Br. J. Nutr. (1979), **41**, 297

The utilization of chopped and pelleted lucerne (*Medicago sativa*) by growing lambs

BY D. J. THOMSON AND S. B. CAMMELL

Grassland Research Institute, Hurley, Maidenhead, Berks. SL6 5LR

(*Received* 16 *May* 1978 – *Accepted* 13 *June* 1978)

1. The efficiency of utilization of the dietary energy and nitrogen contained in a dried lucerne (*Medicago sativa* cv. Chartainvilliers) given either chopped (CL) or ground (1·96 mm screen) and pelleted (PL), was measured in a comparative slaughter experiment. Growing lambs were given equal amounts of digestible energy in the chopped or pelleted form at each of the three planes of nutrition for a period of 100 d.

2. The initial energy, fat and protein content of both the carcass and the total body of the test lambs was estimated from regression equations between fasted (18 h) live weight and these components, derived from a group of twenty-three comparable lambs. The final energy, fat and protein content of the test lambs was determined directly by chemical analyses.

3. The metabolizable energy (ME) content of the diets was derived at each plane of nutrition from measured faecal and urinary losses and estimated methane losses. The depression in ME content with grinding and pelleting the dried lucerne was small (CL 8·69 MJ/kg dry matter (DM), PL 8·42 MJ/kg DM).

4. The efficiency of utilization of the ME of the dried lucerne for growth and fattening was higher ($P < 0{\cdot}01$) when given in the ground pelleted form (0·533), than in the chopped form (0·284). The net energy value of the PL (3·5 MJ/kg DM) was higher than that of CL (2·2 MJ/kg DM).

5. Thus lambs fed on PL grew faster and had a higher caracass weight gain, carcass protein and fat retention than lambs fed on CL. The composition of the carcass was not altered by the physical processing treatment.

6. Digestion studies with these same CL and PL diets had shown that grinding and pelleting depressed digestion in the forestomachs and increased digestion in the small intestine compared with the chopped form. The increased efficiency of utilization of the gross energy and ME and the higher net energy value of PL was attributed primarily to a change in the site of digestion within the alimentary tract. Associated with this change was a higher value for absorbed amino acids : absorbed energy and an increased apparent absorption of methionine for lambs fed on PL. The difference in the energy costs of eating and ruminating the CL and PL was small.

The physical form of forage influences voluntary food consumption, digestibility and hence the productive response of ruminant animals fed on processed diets. Associated with alterations in physical form of forage diets are changes in eating and ruminating behaviour (Balch, 1969; Osuji *et al.* 1975), rate of digestion and the end-products of digestion within the rumen (Meyer *et al.* 1959) and also the rate of passage of digesta from the rumen (Blaxter *et al.* 1956).

Grinding and pelleting forage alters the efficiency of energy utilization but variable responses have been measured with grasses and several conflicting reasons evoked to account for the changes measured. The present work was undertaken to examine the effect of processing a dried lucerne (*Medicago sativa* cv. Chartainvilliers) by grinding and pelleting on the efficiency of utilization of the dietary energy and nitrogen for growth and fattening. A preliminary report of this work has been published (Thomson & Cammell, 1971). Concurrent digestion studies, using the same CL and PL diets were undertaken and have been published (Thomson *et al.* 1972; Coehlo da Silva *et al.* 1972).

EXPERIMENTAL

Preparation of diets

A regrowth of lucerne dried commercially in a high-temperature pneumatic drum drier (British Crop Driers, Navenby, Lincs.), was used to prepare two diets of different physical form from the same crop. The diets were (1) CL chop length of stems 60 mm; and (2) PL prepared by grinding the chopped lucerne through a 1·96 mm screen before extrusion as pellets of 12 mm diameter and 25 mm in length.

Design

The comparative slaughter technique (Lawes & Gilbert, 1861; Milford, 1965; Thomson, 1968) was used to measure energy, fat and protein retention. Young, worm-free lambs (Suffolk ♂ × (Border Leicester ♂ × Cheviot ♀) ♀) which had been reared artificially from birth (Treacher & Penning, 1971) were fed on the two experimental diets at three planes of nutrition above maintenance for 100 d. Six pairs of male twin lambs and three pairs of twin female lambs were divided between the two treatments. Six additional lambs were allocated to each treatment; there were thus fifteen lambs in total on each dietary treatment with four males and one female at each plane of nutrition. The planes of nutrition were level 1, approximately 90% of *ad lib.* intake, level 2 intermediate between level 1 and level 3, i.e. three quarters of the growth rate on level 1 and level 3, designed to give a growth rate approximately half the rate of live-weight increase of lambs fed at level 1. The rates of feeding were approximately 65, 75, and 90 g DM/kg$^{0.75}$ per d.

The initial energy, fat and protein content of the test lambs was estimated from their fasted live weight. Linear relationships between fasted live weight (18 h) and body energy, fat and protein were derived from an initial slaughter group (ISG) of twenty-three lambs of similar breeding and nutritional history as the test lambs. This group of twenty-three lambs was comprised of ten lambs slaughtered at the beginning of this experiment, and thirteen lambs slaughtered at the beginning of another similar experiment (Thomson & Cammell, 1971). The range of fasted live-weight of the ISG, was from 11·0 to 28·5 kg. The mean initial fasted weight of all test lambs was 23·2 kg.

Management and feeding of the lambs

The lambs were housed in metabolism crates throughout the period of the experiment. The experiment was conducted during the months of August, September, October and November. The experimental diets were offered twice daily at 09.00 and 16.30 hours. The test lambs were weighed weekly and the amount of CL or PL offered to each lamb was adjusted weekly on the basis of the live weight and the rate of gain of each lamb and with the objective of feeding equal amounts of digestible energy (DE) as CL and PL at each plane of nutrition. Fresh water was available to all lambs and water consumption was recorded daily. No alternative sources of nutrients or additional minerals were fed to the lambs other than those supplied by the forage diets.

The lambs were free from intestinal worms at the beginning of the experiment and remained so throughout the period of 100 d. During the experiment the level of coccidia was kept low. No problems of ill health occurred during the experiment, but lambs fed on PL resorted to chewing their own wool from approximately day 40 until the end of the experiment. Efforts to prevent, or minimize the extent of this wool chewing were not successful.

Digestibility and metabolizability of CL and PL

Two separate estimates of digestibility were made on three male lambs at each plane of nutrition on each diet. Total faeces were collected for seven successive days in the first measurement period (week 4) and for 14 consecutive days in the second measurement period (weeks 7 and 8). The values obtained in week 4 were used to calculate the amount of DE to be offered each week.

No adjustments were made in the amount of food offered for 7 d before, and during, faecal and urine collections for the determination of digestibility and metabolizable energy

(ME) content of the diets at each plane of nutrition. The planes of nutrition at which the measurement of digestibility was conducted were also those which applied for each individual lamb throughout the whole experiment. Similar values were obtained for the measurements conducted in week 4 and weeks 7 and 8.

The results from the second period were used to derive the ME of the diet based on a 14 d faecal collection. Urine was collected for 4 d at the end of the 14 d faecal collection period. Methane was estimated from the relationship based on apparent energy digestibility and plane of nutrition given by Blaxter & Clapperton (1965). The ME intakes for each lamb for the whole experiment were derived from the individually measured gross energy (GE) intakes and the individual ME values, where these were measured and the mean value for each plane of nutrition for remaining lambs (two) fed at each level.

Chemical analysis

GE of feed, faecal and animal tissue samples was determined in an adiabatic bomb calorimeter (Grassland Research Institute, 1961) and total N by the macro-Kjeldahl procedure. The modulus of fineness (MF) and modulus of uniformity (MU) were derived from the measurements of particle size distribution made by the method of the American Society of Agricultural Engineers (1967). Cellulose was determined by the method of Crampton & Maynard (1938). Diethyl ether extract, moisture and ash determinations on the animal tissue samples were according to the Association of Official Agricultural Chemists (1969).

Total body energy, fat and N were calculated by summating the values for carcass, gut, blood, wool and skin. The tissue samples were prepared as previously described (Thomson, 1963; Thomson, 1968) and standard values were applied for the energy, fat and N content of blood (Thomson, 1963).

RESULTS

The chemical composition, particle size distribution and physical characteristics of the diets are presented in Table 1. The two diets differed in their physical characteristics, but their chemical composition was similar. The total N content of the CL was however lower than the PL.

Table 2 gives the results for DE and the calculated ME content of the GE for the two diets at each plane of nutrition. There was a small depression in DE and ME with increasing plane of nutrition with PL but no change with CL. Table 2 also contains the values for apparent nitrogen digestibility (DN). The values for DN indicate a small depression with increasing plane of nutrition for both diets, but no difference ($P > 0.05$) between the diets.

Energy and N intake of lambs

Table 3 gives the mean daily intake of GE, DE and ME and total nitrogen (TN) and DN for the lambs fed on the CL and PL diets.

The intakes of DE and ME were similar for lambs fed on CL and PL at each plane of nutrition ($P > 0.05$). However, the intakes of TN and DN were higher for lambs fed on PL ($P < 0.001$).

ISG

Separate relationships between fasted (18 h) live weight and carcass weight, energy, protein, fat, wool protein, total body energy, protein and fat were derived for a group of ten lambs slaughtered at the beginning of this experiment, and a comparable group of thirteen lambs from the same flock, reared artificially in the same manner, slaughtered earlier in the same year (Thomson & Cammell, 1971). The relationships did not differ ($P > 0.05$) for the two groups of lambs and the pooled results from all twenty-three lambs had been used to estimate the composition of the 'test' lambs on day 1 of the experiment.

Table 1. *The chemical composition (g/kg* DM) *and physical characteristics of chopped and pelleted lucerne* (Medicago sativa *cv. Chartainvilliers*)

	Chopped	Pelleted
Nitrogen	27	30
Cellulose	300	291
Ash	91	91
Sodium	0·7	0·7
Potassium	19·8	19·0
Calcium	15·2	15·6
Phosphorus	2·6	2·9
Magnesium	1·6	1·7
Copper (mg/kg)	59	62
Gross energy (MJ/kg DM)	18·9	18·7
Particle size distribution (% retained in each sieve)		
Sieve aperture		
4760	5·0	0
2400	20·6	0·2
1200	34·9	1·4
600	24·7	17·3
300	10·7	30·8
150	3·3	28·5
	0·9	21·8
Modulus of fineness*	3·5	1·5
Modulus of uniformity*	3:6:1	0:3:8

DM, dry matter.
* Derived from the measurements of particle size distribution by the method of the American Society of Agricultural Engineers (1967).

Table 2. *The apparent digestibility of energy* (DE) *and protein (DN) and the metabolizability of the gross energy* (ME) *contained in chopped and pelleted lucerne* (Medicago sativa) *fed at three planes of nutrition to growing lambs**

Physical form	Plane of nutrition	DE	ME	DN
Chopped	1	0·58	0·47	0·66
	2	0·56	0·45	0·66
	3	0·58	0·46	0·69
	Mean	0·57	0·46	0·67
Pelleted	1	0·52	0·42	0·66
	2	0·54	0·44	0·68
	3	0·55	0·45	0·69
	Mean	0·54	0·43	0·68
	SEM	0·007	0·009	0·004

* For details, see p. 299.

The 'test' lambs were fasted for 18 h and weighed to the nearest 50 g before being offered food on day 1. These linear regression equations are given in Table 4, and the relationship between initial fasted live weight and total body energy is given in Fig. 1.

The regression equations were reasonably precise with the exception of the equation used to predict the wool protein content of the lambs. For this relationship only 64% of the variance was accounted for by fasted live weight.

Table 3. *The daily intake of dry matter* (DM), *gross energy (GE), digestible energy* (DE), *metabolizable energy* (ME), *total nitrogen (TN) and digestible nitrogen (DN) of lambs fed on chopped pelleted lucerne* (Medicago sativa) *at three planes of nutrition**

Physical form	Plane of nutrition	MJ/d			g/d		
		GE	DE	ME	DM	TN	DN
Chopped	1	20·01	11·55	9·33	1058	28·6	18·8
	2	16·25	9·16	7·26	859	23·2	15·3
	3	14·56	8·42	6·77	769	20·8	14·4
Pelleted	1	22·58	11·73	9·44	1210	36·8	24·4
	2	18·10	9·87	7·91	970	29·5	20·1
	3	14·46	8·01	6·45	775	23·5	16·3
	SEM	0·699	0·389	0·315		1·02	0·68

* For details, see p. 298.

Table 4. *Regression equations for initial slaughter group*†

Equation	Residual standard deviation	Correlation coefficient	Equation no.
$Y_1 = 0·490X - 1·194$	0·33	0·99	1
$Y_2 = 6·761X - 55·65$	3·79	0·97	2
$Y_3 = 90·05X - 188$	82·60	0·98	3
$Y_4 = 110X - 1141$	223·07	0·92	4
$Y_5 = 15·49X + 38·95$	54·35	0·81	5
$Y_6 = 9·104X - 62·97$	4·86	0·98	6
$Y_7 = 147X - 135$	120·2	0·99	7
$Y_8 = 133X - 1321$	268·0	0·92	8

X, initial fasted live weight (18 h) (kg); Y_1, initial carcass weight (kg); Y_2, initial carcass energy (MJ); Y_3, initial carcass protein content (g); Y_4, initial carcass fat content (g); Y_5, initial total wool protein (g); Y_6, initial total body energy (MJ); Y_7, initial total body protein (g); Y_8, initial total body fat (g).

† Twenty-three lambs were in the initial slaughter group.

Production responses of lambs fed on CL and PL

The main objective of the experiment was to examine the efficiency of utilization for growth and fattening of the dietary energy and N in dried lucerne diets of different physical form. As the comparative slaughter technique was used to measure energy, fat and protein retention in growing lambs and the results for the total body were derived by summating the components carcass, gut, wool, skin and blood, information for carcass and wool could be examined separately. Table 5 contains the results for daily live-weight gain (from initial and final live weight measurements), carcass weight gain (derived from using Table 4 equation No. 1), and wool protein retention (using Table 4 equation No. 5).

Live-weight gain and carcass-weight gain ($P < 0·001$) were higher for lambs fed the PL diet. The mean carcass-weight gain of lambs fed on PL (61 g/head per d) was greater than that for lambs fed equal amounts of digestible energy in the chopped form (35 g/head per d). The difference in wool growth and wool protein retention was not significant ($P > 0·05$). However, several lambs fed on PL diet chewed their own wool. No satisfactory basis was obtained to make adjustments for the reduction in measured wool growth of these lambs, and no corrections were made. Thus wool protein retention values for the lambs fed on PL may be considered to be underestimates.

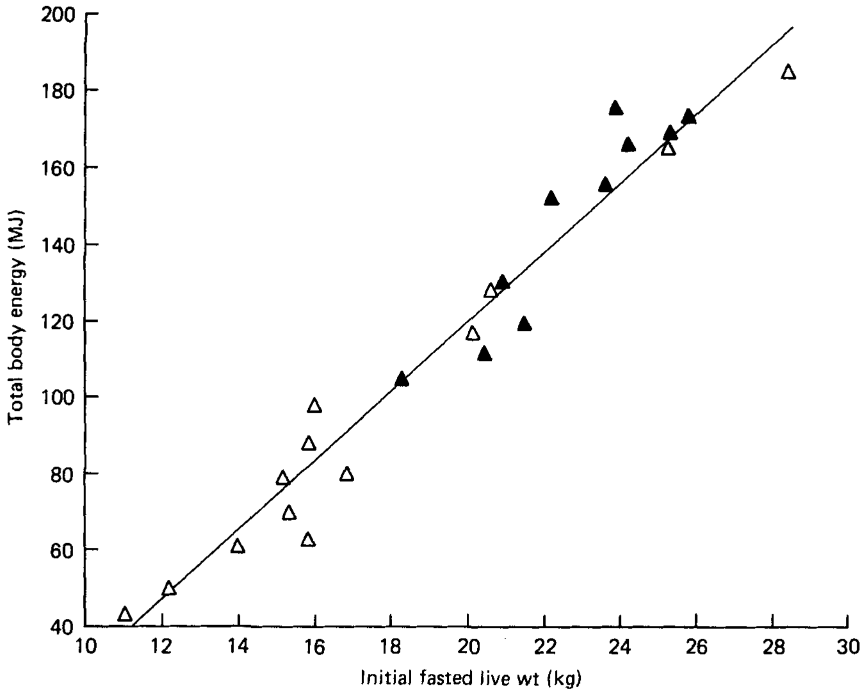

Fig. 1. The relationship between initial fasted live weight (kg) and the total body energy content of groups of ten (▲) and thirteen (△) lambs.

Table 5. *The live weight gain, carcass gain and wool protein retention (g/d) of lambs fed on chopped (CL) and pelleted (PL) lucerne* (Medicago sativa) *at three planes of nutrition**

Plane of nutrition	Live-wt gain		Carcass-wt gain		Wool protein retention	
	CL	PL	CL	PL	CL	PL
1	113	162	51	87	5·2	6·5
2	81	106	31	58	5·3	4·9
3	59	65	25	37	4·7	6·2
Mean	84	111	35	61	5·1	5·9
SEM	7·1		4·0		0·83	

* For details, see p. 298.

Carcass composition

The birth weights and rates of gain of lambs from birth to the commencement of the experiment were similar for lambs allocated to the two diets ($P > 0·05$). The mean initial fat and the mean initial protein content of the carcasses of lambs allocated to the CL and PL diets did not differ between treatments ($P > 0·05$). The composition of the final carcass was not influenced by the physical form of the diet. The relationship between carcass fat and carcass weight, and carcass protein and carcass weight did not differ for the two diets ($P > 0·05$). The protein and fat contents of the final carcasses of individual lambs are presented in Figs 2 and 3.

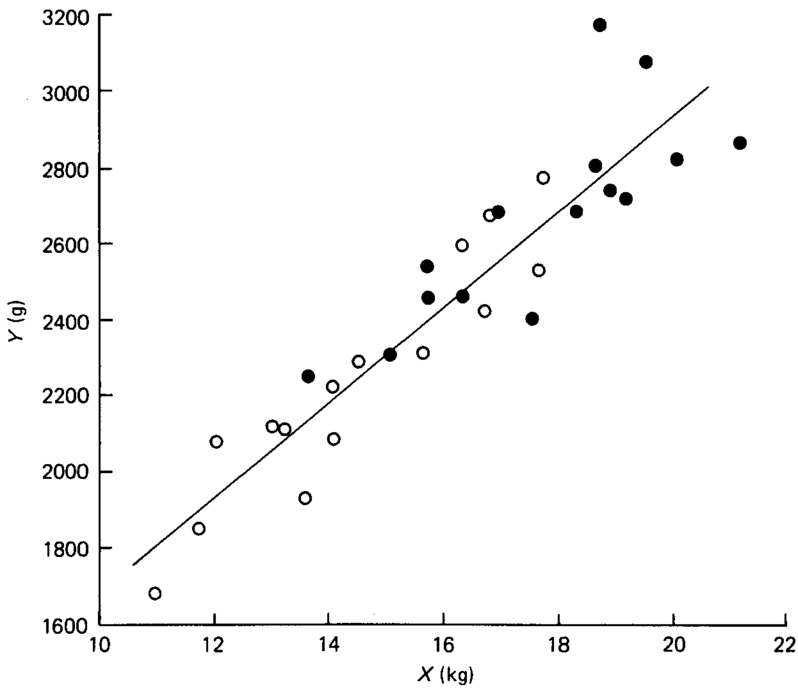

Fig. 2. The relationship between carcass weight (kg) at slaughter (X) and the weight of protein in the carcass (Y; g) of lambs fed on chopped (○) and pelleted (●) lucerne (*Medicago sativa*) (for details, see p. 298) ($Y = 0{\cdot}124X + 0{\cdot}457$ (r 0·92)).

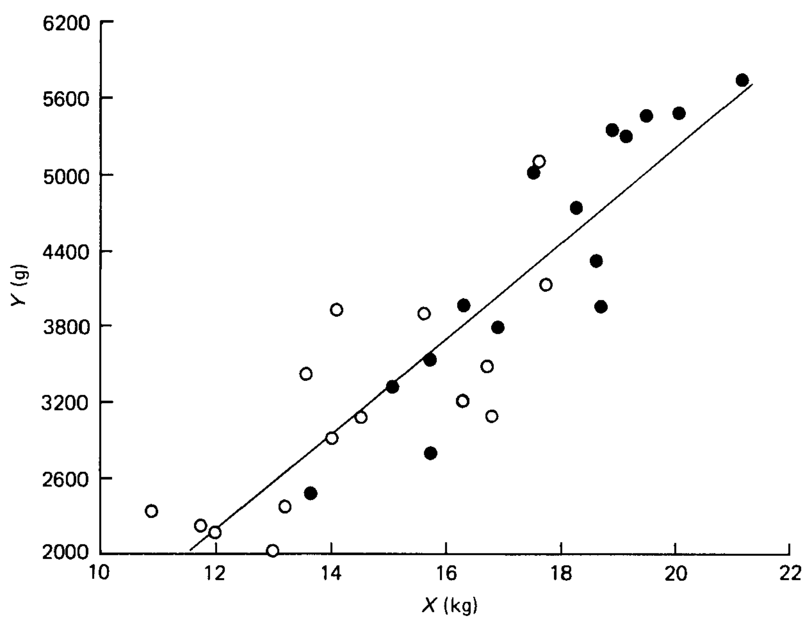

Fig. 3. The relationship between carcass weight (kg) at slaughter (X) and the weight of fat in the carcass (Y; g) of lambs fed on chopped (○) and pelleted (●) lucerne (*Medicago sativa*) (for details, see p. 298) ($Y = 0{\cdot}377X - 2{\cdot}329$ (r 0·89)).

Table 6. *The total body energy (TBER), protein (TBPR) and fat (TBFR) retention of lambs fed on chopped (CL) and pelleted (PL) lucerne* (Medicago sativa) *at three planes of nutrition**

Plane of nutrition	TBER (kJ/d)		TBPR (g/d)		TBFR (g/d)	
	CL	PL	CL	PL	CL	PL
1	1598	2539	14·9	22·3	34·1	50·2
2	954	1741	10·6	13·4	20·7	37·3
3	883	1105	7·8	11·6	17·7	21·9
Mean	1146	1795	11·1	15·7	24·2	36·5
SEM	126·9		1·29		3·02	

* For details, see p. 298.

Table 7. *The efficiency of utilization of metabolizable energy for growth and fattening* (k_f) *and the net energy (NE) values determined by linear regression analysis for lambs fed on chopped and pelleted lucerne diets* (Medicago sativa) *at three planes of nutrition*†

Physical form	k_f	Residual standard deviation	Correlation coefficient	Statistical significance	Equation no.
Chopped	$Y = 0{\cdot}284X_1 - 89{\cdot}773$	22·98	0·74	**	9
Pelleted	$Y = 0{\cdot}533X_1 - 193{\cdot}214$	21·36	0·90	***	10
	Net energy				
Chopped	$Y = 2{\cdot}21X_2 - 69{\cdot}69$	25·09	0·66	**	11
Pelleted	$Y = 3{\cdot}54X_2 - 134{\cdot}491$	20·93	0·91	***	12

X_1, metabolizable energy intake (kJ/kg$^{0{\cdot}75}$ per d); X_2, dry matter intake (g/kg$^{0{\cdot}75}$ per d); Y, total body energy retention (kJ/kg$^{0{\cdot}75}$ per d).

** $P < 0{\cdot}01$, *** $P < 0{\cdot}001$.

† For details, see p. 304.

Table 8. *Period of time (h) spent eating and ruminating by lambs fed on chopped (CL) and pelleted (PL) lucerne* (Medicago sativa) *at three planes of nutrition**

Plane of nutrition	Eating		Ruminating	
	CL	PL	CL	PL
1	4·80	1·32	9·04	5·40
2	3·64	0·68	8·76	4·48
3	1·60	0·84	7·48	4·64
Mean	3·35	0·95	8·43	4·84

* For details, see p. 305.

Energy, fat and protein retention

Table 6 gives the energy, protein and fat retention values. The initial total body energy, protein and fat contents of the lambs were estimated from Table 4 equation nos. 6, 7 and 8. Lambs fed on the PL grew faster and retained significantly more energy, protein and fat than lambs fed on CL ($P < 0{\cdot}001$).

Efficiency of utilization of dietary energy and N

Energy utilization. The efficiency of utilization of ME for growth and fattening (k_f) was derived by linear regression analysis of the individual lambs total body energy retention

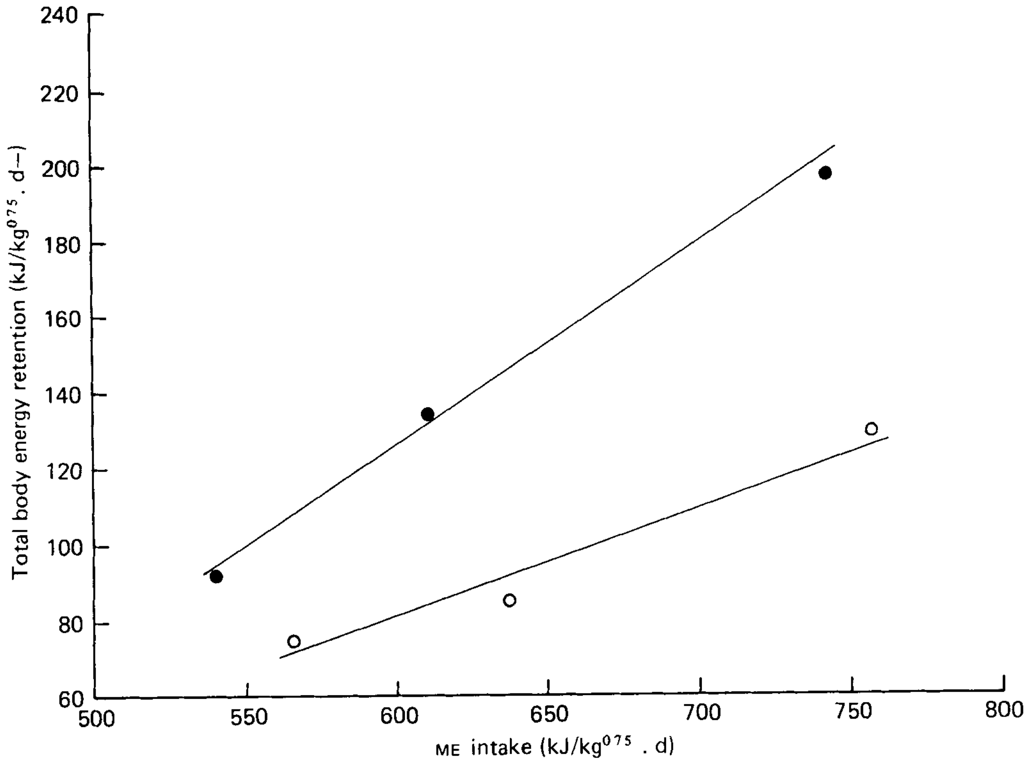

Fig. 4. The relationship between metabolizable energy (ME) intake (kJ/kg$^{0.75}$ per d) and total body energy retention (k_f) (kJ/kg$^{0.75}$ per d) for lambs fed on chopped (○) or pelleted (●) lucerne *Medicago sativa*) (for details, see p. 304). Each point is the mean of five values.

(kJ/kg$^{0.75}$ per d) and DM intake (g/kg$^{0.75}$ per d). The derived equations are presented in Table 7.

The slopes of the respective lines represent the k_f and NE values for the CL and PL diets. The ME of the PL diet was utilized with an efficiency for growth and fattening of 0·533. CL had a significantly ($P < 0.01$) lower measured k_f value of 0·284 (Fig. 4). The NE value (Table 7) of the PL (3·54 MJ/kg DM) was significantly ($P < 0.001$) higher than that of the CL (2·21 MJ/kg DM) (Fig. 5).

N utilization. The individual total body N retention in relation to TN and DN intake were also compared by regression analysis. More conventional methods of assessing N utilization, (percentage retention), give values which measure gross efficiency and are influenced by the amount of N or DN consumed. From Fig. 6 it can be seen that the N contained in the CL and PL diets was used with similar efficiency for TN retention. Separate lines for each diet were not significantly different ($P > 0.05$) and a common line was fitted to the values.

Behavioural and physiological responses to the feeding of CL and PL

Eating and ruminating. The time spent eating and ruminating by the lambs consuming the CL and PL diets are given in Table 8. The lambs spent significantly ($P < 0.01$) less time eating and ruminating when consuming the PL compared with CL diet.

Reticulo-rumen weight. At slaughter, after the contents of the alimentary tract had been removed, the reticulo-rumens were weighed. The results given in Fig. 7 show that there was

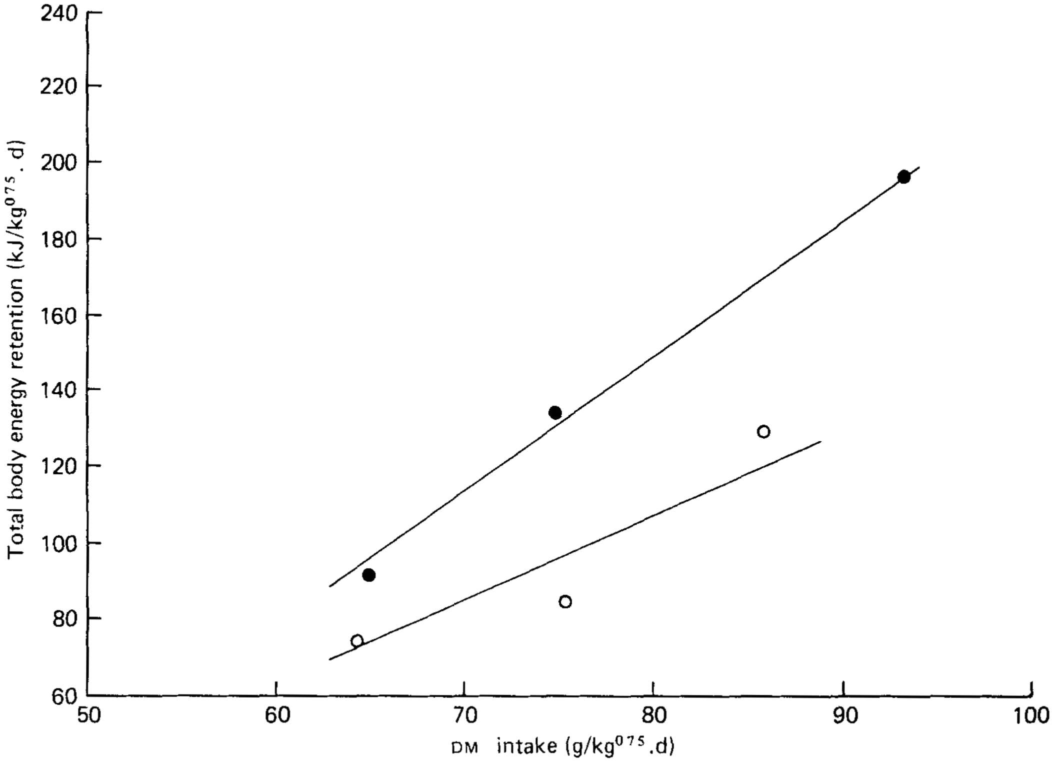

Fig. 5. The relationship between dry matter (DM) intake (g/kg$^{0.75}$ per d) and total body energy retention (kJ/kg$^{0.75}$ per d) for lambs fed on chopped (○) or pelleted (●) lucerne (*Medicago sativa*) (for details, see p. 305). Each point is the mean of five values.

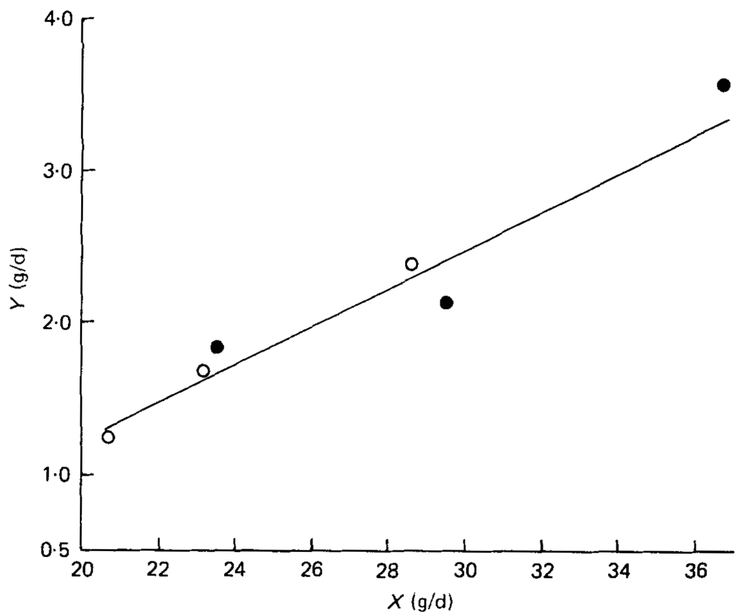

Fig. 6. The relationship between N intake (X; g/d) and total body N retention (Y; g/d) for lambs fed on chopped (○) or pelleted (●) lucerne (*Medicago sativa*) (for details, see p. 305). Each point is the mean of five values.

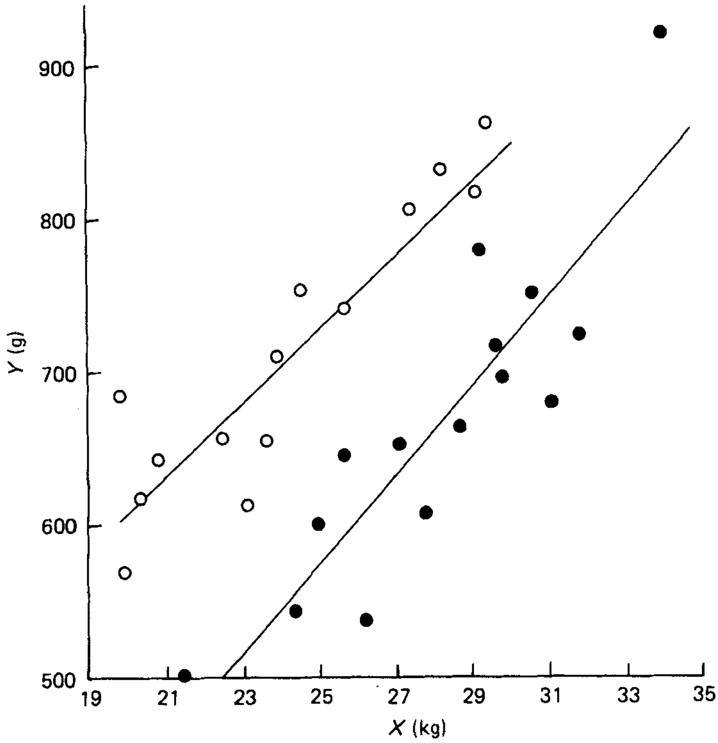

Fig. 7. The weight of the reticulorumen (*Y*; g) of lambs in relation to their empty-body-weight (*X*; kg) at slaughter when fed on chopped (○) or pelleted (●) lucerne (*Medicago sativa*) (for details, see p. 305).

a large difference in the weight of the reticulo-rumen of lambs fed on CL and those fed on PL ($P < 0.01$) when the comparison was made at the same empty-body-weight.

DISCUSSION

The physical form of the regrowth crop of lucerne was altered by grinding and pelleting. The particle size distribution of the PL was markedly different from that of the CL diet (Table 1), but the chemical composition of the diet as ingested by the lambs was very similar with the exception of TN, which was lower in the CL than in the PL diet. This was probably due to loss of leaf from the dried CL diet.

There was no change in the ME with level of feeding for the CL (Table 2) and only a small decrease for the PL diet (level 3, 0·446; level 1, 0·418). Altering the physical form of the lucerne diet by grinding and pelleting led to a reduction in DE and in ME, but the depression with processing of lucerne was small (CL, 0·459; P, 0·434), compared with reductions in DE and ME which have been measured with pelleted grasses (Blaxter & Graham, 1956; Balch, *et al.* 1965).

The response in carcass-weight gain to pelleting lucerne was marked (Table 5). Live-weight gains of the lambs over the 100 d of the experiment reflected the difference between the diets. The ME contained in the PL was utilized more efficiently (k_f 0·533) than that of the CL diet (k_f 0·284). A combination of a large increase in the efficiency of utilization of ME and a small reduction in the ME with grinding and pelleting led to a higher net energy value for the PL compared with CL (Fig. 5, Table 7).

Table 9. *The observed and predicted values for the efficiency of utilization of metabolizable energy for growth and fattening* (k_f) *values for chopped and pelleted lucerne* (Medicago sativa)

Physical form	q	M/D	k_f Present study	Agricultural Research Council (1965)	Blaxter (1974)	Ministry of Agriculture, Fisheries & Food (1975)
Chopped	46	8·7	28	40	23	38
Pelleted	47	8·8	53	41	48	38

q, metabolizable energy at maintenance; M/D, metabolizable energy in the dry matter.

An improvement in k_f in ground pelleted forage diets may merely compensate for a large reduction in ME to give a similar NE value (Blaxter & Graham, 1956), or may, as in the present experiment, when the depression in ME is small, lead to a higher NE value. A knowledge of the changes in ME with processing by grinding and pelleting and with plane of nutrition, may help to explain some of the variation in responses to processing which have been reported (Greenhalgh & Wainman, 1972). Smith *et al.* (1976) obtained k_f values of 0·34 and 0·31 for primary and regrowth diets of CL of 0·58 and 0·60 respectively. The response in k_f to processing by grinding and pelleting was 0·40 in their calorimetric experiments using adult sheep, compared with 0·70 in the present comparative slaughter experiment conducted with lambs fed re-growth lucerne of 460 kJ ME/kg in the chopped form. The k_f value obtained in the present experiment for CL (0·284) is similar to that obtained by Fennessey *et al.* (1972) who fed fiesh lucerne, Vermorel, *et al.* (1974) and Forbes *et al.* (1925) have reported k_f values for pelleted lucerne comparable to that obtained in this experiment.

In Table 9 the measured values obtained have been compared with the k_f values that would be predicted on the basis of the relationships published by the Agricultural Research Council (1965), by Blaxter (1974), and by the Ministry of Agriculture, Fisheries & Food (1975). From the Agricultural Research Council (1965) publication the general relationship between q (ME at maintenance) and k_f was used. The separate relationships between q and k_f for regrowth forages fed in the long form and for pelleted forages were used from Blaxter (1974). The relationship between ME concentrations in DM (M/D) and k_f (k_f = 0·0435 M/D) was the equation used from the Ministry of Agriculture, Fisheries & Food (1975) publication.

Both the Research Council and the Ministry equations gave predicted values of k_f which were higher for the CL but lower for the PL than the observed values. The separate relationships provided by Blaxter (1974) gave predicted values in close agreement with the measured values and also distinguished between the CL and PL, which was not the case for the Research Council and Ministry equations which gave similar predicted values for both physical forms. Forage diets processed by grinding and pelleting and fed as the only diet require separate classification from forage fed in the long form (Blaxter, 1974).

The digestion of CL and PL

Digestion studies with these same chopped and pelleted lucerne diets (Thomson *et al.* 1972; Coehlo da Silva *et al.* (1972) demonstrated that the pattern of energy digestion within the alimentary tract was different for the contrasting physical forms of lucerne prepared from the same crop. Energy digestion in the rumen was reduced and digestion in the small intestine increased for sheep fed on PL compared with CL. The reduction in energy digested in the rumen of sheep consuming PL implies a reduction in the production of volatile fatty acids (VFA) in the rumen and therefore a reduced contribution of VFA energy to energy available for metabolism in comparison with CL. The reticulo-rumen of lambs fed PL was smaller and weighed less than that of those fed on CL (Fig. 7). In the digestion experiment there were no differences in the molar proportions of the VFA in rumen liquor of sheep fed on CL and PL (Thomson *et al.* 1972), and subsequent experiments in which VFA production rate was measured on chopped and pelleted forage diets have confirmed that total VFA production is reduced, but there is no difference in VFA composition, when sheep are fed pelleted compared with chopped forage (Beever *et al.* 1971; Thomson & Beever, 1972).

The alterations in the pattern of energy digestion within the alimentary tract, resulting in increased post-ruminal digestion of energy, may have contributed to the more efficient utilization of the ME in PL compared with the CL (Thomson *et al.* 1972). Other work with forage diets has also demonstrated a reduction in the digestion of energy in the rumen and a marked increase in the amount of energy digested in the small intestine with grinding and pelleting when the diet was fed twice daily (Hinders & Owen, 1968; Beever *et al.* 1971; Beever *et al.* 1972; Thomson & Beever, 1972; Thomson, 1972), but not when fed at 3 h intervals (Hogan & Weston, 1967). Black (1971) has calculated, and Black & Tribe (1973) have demonstrated, the marked improvements in k_f which can be obtained when lambs digest a high proportion of the digested energy in the lower alimentary tract rather than in the rumen.

Altering the particle size distribution in forage by grinding and pelleting increases the rate of passage of particulate matter from the rumen (Blaxter *et al.* 1956) and reduces the microbial and increases the dietary protein in the total protein entering the duodenum of sheep fed PL compared with CL (Coehlo da Silva *et al.* 1972). In the analysis of a range of chopped and pelleted forage diets, Osbourn *et al.* (1976) observed that there was an increased flow of total amino acids at the duodenum per kg DM consumed in sheep fed on pelleted compared with chopped forage, and that an increased proportion of dietary protein escaped ruminal digestion when the forage was fed in the pelleted form. The combination of a reduction in energy absorbed as VFA and an increase in the contribution of absorbed energy from protein digested in the small intestine altered the value for protein energy : VFA energy absorbed. The alteration in the balance of nutrients absorbed in the alimentary tract was probably one of the major contributing factors to the increased k_f measured on the PL fed in the present experiment.

More methionine was apparently absorbed from the small intestine of sheep fed on PL compared with CL in the digestion experiment. The increase of 18% in methionine uptake was associated with a 16% higher retention of wool protein in the lamb experiment for animals fed on PL, but due to the high error attached to this measurement and the effect of wool chewing by lambs fed on pellets, the difference in wool growth rate was not significant.

The energy costs of eating and ruminating were calculated using the values given by Osuji *et al.* (1975) for sheep consuming a chopped or pelleted forage. The values given in Table 8 indicate a clear difference in the period of time spent on these activities by lambs consuming lucerne in the contrasting physical forms. However, the total energy cost amounted to only 4–6 kJ/MJ GE consumed and was unlikely to have been a major factor influencing the different k_f and NE values measured for CL and PL.

Grinding and pelleting forage normally leads to a reduction in digestibility but an increase in food consumption (Demarquilly & Journet, 1967). The size of the increase in k_f or NE with grinding and pelleting will be influenced by the digestibility of the diet, and the increase is greater for forage diets of low digestibility (Wainman *et al.* 1972; Greenhalgh & Wainman, 1972; Osbourn *et al.* 1976). The higher k_f and NE value of pelleted compared with chopped forage results in improved rates of live-weight, empty-body-weight and carcass-weight gain per unit of DM consumed for sheep fed pelleted forage (Paladines *et al.* 1964). The enhanced rate of gain achieved by lambs consuming pelleted forage, due to both higher intake and improved utilization, indicate, as in the calf experiments of Hodgson (1968), that substantial benefits can be obtained by feeding pelleted forage to young ruminants in the post-weaning phase of growth.

The authors would like to thank Mr D. Cole and Mr R. Watson for technical assistance and Mr R. J. Barnes for chemical analysis.

REFERENCES

American Society of Agricultural Engineers (1967). *Am. Soc. agric. Engrs.* p. 301.
Agricultural Research Council (1965). *The Nutrient Requirements of Farm Livestock No.* 2, *Ruminants.* London: H.M. Stationery Office.
Association of Official Agricultural Chemists (1969). *Official Methods of Analysis.* 11th ed. Washington, DC: Association of Official Agricultural Chemists.
Balch, C. C. (1969). *Proc. 3rd gen. Mtg eur. Grassld Fedr. Braunschweig* p. 245.
Balch, C. C., Broster, W. H., Rook, J. A. F. & Tuck, V. J. (1965). *J. Dairy Res.* **32**, 1.
Beever, D. E., Coehlo de Silva, J. F., Prescott, J. H. D. & Armstrong, D. G. (1972). *Br. J. Nutr.* **28**, 347.
Beever, D. E., Thomson, D. J. & Harrison, D. G. (1971). *Proc. Nutr. Soc.* **30**, 86A.
Black, J. L. (1971). *Br. J. Nutr.* **25**, 31.
Black, J. L. & Tribe, D. E. (1973). *Aust. J. agric. Res.* **24**, 763.
Blaxter, K. L. (1974). In *Nutrition Conference for Feed Manufacturers*, p. 3 [H. Swan and D. Lewis, editors]. London: Butterworths.
Blaxter, K. L. & Clapperton, J. L. (1965). *Br. J. Nutr.* **19**, 511.
Blaxter, K. L. & Graham, N. McC. (1956). *J. agric. Sci., Camb.* **47**, 207.
Blaxter, K. L., Graham, N. McC. & Wainman, F. W. (1956). *Br. J. Nutr.* **10**, 69.
Coehlo da Silva, J. F., Seeley, R. C., Thomson, D. J., Beever, D. E. & Armstrong, D. G. (1972). *Br. J. Nutr.* **28**, 357.
Crampton, E. W. & Maynard, L. A. (1938). *J. Nutr.* **15**, 383.
Demarquilly, C. & Journet, M. (1967). *Annls Zootech.* **16**, 123.
Fennessy, P. F., Woodlock, M. R. & Jagusch, K. T. (1972). *N.Z. Jl. agric. Res.* **15**, 795.
Forbes, E. B., Fries, J. A. & Braman, W. W. (1925). *J. agric. Res.* **31**, 987.
Grassland Research Institute (1961). *Research Techniques in use at the Grassland Research Institute, Hurley, Bull.* 45 Commonw. Bur. Past. Fld. Crops, Farnham Royal: Commonwealth Agricultural Bureaux.
Greenhalgh, J. F. D. & Wainman, F. W. (1972). *Proc. Br. Soc. Anim. Prod.* **1**, 6.
Hinders, R. G. & Owen, F. G. (1968). *J. Dairy Sci.* **51**, 1253.
Hodgson, J. (1968). A study of some factors influencing the intake of solid food by young calves. Ph D Thesis, University of Leeds.
Hogan, J. P. & Weston, R. H. (1967). *Aust. J. agric. Res.* **18**, 803.
Lawes, J. B. & Gilbert, J. H. (1861). *Jl. R. agric. Soc.* **21**, 1.
Meyer, J. H., Gaskill, R. L. Stoewsand, G. S. & Weir, W. C. (1959). *J. Anim. Sci.* **18**, 336.
Milford, R. (1965). Herbage digestibility and animal production. Ph D Thesis, University of Reading.
Ministry of Agriculture, Fisheries & Food (1975). *tech. Bull.* No. 33.
Osbourn, D. F., Beever, D. E., Thomson, D. J. (1976). *Proc. Nutr. Soc.* **35**, 191.
Osuji, P. O., Gordon, J. G. & Webster, A. J. F. (1975). *Br. J. Nutr.* **34**, 59.
Paladines, O. L., Reid, J. T., Van Niekerk, B. D. H. & Bensadoun, A. (1964). *J. Nutr.* **83**, 49.
Smith, J. S., Wainman, F. W. & Dewey, P. J. S. (1976). *Proc. Nutr. Soc.* **35**, 97A.
Thomson, D. J. (1963). *Publ. Eur. Ass. Anim. Proc.* no. 11, p. 319.
Thomson, D. J. (1968). The utilization of herbage diets by growing sheep. Ph D Thesis, University of Reading.
Thomson, D. J. (1972). *Proc. Nutr. Soc.* **31**, 127.
Thomson, D. J. & Beever, D. E. (1972). *Proc. Nutr. Soc.* **31**, 66A.
Thomson, D. J., Beever, D. E., Coehlo da Silva, J. F. & Armstrong, D. G. (1972). *Br. J. Nutr.* **28**, 31.
Thomson, D. J. & Cammell, S. B. (1971). *Proc. Nutr. Soc.* **30**, 88A.
Treacher, T. T. & Penning, P. D. (1971). *Outl. Agric.* **6**, 227.
Vermorel, M., Bouvier, J. C. & Demarquilly, C. (1974). *Publ. Eur. Ass. Anim. Prod.* no. 14, p. 213.
Wainman, F. W., Blaxter, K. L. & Smith, J. S. (1972). *J. agric. Sci. Camb.* **78**, 441.

Printed in Great Britain