production cycle, the only really effective way of increasing amino acid absorption from the small intestine is through changing plant chemical composition in such a way as to regulate the digestive process. In this connexion the incorporation of condensed tannins into plants increases the quantity of undegraded plant protein arriving at the duodenum; also total protein arriving at the duodenum increases as rumen turnover of total organic matter (OM) (duodenal OM flow ÷ rumen OM pool) increases (John *et al.* 1980). The latter is proportional to the rate of plant OM degradation in the rumen, and this may well be an important plant characteristic related to voluntary intake as well as to amino acid supply.

In addition to increasing the supply of one or more essential amino acids, Clark (1975) postulated that increasing amino acid absorption from the small intestine could increase the productivity of ruminants through increasing glucose production or by causing changes to the endocrine system. Measurement of these criteria in the present experiment, and their relationship to increased protein deposition in the lambs infused with casein+methionine, are reported by Barry *et al.* (1982).

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