Studies on the protein requirements of growing cattle

Effects of differing intakes of protein and energy on growth and nitrogen metabolism in young entire males

BY T. W. GRIFFITHS

The Agricultural Institute, Dunsinea, Castleknock, Co. Dublin, Irish Republic

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1. Forty-eight Friesian entire male cattle, with an initial live weight (LW) of 135 kg, were used in two experiments to measure the response to increasing levels of dietary protein (9–11 and 7·5–10·5 g nitrogen × 6·25/kg $LW^{0·75}$) at differing energy levels (800–900 kJ metabolizable energy (ME) kg $LW^{0·75}$) over 120-d periods. Digestibility and N balance measurements were also made during the experiments. The diets, which were based on barley and soya-bean meal, were individually fed twice daily.

2. In a third experiment, similar diets were given to four similar animals fitted with intestinal cannulas, at constant energy intake but with variations in dietary protein of 7·5–13·5 g N × 6·25/kg $LW^{0·75}$. Chromic oxide paper was used as a digesta marker.

3. Positive responses in LW gain and N balance to additional protein were found in both experiments but these were significant ($P < 0·05$) only in the second experiment and were associated with significant ($P < 0·01$) increases in the digestibility of modified acid-detergent fibre and ME intake.

4. Mean values, which were not significantly different between treatments, for the degradability of dietary protein in the rumen and the efficiency of microbial protein synthesis were 0·57 and 31·3 g/kg organic matter apparently digested in the rumen respectively. Corresponding values obtained by regression analysis were 0·56 and 28·2.

5. The results in general support the Agricultural Research Council (1980) proposals and suggest that undegraded dietary protein was not limiting in these experiments but that rumen-degradable protein levels were limiting on some treatments.

6. Regression analysis indicated that the mean response to additional protein (g LW gain/g N × 6·25) per kg LW was 0·52 in Expt 1 and 0·51 in Expt 2. These responses could be largely explained by increases in ME intakes.

7. Measurements of duodenal amino acid flow showed marked increases in essential amino acids (EAA) across the rumen. However, EAA flows, were not significantly increased at higher N intakes suggesting that protein *per se* was not limiting in these experiments.

The protein requirements of growing cattle have recently been reviewed by Geay (1980). Allowances recommended by various authors varied widely when expressed in terms of digestible crude protein (DCP), but there was a tendency for the more recent recommendations to be lower than earlier estimates. Some of this variation might be due to known limitations of DCP (Miller *et al.* 1977) and revised recommendations for protein requirements have recently been published (e.g. Agricultural Research Council (ARC), 1980). These recommendations are based on the concepts of rumen-degradable protein (RDP) to satisfy the requirements of the microflora and undegraded dietary protein (UDP) plus microbial protein to meet the requirements of the animal. Whilst these proposals give detailed requirements for various classes of animals and take into account the effect of energy intake on the synthesis of microbial protein, they are based to a considerable extent on information obtained with surgically-modified animals, usually sheep, and consider protein primarily as a source of essential amino acids (AA). In order to apply the ARC (1980) recommendations, it is necessary to have information on the metabolizability of dietary energy and the degradability of dietary protein. Measurements of degradability are technically difficult in vivo, and in vitro results vary with the nature of the diet and need correction for retention time in the rumen (Ganev *et al.* 1979; Siddons & Paradine, 1981). A further determinant of animal production is the supply of individual AA to the small

intestine and it has been pointed out by Miller (1973) that protein requirements must eventually be expressed in terms of essential AA. It is therefore recognized that models such as that proposed by the ARC (1980) require extensive validation and will be subject to periodic revision (Smith, 1982).

The work described in the present paper consists of an evaluation of the responses in young entire male cattle to varying levels of dietary protein in terms of crude protein (CP, nitrogen × 6·25), DCP, RDP and UDP at different levels of dietary energy intake. Growth, digestibility and N balance techniques were used and these were supported by measurements of degradability, efficiency of microbial protein synthesis and duodenal AA flow using similar animals fitted with intestinal cannulas. Whilst the results support the concept of RDP and UDP, they illustrate the difficulties of defining dietary requirements for RDP in growing cattle.

EXPERIMENTAL

Animals and their management

Twenty-four Friesian entire male cattle with a mean initial live weight (LW) of 135 kg were used in each of two growth and balance experiments (i.e. Expts 1 and 2). Animals were assigned to blocks in groups of six according to LW and within each block were allocated at random to treatments. In each experiment, alternate blocks (i.e. a total of twelve animals) were used for digestibility and balance studies. All animals remained on experiment for 120 d. Food intake was measured daily and LW weekly. Four similar animals fitted with simple cannulas in the rumen and proximal duodenum were used in Expt 3 for measurements of duodenal flow of organic matter (OM) and N. Expt 3 was carried out in two phases using a generalized randomized block design where each phase corresponded to a block. Within each block, each of three treatments were given to two animals in random order. Animals were normally housed in stalls on sawdust bedding with free access to water and given food twice daily. However, selected animals were transferred to metabolism stalls with facilities for the separation and collection of urine and faeces and for the sampling of duodenal contents.

Treatment and diets

Each animal in all experiments was fed individually and given a basal diet of 0·75 kg hay and 0·75 kg ground and pelleted dried grass daily. In Expts 1 and 2 treatments consisted of differing levels of dietary energy (kJ metabolizable energy (ME) kg $LW^{0·75}$) and protein (g N × 6·25/kg $LW^{0·75}$) arranged in 3 × 2 factorial layouts as shown in Table 1. These treatments were designed to supply energy levels sufficient to support rates of LW gain of 0·75–1·0 kg/d but with the lowest protein intake being near (Expt 1) or below (Expt 2) ARC (1980) recommendations. The nutritional levels were achieved by alterations (approximately every 28 d) in the amounts of supplementary feeds offered. In Expt 1, adjustments were made to the levels of barley and concentrate mixtures A and B, (based on soya-bean meal; for detailed composition, see Table 2). Within any protein level (P2, P3) increases in energy content (E1, E2, E3) were made by increasing the amount of barley and decreasing the amount of concentrate fed. Concentrate A was used for the P2 diets and concentrate B for the P3 diets. In Expt 2, increases in energy intake were made by increasing the amount of barley and protein levels were achieved by the simple substitution of 0·25 and 0·5 kg soya-bean meal for barley/d. Expt 3 used similar diets to Expt 2 and measured the effects on duodenal flow of nutrients of the substitution of 0·5 and 1·0 kg soya-bean meal for barley at a constant feed intake of 5 kg/d. This level was chosen as being appropriate to the use of chromic oxide as a whole digesta marker (Beever *et al.* 1978). All diets were supplemented with (per kg non-basal diet): retinol equivalent 0·9 mg, cholecalciferol 19 mg.

Table 1. *Main dietary treatments and approximate dietary levels of energy and protein in each experiment*

Treatment...	Energy		Protein	
Expt	Diet	(MJ ME/kg $LW^{0.75}$)	Diet	(g Nitrogen × 6·25/kg $LW^{0.75}$)
1	E1	800		
	E2	850	P2	9·0
	E3	900	P3	11·0
2	E1	800	P1	7·5
	E2	850	P2	9·0
			P3	10·5
3	E2	825	P1	7·5
			P2	10·5
			P3	13·5

ME, metabolizable energy; LW, live weight.
For details of treatments and diets, see p. 134.

Table 2. *Mean values for the composition of the feed ingredients used in the experiments (g/kg DM)*

Expt	Ingredient	OM	MADF	Nitrogen × 6·25	GE (MJ)
1	Hay	941	372	80	18·6
	Dried grass	931	294	124	18·6
	Barley	978	59	99	18·3
	Concentrate A*	922	68	162	17·5
	Concentrate B†	908	80	298	17·9
2 and 3	Hay	925	379	75	18·4
	Dried grass	914	283	99	18·1
	Barley‡	970	65	105	18·3
	Soya-bean meal	934	101	443	19·3

DM, Dry matter; OM, organic matter; MADF, modified acid-detergent fibre; GE, gross energy.
* Composition (g/kg): barley 710, soya-bean meal 200, molasses 40, calcium carbonate 30, sodium chloride 20.
† Composition (g/kg): barley 310, soya-bean meal 600, molasses 40, $CaCO_3$ 30, NaCl 20.
‡ Contained (g/kg): $CaCO_3$ 5, NaCl 5.

Experimental procedures

During each 120 d feeding period in Expts 1 and 2 alternate blocks were transferred to metabolism stalls in groups of six animals for separate collection of urine and faeces over 8 d periods (Griffiths, 1982) on two occasions after approximately 30 and 90 d on experiment. In Expt 3 the animals with duodenal cannulas were housed in metabolism stalls for the duration of the experiment. Each of these animals received 2 × 10 g Cr_2O_3 paper/d (Corbett *et al.* 1960) as an indigestible marker for at least 7 d before and during the 3 d sampling period. Diets were given in two equal portions at 12 h intervals to each animal in random order. Each diet was given for at least 11 d before sampling began. Samples of duodenal contents were collected manually over 12 h at intervals of 2 h. These were immediately deep-frozen and subsequently dried at 40°.

Chemical analyses

The gross energy (GE), OM, modified acid-detergent fibre (MADF) and N content of feeds, duodenal digesta (DD) and faeces samples, the N content of urine samples and the ammonia N content of DD were determined as previously described (Griffiths & Smith, 1974). The Cr_2O_3 content of the administered paper and DD were determined using an automated colorimetric technique (Christian & Coop, 1954). AA analysis of feed and DD was carried out by ion-exchange chromatography (Moore *et al.* 1958) using an automatic AA analyser (Locarte Ltd, London). Samples of feeds and DD were hydrolysed using 6 M-hydrochloric acid containing mercapto-ethanol (1:2000, v/v) and under an atmosphere of N_2 to minimize the losses of methionine (Keutmann & Potts, 1969). The standard AA programme was modified to obtain separation of 2,6-diaminopimelic acid (DAPA) from methionine and isoleucine.

Calculation of results

ME intakes were calculated from GE intakes and faecal losses and estimated urinary and methane energy losses (Griffiths, 1978, 1982). The flow of constituents through the duodenum was calculated using Cr_2O_3 as an indigestible marker (MacRae & Armstrong, 1969). Bacterial protein synthesis was calculated from the duodenal passage of DAPA assuming that bacteria contain 44 mg DAPA/g N. This value was chosen as being typical for mixed hay concentrate diets (Hutton *et al.* 1971; Ling & Buttery, 1978; Chamberlain *et al.* 1982). The flow of undegraded food protein to the intestine was estimated by difference from duodenal non-ammonia N (NAN) after an arbitrary correction of 2·7 g N/kg DM passing the duodenum had been made for protein of endogenous origin (Van't Klooster & Rogers, 1969).

Statistical assessment

Values from Expts 1 and 2 were subjected to analysis of variance as a 3×2 factorial. Effects of blocks, treatments and interactions were removed. Comparisons between treatment means were based on 15 df. In the digestibility and balance values each collection period was considered to be independent. In Expt 3, the effects of blocks, treatments and treatments × blocks were removed in the analysis of variance. The interaction term being non-significant, it was combined with the residual component to form experimental error (8 df). A programme for parallel regression was used to fit models to the values from Expts 1 and 2 for the relationship between LW gain and protein and energy intake. Duodenal flow measurements were analysed using the regression equation of Hvelplund *et al.* (1976) which is of the form $Y = A + b/X$ where A represents the proportion of dietary N entering the small intestine undegraded, b the amount of microbial N synthesized/kg DM ingested, Y the value of the ratio, duodenal NAN:feed N and X the N content of the diet (g/kg DM).

RESULTS

Chemical composition of the diets

The chemical composition and the GE of the feed ingredients used in the experiments are given in Table 2. Dried grass with a low protein content was used in Expts 2 and 3; the soya-bean meal used in these experiments also had lower protein and higher fibre contents than normally found.

Food intake and LW gain

One animal was withdrawn from Expt 1 after 83 d due to chronic bloat and one animal died accidentally after 106 d in Expt 2; otherwise the health of the animals was good throughout. Missing values were calculated for the digestibility data in Expt 2. Mean values

Table 3. *Expts 1–3. Feed intake, crude protein (nitrogen × 6·25; CP) and estimated metabolizable energy (ME) intakes for the main treatments and initial live weight (LW) and LW gain in Expts 1 and 2*

(Values in parentheses indicate no. of animals per treatment)

Expt	Treatment...	Energy levels				Protein levels				df	Significance of difference between main treatment means	
		E1	E2	E3	SEM	P1	P2	P3	SEM		Energy	Protein
1		(8)	(8)	(8)			(12)	(12)				
	Initial LW (kg)	133	135	132	1·7		133	133	1·4	15	NS	NS
	LW gain (kg/d)	0·82	0·95	1·03	0·026		0·91	0·96	0·022	15	**	NS
	Intake											
	Total (kg DM/d)	3·90	4·24	4·53	0·010		4·22	4·22	0·008	15	***	NS
	Barley (kg DM/d)	1·64	2·16	2·62	0·009		2·14	2·14	0·007	15	***	NS
	+Concentrate (kg DM/d)	0·93	0·76	0·59	0·009		0·76	0·76	0·008	15	***	NS
	CP (kg DM/d)	0·51	0·52	0·53	0·003		0·47	0·57	0·002	15	NS	***
	Estimated ME (MJ/d)	42·30	46·40	49·60	0·110		45·50	46·70	0·090	15	***	*
2		(12)	(12)			(8)	(8)	(8)				
	Initial LW (kg)	138	140		1·6	139	139	139	2·0	15	NS	NS
	LW gain (kg/d)	0·78	0·90		0·024	0·78	0·84	0·90	0·030	15	**	*
	Intake											
	Total (kg DM/d)	3·78	4·16		0·019	3·95	3·95	4·00	0·023	15	***	NS
	Barley (kg DM/d)	2·26	2·64		0·016	2·65	2·44	2·26	0·019	15	***	***
	Soya-bean meal (kg DM/d)	0·22	0·22		0·001	0·00	0·21	0·43	0·002	15	NS	***
	CP (kg/d)	0·45	0·49		0·002	0·39	0·47	0·55	0·003	15	***	***
	Estimated ME (MJ/d)	41·30	45·50		0·21	41·90	44·00	44·20	0·250	15	***	***
3						(4)	(4)	(4)				
	Intake											
	Total (kg DM/d)					4·26	4·26	4·27	0·003	8		NS
	Barley (kg DM/d)					2·94	2·52	2·10	0·001	8		***
	Soya-bean meal (kg DM/d)					0·00	0·43	0·87	0·002	8		***
	CP (kg/d)					0·44	0·59	0·74	0·006	8		**

DM, dry matter; NS, not significant.

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

† Concentrate A for P2 diets and concentrate B for P3 diets.

Table 4. *Expts 1 and 2. Apparent digestibilities of organic matter (OM), modified acid-detergent fibre (MADF), gross energy (GE) and nitrogen, and N balance and estimated metabolizable energy (ME) intakes for the main treatments*

(Values in parentheses indicate no. of animals per treatment)

Expt	Treatment...	Energy levels				Protein levels				df	Significance of the difference between main treatment means	
		E1	E2	E3	SEM	P1	P2	P3	SEM		Energy	Protein
1		(4)	(4)	(4)			(6)	(6)				
	Apparent digestibility											
	OM	0·71	0·71	0·71	0·005		0·70	0·72	0·004	15	NS	***
	MADF	0·33	0·31	0·30	0·015		0·29	0·34	0·012	15	NS	**
	GE	0·68	0·68	0·68	0·007		0·67	0·69	0·005	15	NS	*
	N	0·66	0·64	0·60	0·014		0·59	0·68	0·011	15	*	***
	N intake (g/d)	83·50	84·00	84·40	1·13		76·10	91·90	0·92	15	NS	***
	Faecal N (g/d)	27·40	29·50	33·10	0·96		30·80	29·30	0·78	15	**	NS
	Urinary N (g/d)	30·80	27·30	24·50	2·01		21·50	33·60	1·64	15	NS	***
	N balance (g/d)	25·30	27·20	26·80	2·34		23·80	29·10	1·91	15	NS	NS
	ME intake (MJ/d)	43·50	47·40	50·40	0·67		46·50	47·70	0·55	15	***	NS
	ME (MJ/kg DM)	10·90	11·00	10·90	0·13		10·80	11·10	0·10	15	NS	NS
2		(6)	(6)			(4)	(4)	(4)				
	Apparent digestibility											
	OM	0·70	0·70		0·004	0·68	0·71	0·71	0·005	14	NS	***
	MADF	0·29	0·30		0·011	0·22	0·34	0·32	0·014	14	NS	***
	GE	0·67	0·67		0·005	0·65	0·68	0·68	0·006	14	NS	***
	N	0·62	0·61		0·009	0·55	0·63	0·67	0·010	14	NS	***
	N intake (g/d)	75·60	82·70		0·22	67·50	79·10	90·80	0·27	14	***	***
	Faecal N (g/d)	28·20	31·30		0·57	29·70	29·10	30·40	0·80	14	**	NS
	Urinary N (g/d)	22·50	22·00		1·03	13·60	24·00	29·20	1·26	14	NS	***
	N balance (g/d)	24·90	29·40		1·18	24·30	26·00	31·20	1·45	14	*	*
	ME intake (MJ/d)	43·80	48·40		0·40	44·60	46·90	46·70	0·49	14	***	**
	ME (MJ/kg DM)	11·00	10·90		0·97	10·60	11·10	11·10	0·12	14	NS	*

DM, dry matter; NS, not significant.
* $P < 0·05$; ** $P < 0·01$; *** $P < 0·001$.

Table 5. *Expt 3. Organic matter (OM) and nitrogen intakes, OM, total N, non-ammonia N (NAN), bacterial N and undegraded food N flowing through the duodenum, the effeciency of microbial protein synthesis and the apparent degradability of dietary protein for diets used*

(Mean values for four animals)

Protein level*...	P1	P2	P3	SEM	df
OM intake (kg/d)	4·05	4·05	4·05	0·003	8
N intake (g/d)	70	95	119	1·05	8
Flow at the duodenum					
OM (kg/d)	2·10	1·99	2·03	0·053	8
Total N (g/d)	106	123	124	1·5	8
NAN (g/d)	98	115	116	1·9	8
Bacterial N (g/d)	62	65	63	4·0	8
Undegraded food N†	29	43	46	2·6	8
Efficiency of microbial protein synthesis (g N/kg OM apparently digested in the rumen)	32	32	31	2·8	8
Apparent degradability of dietary protein	0·57	0·54	0·61	0·05	8

* For details, see Table 1.

† Undegraded food N (g/d) = duodenal NAN − (microbial N + 2·7 × duodenal dry matter (kg)).

for daily DM, crude protein (CP) and estimated ME intakes and LW gains for each main treatment in Expts 1 and 2 are given in Table 3 together with feed intake values for Expt 3. (ME intakes were calculated from values obtained in the digestibility trials, see p. 136.) Interactions were not significant and the significance of the main effects are given. In the first experiment, DM intake and LW gains were significantly higher on the higher energy diets ($P < 0·01$). Increased protein intake had no significant effect on LW gains. In the second experiment, LW gains were significantly increased both by the higher energy ($P < 0·01$) and the higher protein diets ($P < 0·05$). In the third experiment, DM intakes were similar but CP intakes were significantly different ($P < 0·001$).

Digestibility and N balance

Table 4 summarizes the mean values for the apparent digestibility of OM, MADF, N and GE, the N balance results and the estimated ME intake for the main dietary treatments used in Expts 1 and 2. Again, interactions were not significant and the significance of the main effects is given. Variations in energy intake had no significant effect on the digestibility of OM, MADF or GE in either experiment. Lower protein intakes depressed the digestibility of MADF in both experiments ($P < 0·001$ in Expt 2) with consequent depressions in the digestibility of OM and GE. Apparent digestibility of N was also significantly depressed on the lower protein diets in both experiments ($P < 0·001$).

Higher energy intakes were associated with higher faecal N excretion and higher N intakes with higher urinary N excretion. Although N balance was increased at the higher protein intakes in Expt 1, the effect was not significant. However, N balance was significantly increased at the highest protein intake in Expt 2 ($P < 0·05$). Estimated ME intakes (MJ/kg DM) were significantly ($P < 0·05$) depressed on the lowest protein diets in Expt 2 due to the effect on digestibility mentioned previously.

Table 6. *Expt 3. The quantities (g/d) of amino acids consumed and entering the small intestine of cattle for each treatment*

(Mean values for four animals)

	Consumed				Entering small intestine				
Treatment*...	P1	P2	P3	SEM	P1	P2	P3	SEM	df
Aspartic acid	26·6	44·1	61·6	0·13	50·5	58·8	56·4	2·33	8
Threonine	13·1	17·3	21·5	0·04	23·4	26·4	25·2	0·38	8
Serine	17·0	23·8	30·7	0·06	25·2	28·4	27·0	0·54	8
Glutamic acid	78·4	98·8	119·2	0·20	60·3	68·3	64·1	3·22	8
Proline	33·9	36·8	39·8	0·05	17·4	21·3	20·0	0·83	8
Glycine	15·5	20·7	25·9	0·05	47·9	50·0	50·2	1·63	8
Alanine	17·8	23·3	28·7	0·05	30·2	33·7	33·6	0·59	8
Valine	12·9	15·2	17·5	0·02	18·9	19·9	20·4	0·35	8
Methionine	4·2	5·4	6·6	0·01	7·8	8·7	8·8	0·42	8
Isoleucine	11·5	14·1	16·6	0·03	15·4	17·4	16·7	0·83	8
Leucine	26·0	34·8	43·6	0·08	32·4	36·3	36·1	0·91	8
Tyrosine	13·7	18·1	22·5	0·04	23·3	24·5	26·4	0·91	8
Phenylalanine	18·1	23·7	29·3	0·05	23·8	27·1	29·8	1·69	8
Histidine	7·3	10·6	13·9	0·03	9·0	10·0	10·2	0·29	8
Lysine	14·0	23·1	32·3	0·07	31·3	34·9	35·8	1·64	8
Arginine	16·8	26·6	36·3	0·08	19·2	23·4	22·1	0·41	8
Total	327	436	546	0·8	439	493	486	12·6	8

* For details, see Table 1.

Duodenal flow of OM, N and AA

Mean values for OM and N intake and the duodenal flow of OM, total N, NAN, microbial N and undegraded feed N on diets used in Expt 3 are given in Table 5. There were no significant differences between treatments in OM intake or duodenal OM flow. Total N, NAN and undegraded feed N flows were all significantly ($P < 0·05$) higher on the higher protein diets. Differences in the efficiency of microbial protein production per kg OM apparently digested in the rumen (OMDR) and apparent degradability of dietary protein were not significant. There was a net gain of N between the mouth and the duodenum on all diets. The derived regression equation (Hvelplund *et al.* 1976) for the duodenal N flow measurements was:

$$Y = 0·44(\text{SE } 0·15) + 14·1(\text{SE } 3·05)/X \quad (r^2\ 0·66)$$

This would suggest that the mean degradability of dietary protein was 0·56 and that the mean efficiency of microbial protein synthesis was equivalent to 28 g/kg OMDR since on average 50% of the OM disappeared between the mouth and the duodenum. Table 6 shows the dietary intake of individual AA and the corresponding flow at the duodenum for the three diets used in Expt 3. Intakes of all AA were significantly different ($P < 0·001$) on each treatment. There was a net gain of most essential AA, in particular threonine, methionine and lysine, between the mouth and the duodenum. Duodenal flows of all AA were similar on the P2 and P3 diets but were lower on the P1 diet. Treatment differences were not significant for threonine, methionine or lysine and were significant only for arginine ($P < 0·01$).

Table 7. *Expts 1 and 2. Mean values for the mean live weight (LW;kg) of the animals, the metabolizability* (Q) *of the diets and the daily intake (kg) of digestible crude protein (DCP), undegraded dietary protein (UDP) and rumen-degradable protein (RDP) for each treatment*

	Expt 1						Expt 2					
Energy level...	E1		E2		E3		E1			E2		
Protein level...	P2	P3	P2	P3	P2	P3	P1	P2	P3	P1	P2	P3
LW	182	179	188	195	193	195	180	185	191	189	193	197
Q	0·59	0·59	0·59	0·59	0·60	0·61	0·57	0·61	0·61	0·59	0·60	0·60
DCP	0·30	0·38	0·30	0·36	0·30	0·34	0·20	0·28	0·36	0·23	0·31	0·37
UDP	0·18	0·23	0·19	0·23	0·19	0·23	0·15	0·18	0·21	0·16	0·19	0·23
RDP	0·27	0·34	0·29	0·35	0·29	0·34	0·22	0·27	0·32	0·25	0·29	0·34

DISCUSSION

The requirements of ruminants for protein have traditionally been derived by feeding increased dietary levels with the object of determining the point of maximum response (Miller, 1973). The results of the experiments reported in the present paper and other work (e.g. Kay *et al.* 1968; Griffiths, 1978) illustrate the limitations of this approach since in all cases small positive responses were found in both LW gain and N retention to additional protein. These responses were significant only in Expt 2 where associated effects on digestibility were also found.

Measurements of the in vivo degradability of dietary protein, necessary for the validation of the ARC (1980) recommendations, require reliable estimates of duodenal OM flow and microbial protein synthesis. In addition, assumptions regarding endogenous N secretion are important particularly where low-N diets are used. The values for endogenous N used in the present work were similar to those recently suggested by Ørskov & MacLeod (1983). Values obtained for the efficiency of microbial protein synthesis were near to the value of 30 g N/kg OMDR used by the ARC (1980). There was a high error associated with the measurement of bacterial N flow and of degradability of dietary protein in the present work, and treatment differences were not significant. Similar variation has also been found by other workers (Thomson *et al.* 1981; Chamberlain *et al.* 1982) for those measurements which are dependent on the use of markers. The estimation of microbial protein synthesis from a single DAPA:N value taken from other work may contribute to this error since there is abundant evidence that DAPA:N values in rumen bacteria vary with the nature of the diet (Ling & Buttery, 1978). However, the agreement between the value for degradability obtained using this method and the regression technique of Hvelplund *et al.* (1976) suggest that the error associated with the use of a single DAPA:N value may not have been high in this case. The ARC (1980) allocate feed ingredients to broad groups only for protein degradability. It is suggested that the degradability of protein in these experiments should be taken as 0·60, i.e. a rounded mean value derived from both DAPA and regression analysis.

Mean values for the mean LW of the animals, the metabolizability (*Q*) of the diets and the daily intake of DCP, UDP and RDP for each treatment in both experiments are presented in Table 7. Compared with ARC (1980) recommendations for bulls of large mature size (LW 200 kg, *Q* 0·6), it would appear that UDP was not limiting in these experiments. It is, however, probable that RDP was limiting on the lower protein diets since there was a significant depression in the digestibility of MADF in both experiments and

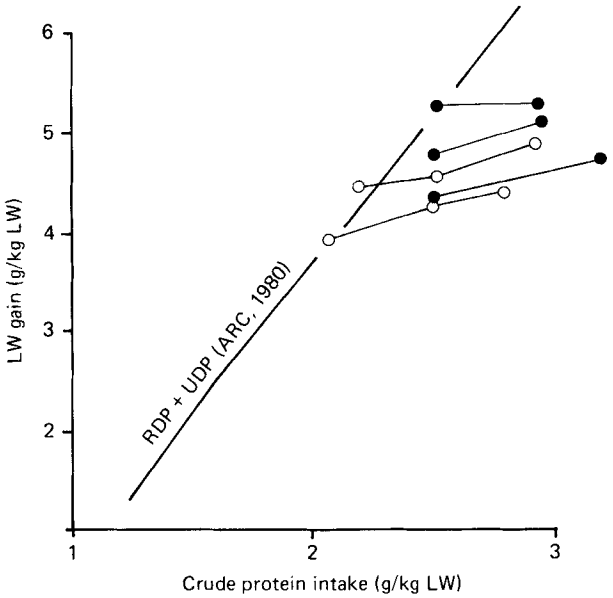

Fig. 1. Relationships between treatment mean values for crude protein (nitrogen × 6·25) intake and live weight (LW) gain in Expt 1 (●) and Expt 2 (○) compared with Agricultural Research Council (ARC, 1980) recommendations for rumen-degradable protein (RDP) and undegraded dietary protein (UDP) for animals of 200 kg LW.

the RDP levels were in general below the ARC (1980) recommendations. DCP levels agree with the results of Andersen & Foldager (1980) but were in general lower than most recommended values quoted by Geay (1980). It is of interest to note that there was a close similarity between DCP and RDP values.

The relationship between protein intake (RDP + UDP) and LW gain, both scaled for LW, has been plotted in Fig. 1 along with ARC (1980) recommendations (bulls of large mature size, 200 kg LW, Q 0·6). These values broadly fit the model of Balch (1967) for situations where energy is limiting. Regression analyses show that within each experiment the response in LW gain to additional CP was not significantly different at each energy level and the results could be represented by parallel equations. The mean response in LW gain (g/kg LW) to additional CP (g/kg LW) was 0·52 (SE 0·20) in Expt 1 and 0·51 (SE 0·17) in Expt 2. These responses, although small in practical terms, can be largely explained by differences in ME intake. Recommended allowances (ARC, 1980) suggest a ME requirement of approximately 18 MJ/kg LW gain for animals of this type.

The ideal system for calculating the N requirements of ruminants must provide estimates of the total and individual AA absorbed from the small intestine, and information on duodenal flow of AA is but a first step. Whilst there is considerable information on duodenal flow of AA in sheep and dairy cows, there are few values for growing cattle of around 200 kg LW (Thomson *et al.* 1981). The results presented agree broadly with the values of McMeniman & Armstrong (1979) for animals of similar LW and range of OM and N intakes. It is possible that methionine might be the first limiting AA on diet P1 in Expt 3 since levels of lysine and threonine were well above those suggested by Fenderson & Bergen (1975). However, the lack of a significant difference between treatments for the duodenal flow of methionine suggests that AA supply *per se* was not limiting in these experiments.

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