Studies of protein requirements of ruminants

4.* Live-weight changes of two breeds of African cattle given three levels of dietary protein each with varying amounts of digestible energy

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The results of previous work (Elliott, 1963; Elliott & Topps, 1963*a*, *b*) have indicated that, under certain conditions, protein requirements for maintenance of beef cattle are much lower than is generally recognized. Differences in requirements between breeds are apparently small, but composition of the diet appears to have an important effect on efficiency of nitrogen utilization. In feeding trials of 15 weeks' duration (Elliott & Topps, 1963*b*), large differences occurred in live-weight gain of steers when they were given approximately equal amounts of digestible crude protein contained in diets which differed widely in digestible energy content. However, in that trial, variations in the energy content of the diets were obtained by varying the proportions of roughage to concentrate and it was not possible to ascertain whether one or both factors (i.e. amount of digestible energy or the ratio of roughage to concentrate in the diet) affected protein utilization. Elliott & Topps (1964*a*) have shown with sheep that the ratio of roughage to concentrate in diets has an effect and that, as the proportion of roughage is increased, increasing amounts of digestible N are required for N equilibrium. The trial now reported was carried out to assess the effect of level of intake of digestible energy on protein requirements of African cattle. The digestible energy was provided by diets that contained almost equal proportions of roughage to concentrate.

EXPERIMENTAL

Animals and diets. Eighteen Africander and eighteen Mashona steers, aged approximately 2 years, were used. Two animals of each breed were allocated at random to nine different levels of energy and protein feeding. The nine levels of feeding were arranged factorially to provide three levels of dietary protein combined with three levels of digestible energy. The three levels of protein were 33, 66 and 99% of the level of digestible crude protein (DCP) advocated by Brody (1945) for maintenance, and the levels of digestible energy were 66, 100 and 133% of Brody's maintenance

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standard for energy, expressed as total digestible nutrients (TDN). Brody's recommended allowances for maintenance are 3·65 g DCP/kg $W^{0.73}$ and 35·2 g TDN/kg $W^{0.73}$, where W = body-weight.

Variations in the level of dietary protein and in TDN intake were obtained by varying the relative amounts of ingredients in the diets and by altering the amounts of food provided.

The diets, the detailed compositions of which are shown in Table 1, were composed of approximately equal parts of roughage and concentrate. All ingredients were analysed for crude protein content and the results used in the initial formulation of the diets. The ingredients were finely ground and thoroughly mixed. The mixtures were sampled and these samples analysed for crude protein content. It was found that the protein content of nearly all the mixtures differed from the content originally calculated from the composition of the ingredients. Either cassava or groundnut cake was added to the mixtures to obtain diets with the desired protein content. The diets were pelleted to prevent selection by the steers of the more palatable components. An intramuscular injection of approximately 24000 i.u. vitamin A/100 lb body-weight was given to the steers at monthly intervals during the trial.

Methods. The diets were given to the steers for 18 weeks, the first 2 of which provided a preliminary period for stabilization of 'gut-fill'. The steers were weighed initially on 2 successive days and these weights were used to calculate the amount of food each animal was offered. The steers were weighed again at the end of the preliminary period and these weights were used as initial weights for the trial. Further weighings were made weekly during the ensuing 16 weeks.

The animals were housed in individual pens and were fed once daily at 7 am. The amount of a particular diet given was calculated from its DCP and TDN content (obtained from digestibility trials with sheep), the metabolic body size ($W^{0.73}$) of the steer and the nutritional treatment to which the animal had been allocated. This scale of feeding was adhered to throughout the trial, irrespective of weight changes. Waste food from a meal was removed and weighed daily immediately before the next meal. Samples of food were taken each day, bulked over 7 days and analysed for dry matter and crude protein content. Dry matter was determined by heating a sample to constant weight at 105° and crude protein content by a macro-Kjeldahl method.

RESULTS

Intake of food. Intakes of dry matter and digestible nutrients, expressed in g/kg $W^{0.73}$, are given in Table 2. The body-weight was taken as the mean of the weights at the beginning and at the end of the trial. Most of the diets were readily eaten, but some animals refused small amounts of two diets, both of which were low in protein and high in digestible energy. On average, the two breeds ate almost the same amounts of food and digestible nutrients. However, slight deviations occurred from planned levels of nutrient intake in the amounts eaten by the various groups. Animals given the highest levels of TDN and DCP (133 and 99% of Brody's standards respectively) obtained less than the prescribed amounts, whereas those given the lowest levels of

Table 1. *Crude protein content and constituents (%) of nine diets supplying steers with three levels of digestible crude protein (DCP), each at three levels of total digestible nutrients (TDN)*

Level of feeding (% of Brody's standards*)		Crude protein content of dry matter of diet	Constituent								
DCP	TDN		Rhodes grass hay	Lucerne hay	Cassava	Maize	Maize bran	Molasses	Groundnut cake	Distillers residue†	Mineral mixture‡
33	66	6·8	46·1	8·8	24·6	6·7	1·8	5·8	4·1	0·9	1·2
	100	5·6	47·0	5·7	27·6	6·2	0·7	7·3	3·0	1·1	1·4
	133	5·0	50·6	3·2	28·2	6·8	0·6	6·3	2·1	0·9	1·3
66	66	10·4	36·1	18·1	18·7	6·5	4·5	6·0	7·9	0·9	1·3
	100	8·2	39·7	11·8	24·1	5·9	2·4	7·9	5·5	1·2	1·5
	133	6·6	42·4	8·4	26·0	5·6	2·1	8·4	4·2	1·3	1·6
99	66	13·6	24·9	28·6	12·0	—	6·7	6·7	12·7	1·0	1·3
	100	10·1	32·2	18·4	20·0	—	4·2	8·4	8·4	1·3	1·5
	133	8·7	36·4	13·4	23·8	—	2·7	8·9	6·2	1·3	1·8

* Levels of feeding are expressed as percentages of the allowance suggested by Brody (1945) for maintenance (see p. 520).

† Distillers residue was derived from the alcoholic fermentation of molasses.

‡ Mineral mixture was composed of 50 % common salt, 48 % bone meal and 2 % ground limestone. The limestone contained 2·14 g ferrous sulphate ($FeSO_4.7H_2O$), 5·00 g copper sulphate ($CuSO_4.5H_2O$), 0·31 g cobalt sulphate ($CoSO_4.5H_2O$) and 0·04 g potassium iodide (KI) per kg.

TDN and DCP obtained more than was planned. These discrepancies may be accounted for by changes in live weight of animals during the trial and by differences in gut-fill between groups, either of which would influence mean weights of animals.

Table 2. *Mean values for intake of dry matter (DM), digestible crude protein (DCP) and total digestible nutrients (TDN) for groups of four steers given nine different diets*

Level of DCP*	Level of TDN*	Daily intake (g/kg $W^{0.73}$) DM	DCP	TDN
33	66	43·9	1·36	26·3
	100	61·9	1·25	37·1
	133	78·4	1·21	47·0
66	66	42·3	2·69	25·4
	100	60·4	2·66	36·2
	133	75·4	2·20	45·2
99	66	42·2	3·91	25·3
	100	59·5	3·60	35·7
	133	75·3	3·61	45·2
Mean values for eighteen Mashona steers		59·7	2·49	35·8
Mean values for eighteen Africander steers		60·2	2·50	36·1
Pooled SD		±1·32	±0·05	±0·75

W, body-weight.
* Expressed as a percentage of Brody's (1945) standard for maintenance.

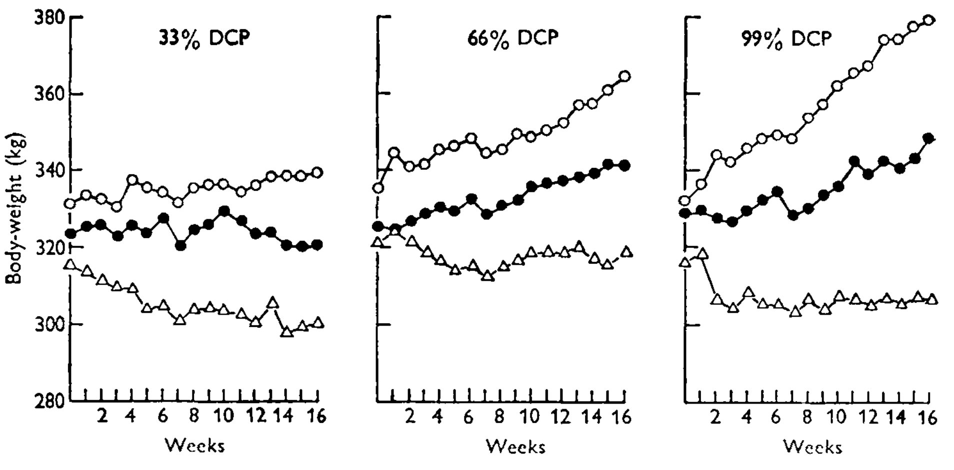

Fig. 1. Mean weekly body-weights of groups of four steers given three levels of digestible crude protein (DCP), each with three levels of total digestible nutrients (TDN). Levels of DCP and TDN are expressed as a percentage of Brody's (1945) standard for maintenance. ○—○, 133% TDN; ●—●, 100% TDN; △—△, 66% TDN.

Changes in body-weight. Mean live weights of the animals in the nine groups during the trial are shown graphically in Fig. 1, and the overall growth performance of the groups of steers is summarized in Table 3. Changes in live weight were approximately rectilinear for all the groups except those given the lowest level of TDN. At this level of energy feeding, weight losses were appreciable in the first few weeks but became progressively less towards the end of the trial. In particular, there was a marked initial fall in weight in the group that received the lowest level of TDN with the greatest amount of DCP. The mean change of live weight of −0·09 kg/day of this group (Table 3) was due entirely to this decrease. Effects due to changes in gut contents should have been largely eliminated by the 2-week stabilization period. Thus, with the possible exception of the group specified above (66 % TDN with 99 % DCP), changes in weight during the trial might be expected to have been due to changes in empty body weight rather than in gut contents. Since a fixed scale of feeding based on initial weight was adhered to, changes in body-weight, particularly of steers given the greatest amounts of TDN and DCP, resulted in appreciable alterations in the level of feeding per unit metabolic body size. For steers that gained the most weight there was a reduction in the level of feeding of 9·3 % between the beginning and end of the trial, whereas for steers that lost the most weight the corresponding change was an increase of 6·3 %.

Table 3. *Mean values for body-weights and weight changes of groups of four steers given nine different diets for 16 weeks*

Level of DCP intake*	Level of TDN intake*	Body-weight (kg) Initial (kg)	Final (kg)	Change (kg)	Mean daily change (kg)
33	66	315	300	−15	−0·14
	100	323	320	−3	−0·03
	133	331	339	8	0·07
66	66	321	318	−3	−0·03
	100	325	341	16	0·14
	133	335	363	28	0·25
99	66	316	306	−10	−0·09
	100	328	347	19	0·17
	133	332	379	47	0·42
Mean values for eighteen Mashona steers		305	319	14	0·12
Mean values for eighteen Africander steers		346	351	5	0·04
Pooled SD		—	—	—	±0·08

* Expressed as a percentage of Brody's (1945) standard for maintenance.

Mean daily changes in body-weight of the animals were subjected to an analysis of variance. The assumption was made that the intake of DCP and TDN by each animal was as planned. The feeding at various levels of DCP and TDN resulted in a highly significant rectilinear response in live-weight gains. However, there was some indication that the response to protein could be better described by a quadratic model. The two main nutritional effects, i.e. response to levels of DCP and of TDN, were not independent and the rectilinear interaction between these factors was highly significant ($P < 0·01$). The mean difference in growth rate between breeds was significant ($P < 0·05$), but there was no evidence of an interaction between breed and diet.

Various regression models were tested for their suitability to describe the effects of levels of DCP and TDN intake on the daily live-weight gain of steers. Models using the actual intakes of nutrients were studied, and it was found that the most appropriate model that described changes in live weight was

$$Y = a+b_1P+b_2P^2+b_3C+b_4PC,$$

where Y is the live-weight change and P and C are the intakes of DCP and TDN respectively. Further, statistical analyses showed a significant difference between breeds in their response to DCP and TDN intake, and separate response curves were calculated for the two breeds of cattle. The response curves are shown in Fig. 2. Equations which described the relationship for each breed were:

Africander steers,

$$Y = -0.726+0.197P-0.049P^2+0.008C+0.004PC;$$

Mashona steers,

$$Y = -0.292+0.036P-0.041P^2-0.0004C+0.007PC;$$

where Y is the daily live-weight change in kg and P and C are the intake of DCP and TDN respectively in g/kg $W^{0.73}$.

Table 4. *Calculated daily changes in body-weight (with 95% confidence limits) of eighteen Africander and eighteen Mashona steers given three different levels of digestible crude protein (DCP) each with three levels of total digestible nutrients (TDN)*

Level of DCP*	Level of TDN*	Body-weight change (kg/24h)	
		Africander steers	Mashona steers
33	66	−0·26 ± 0·14	−0·11 ± 0·08
	100	−0·10 ± 0·08	−0·01 ± 0·05
	133	0·05 ± 0·11	0·09 ± 0·06
66	66	−0·12 ± 0·10	−0·04 ± 0·06
	100	0·08 ± 0·07	0·16 ± 0·04
	133	0·29 ± 0·09	0·36 ± 0·05
99	66	−0·14 ± 0·11	−0·09 ± 0·06
	100	0·12 ± 0·07	0·21 ± 0·04
	133	0·39 ± 0·12	0·52 ± 0·08

* Expressed as a percentage of Brody's (1945) standard for maintenance.

Daily changes of body-weight that would occur at the planned levels of feeding were calculated from the equations and are shown in Table 4. If the amount of DCP and TDN recommended by Brody (1945) for maintenance had been given to the steers, appreciable daily gains in body-weight would have occurred. The calculations also show that the Mashona steers gained weight more rapidly (or lost weight less rapidly) than the Africander steers at all levels of dietary DCP and TDN. This difference was most marked at the highest and lowest levels of feeding but, between these extreme planes of nutrition, differences between breeds in growth rate were apparent but were more constant. The required intake of DCP depended upon the amount of dietary TDN consumed by the animals. There was an inverse relationship between DCP required and TDN consumed, which suggests that high intakes of TDN exerted a marked protein-sparing effect.

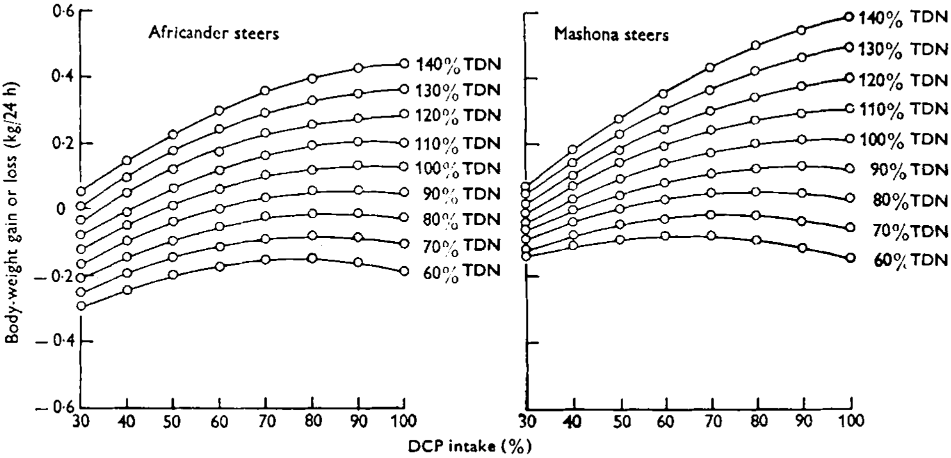

Fig. 2. Calculated daily weight changes of Africander and Mashona steers as a function of their intake of digestible crude protein (DCP) and total digestible nutrients (TDN). Intake of DCP and TDN is expressed as a percentage of Brody's (1945) standard for maintenance.

Table 5. *Calculated daily intake of total digestible nutrients (TDN) required for maintenance of body-weight of Africander and Mashona steers given three levels of digestible crude protein (DCP)*

Level of DCP*	Intake of TDN (g/kg $W^{0.73}$ 24 h)	
	Africander steers	Mashona steers
33	43·4	37·6
66	30·8	26·3
99	29·7	26·9

W, body-weight.

* Expressed as a percentage of Brody's (1945) standard for maintenance.

From the regression equations relating live-weight change to DCP and TDN intake, estimates were obtained of the amounts of TDN required for maintenance of body-weight at given levels of DCP intake. These estimates are shown in Table 5. As the level of dietary protein increased, there was a decline in the amount of TDN required for maintenance of body-weight. For Africanders given the two highest levels of DCP, between 30 and 31 g TDN/kg $W^{0.73}$ were required daily for maintenance, and for Mashonas the corresponding requirement was between 26 and 27 g TDN/kg $W^{0.73}$. These requirements of Africander and Mashona steers for TDN are approximately 83 and 73 % respectively of the Brody (1945) standard for maintenance.

DISCUSSION

The results obtained in this study confirm our earlier observations on protein requirements for maintenance of African cattle (Elliott & Topps, 1963*a*, *b*) and sheep (Elliott & Topps, 1964*a*). These requirements have been shown to be appreciably lower than recognized feeding standards (e.g. those of Brody, 1945), provided that the digestible energy intake of the animal was high or adequate.

In the study now described, appreciable amounts of finely ground and highly digestible ingredients, rich in carbohydrate, were incorporated into the pelleted diets. It is unlikely that under these conditions excessively rapid ruminal deamination, which results in the wasteful use of protein, would occur. It appears more likely, however, that what has been called the 'protein-sparing' effect of energy-rich diets in monogastric animals (cf. Rosenthal & Allison, 1951) may operate in ruminants as well, quite apart from the known ruminal mechanism. The results show also that a single value for the protein requirement for maintenance of cattle may not be either very useful or valid. Instead, protein requirements can be defined only when the amounts of digestible energy contained in the diet are known. This conclusion agrees with the results of Broster, Tuck & Balch (1963).

When the two highest levels of dietary protein, i.e. 66 and 99 % of Brody's maintenance standard for DCP, were given to Africander and Mashona steers, it was estimated that they required daily approximately 31 g TDN/kg $W^{0.73}$ and 27 g TDN/kg $W^{0.73}$ respectively to maintain body-weight. These requirements for TDN are low when compared with the amount of 35·2 g TDN/kg $W^{0.73}$ daily recommended by Brody. Part of this discrepancy may be accounted for by the TDN content of some diets being underestimated in concurrent digestibility trials with sheep. In the sheep digestibility trials, no allowance was made for the effect on digestibility of plane of nutrition. Consequently, the TDN content of some diets may have been underestimated, i.e. in those given to provide the lowest level of digestible energy to the cattle. On the other hand, concomitant work with sheep (Elliott & Topps, 1964*b*) given diets composed of equal parts of roughage and concentrates has suggested that their daily TDN requirement for maintenance is 21 g/kg $W^{0.73}$. This difference of approximately 30 % (of the higher value) between species in their energy requirements agrees with the findings of Blaxter (1962).

The live-weight changes of steers given the lowest levels of TDN are of some interest. In contrast with the almost rectilinear growth curves of steers provided with adequate amounts of energy, the weight losses of steers given low levels of TDN were more pronounced early in the trial, but later became progressively less severe. As mentioned above, since a fixed level of feeding was adhered to regardless of changes in body-weight, the nutritional status of the underfed animals would progressively improve as the trial proceeded. Although the results obtained may not be explained solely by this reasoning, they do indicate an 'adaptation' by the steers to low levels of digestible energy intake. It is not known whether this apparent lowered requirement for maintenance of body-weight was due either to an alteration in the animal's metabolism or to changes in body composition which may influence nutritional requirements. Blaxter (1962) has shown that the basal metabolism of a fasting sheep gradually declines. A similar, but smaller effect, may be present in underfed ruminants. On the other hand, despite an apparent increase in the maintenance requirements of the steers receiving the highest level of feeding during the trial as a result of their increase in weight, the gains in weight remained rectilinear during the 16 weeks.

This performance suggests that deviations of 9% or less from the planned level of feeding, per unit of metabolic body size, had little or no effect on the nutritional status of the animal.

The mean growth rate of the two breeds of cattle differed significantly when their intakes of DCP and TDN were equated according to metabolic body size. Mashona steers either gained weight faster, or lost weight less rapidly, than Africanders at all levels of nutrition studied. The reason for this difference in performance between the breeds was not ascertained, but it is possible that by providing dietary levels of DCP and TDN for the two breeds on the basis of $W^{0.73}$, the Mashona cattle were relatively better fed. As previously mentioned, Blaxter (1962) has shown that energy requirements for maintenance of sheep are appreciably lower than those of cattle on the basis of $W^{0.73}$. This concept of relatively lower energy requirements for maintenance of small ruminants may apply to two breeds of cattle, one of which is large (e.g. Africander) and the other small (e.g. Mashona). Estimated TDN requirements for maintenance, obtained in the study now described, which were relatively lower for Mashona than for Africander steers, support this corollary to Blaxter's findings.

The application to practice of the findings that protein requirements for maintenance of body-weight are unusually low presents several problems. Diets low in protein are not readily eaten by ruminants (Campling, Freer & Balch, 1962; Elliott & Topps, 1963*c*) and depressed intake of such diets is often associated with inadequate energy intake. The effects of both protein content and digestibility on voluntary intake of food by ruminants have yet to be assessed with practical diets that will provide the animal with adequate amounts of protein and energy for maintenance.

SUMMARY

1. Long-term feeding trials (16 weeks) were carried out with eighteen 2-year-old cattle of each of two African breeds given three levels of dietary protein combined with varying amounts of digestible energy.

2. Live-weight gain was significantly affected by level of intake of digestible crude protein (DCP) and total digestible nutrients (TDN) and also by a highly significant interaction between these dietary components.

3. The steers made appreciable gains in body-weight when given amounts of DCP and TDN similar to those recommended by Brody (1945) for maintenance. Protein requirements could be defined only when the amounts of energy provided by the diet were known.

4. There was a significant difference in performance between the two breeds. Mashona steers either gained weight more rapidly, or lost weight less rapidly, than the Africander steers at all levels of intake of DCP and TDN. The difference was most marked at the highest and lowest levels of feeding.

5. As intake of protein increased, the estimated amount of TDN required by the steers for maintenance declined. The calculated TDN requirements of Africander and Mashona steers for maintenance when 'adequate' DCP was given were approximately 83 and 73% respectively of Brody's (1945) standard.

6. The body-weight losses of steers receiving the lowest level of energy were appreciable in the first few weeks of the trial and the rate of loss then progressively decreased. This behaviour may indicate an 'adaptation' by the steers to low levels of energy intake.

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