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EVALUATING THE PROTEIN CONTRIBUTION OF FEEDSTUFFS FOR RUMINANTS

BY

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SUMMARY

In recent years the use of intestinal cannules at various sites of the ruminant intestine has provided detailed knowledge of the site and extent of digestion of dietary nitrogen. This has led to the realisation that the traditional measurement of digestible crude protein (DCP) in a feedstuff is no guide to the quantity of amino acids it will provide for absorption from the small intestine. Thus, the DCP content of a feedstuff does not give a true measure of its protein contribution for ruminants. The main reason for this is that different diets cause variable amounts of microbial protein, synthesised in the rumen, and undegraded dietary protein to pass to the small intestine.

A new system, proposed by the Agricultural Research Council (ARC) Working Party on Nutrient Requirements of Ruminants, for estimating protein reqirements of ruminants and the protein value of feedstuffs is discussed. The proposed system takes account of the dual requirements of the ruminant for:

a) rumen degradable nitrogen to sustain maximal microbial growth rates for a particular energy input so that voluntary food intake and efficiency of utilisation of dietary energy are not impaired.

b) amino acids absorbed from the small intestine to meet tissue needs.

Consequently, the value of dietary protein is best determined in terms of its degradability in the rumen and not its overall apparent digestibility. A rapid laboratory method for assessing degradability is discussed.

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EVALUATING THE PROTEIN CONTRIBUTION OF FEEDSTUFFS FOR RUMINANTS[1]

– by –

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The technique of placing cannulas into various sites of the intestinal tract (abomasum, duodenum, terminal ileum) has provided a wealth of data in recent years. Detailed knowledge of the site and extent of digestion of dietary nitrogen has led to the realisation that the traditional measurement of Digestible Crude Protein (DCP) is no guide to the amount of amino acids absorbed from the small intestine. To take herbage as an example, fresh young grass has a high content of DCP but much of this is absorbed as ammonia from the rumen; the absorption of amino acids from the small intestine is less than would be indicated by DCP (MacRae & Ulyatt, 1974). In contrast, with low protein hay the DCP value will be very low but more amino acids may actually be absorbed from the small intestine than were consumed let alone apparently digested (Harrison, Beever, Thomson & Osbourn, 1973). In between these two extremes, processing herbage by ensilage, freezing, drying, grinding or pelleting can bring about substantial changes in the site of digestion of the herbage and in the amount of amino acids absorbed from the small intestine without commensurate changes in DCP (Beever, Cammell & Wallace, 1974; Beever, Thomson & Cammell, 1976; Beever, Thomson, Cammell & Harrison, 1977).

The main reasons for the disparity between DCP and absorption of amino acids in the small intestine are that different diets cause variable amounts of microbial protein, synthesised in the rumen, and undegraded dietary proteins to pass to the duodenum. Other factors are the extent of digestion of microbial and dietary proteins within the small intestine, the proportion of amino acids in the microbial crude protein and the extent of secondary fermentation in the hind gut. Clearly the current DCP system of determining protein value of feedstuffs for ruminants is unsatisfactory since it takes no account of these changes in form or site of N absorption.

If practical use is to be made of all this new detailed information then it must be incorporated into a new method of determining.

i) the requirements of the ruminant for N

ii) the value of the N content of feedstuffs in meeting the animal's requirement.

Recently at the 2nd International Symposium on Protein Metabolism and Nutrition representatives from France, West Germany, U.S.A. and U.K. put forward new systems of evaluation which are being considered in the respective countries (Journet & Vérité, 1977; Kaufmann, 1977, Satter & Roffler, 1977; Roy, Balch, Miller, Ørskov & Smith, 1977). All systems have in common the estimation of the value of feedstuffs in terms of microbial and dietary amino acids that are absorbed from the small intestine, the prediction of tissue protein requirements by the factorial approach of summing net protein deposited in live weight gain, milk, foetal tissues or needed to replace endogenous urinary losses and the use of an efficiency of utilization factor to equate amino acid supply from the small intenstine with tissue need. The systems differ in their detailed approach and in choice of values to be used for factors such as microbial yield, efficiency of utilization of NPN, degradability of dietary protein, digestibility in the small intestine and efficiency of utilization of absorbed amino acids. All values proposed are averages culled from the world literature; in many cases the data are inadequate and variable. Nevertheless these systems provide a new framework which highlights areas where additional information is required, enables fresh interpretations to be placed on previously discordant data such as the variation in DCP requirement for lactation in different trials (Broster, 1972) and facilitates the design of new methods of feeding that more efficiently match supply with requirement for amino acids.

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[1] First published in the Record of papers presented at the 4th European Symposium on the Use of Fish Meal in Animal Feeding, London, October 1977.

The system advocated by the ARC Working Party on Nutrient Requirements of Ruminants (Roy *et al*, 1977) differs a little from the other new proposals in that greater emphasis is given to the dual requirements of the animal.

i) for rumen degradable nitrogen (RDN) to sustain maximal microbial growth rates for a particular energy input so that voluntary food intake and efficiency of utilization of dietary energy are not impaired.

ii) for amino acids absorbed from the small intestine to meet tissue needs.

The requirement for RDN is taken to be equal to the amount of microbial N leaving the rumen. Under these conditions losses of N from the rumen as ammonia will be balanced by recycled N entering the rumen in the saliva or by diffusion from the blood supply. Should the diet supply less than this required amount of RDN there is opportunity for an increased efficiency of use of the recycled N so that microbial yield may not be depressed to the same extent but under some conditions the slower rate of microbial growth will result in a slower rate of carbohydrate digestion, reduction in voluntary intake and a disproportionately large effect on animal productivity. Since the deficiency of RDN may be readily and cheaply corrected by non-protein nitrogen (NPN) supplements such as urea there seems little point in risking a shortage of RDN.

When N and other trace factors such as S are not limiting, microbial growth is related to the energy obtained through fermentation reactions. This is conveniently measured as microbial N leaving the rumen per kg of organic matter apparently digested in the rumen. Microbial yield, in these terms, can be expected to vary depending on whether the microbes incorporate a substantial portion of dietary amino acids directly or synthesize their protein from ammonia *de novo*, on the rate of rumen fluid turnover since high turnover rates favour passage of microbes from the rumen and less lysis within the rumen and possibly on the rate of fermentation of the carbohydrate energy source. However the data so far are inadequate to define any consistently different yields for particular dietary situations and a mean microbial yield of 30 g N/kg organic matter apparently digested in the rumen has been adopted for the present. In the majority of studies the proportion of the overall digestible organic matter that is apparently digested in the rumen varies between 0.6 and 0.7. Assuming a median value of 0.65 for this ration, and also that 1 kg of digestible organic matter contains 19.0 MJ digestible energy and D_E:M_E ratio is 0.82, then: -

$$\text{RDN required (g/d)} = M_E\ (\text{MJ/d}) \times \frac{1}{(0.82 \times 19.0)} \times 0.65 \times 30$$

$$= 1.25\ M_E$$

Some implications of this simple relationship are shown in Figure 1. The ARC (1965) recommended a minimum crude protein (CP) content of 9% of the dry matter (DM) to sustain the microbial activity of the rumen. The current calculations show this minimum crude protein content varies with both the energy concentration of the diet and the degradability or dietary protein (dg) in the rumen (Figure 1). Practical consequence are that highly lignified straws with low N and low energy are little improved by urea supplementation yet alkali treated straws and high energy but medium N feeds such as maize silage and barley are better digested and have higher voluntary intakes when supplemented with urea (Kay, Andrews, MacLeod & Walker 1968; Miller, Johnson, Briggs & Kempsey, 1977; Thomas, Wilkinson, & Taylor, 1975; Thomas & Wilkinson, 1975; Ørskov, Fraser, McDonald & Smart, 1974).

The next stage of the ARC proposals is to calculate the microbial contribution of amino acids towards the tissue requirements. The ratio of amino acid N to total N in bacteria is approximately 0.80, the apparent digestion of amino acids in the small intestine is 0.70 and the efficiency of utilisation of the absorbed amino acid N is taken to be 0.75. The microbial amino acid N contribution to the tissue need (TMN) is thus

$$\text{TMN (g/d)} = \text{Microbial N yield} \times 0.80 \times 0.70 \times 0.75$$

$$= 1.25\ M_E \times 0.42$$

$$= 0.526\ M_E\ (0.53\ M_E\ \text{adopted})$$

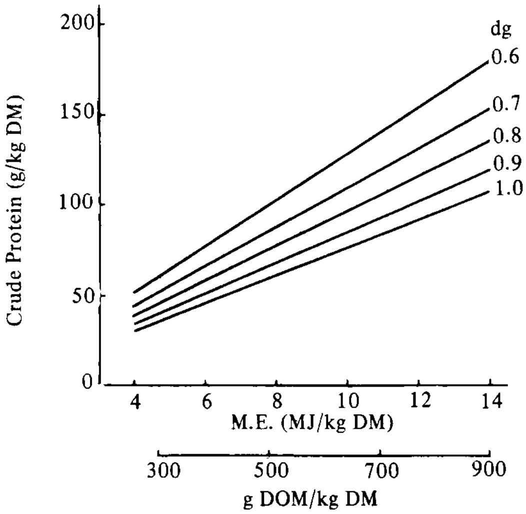

FIG. 1

Dietary crude protein required for microbial growth on diets of varying energy concentration and degradability (dg) of dietary protein.

This microbial contribution is compared with the tissue N (TN) requirement (protein N in milk, N retention in tissues, N required for maintenance) for lactation and for growth of steers in Figures 2 and 3. Microbial synthesis alone is more than adequate for maintenance but additional dietary amino N must be absorbed to sustain milk yields over 7.5 kg and growth in young steers up to approximately 230 kg live weight.

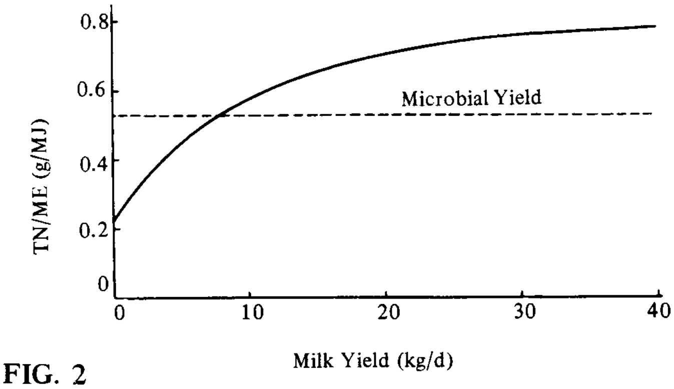

FIG. 2

Relationship between milk yield of Friesian (600 kg) given a diet of 11 MJ metabolisable energy/kg DM to meet energy needs and tissue N requirement/MJ ME. Also the predicted microbial contribution (0.53 gN/MJ) is shown.

Where the microbial contribution (TMN) is in excess of tissue needs (TN) then the rumen degradable N (RDN) is also the minimum N requirement of the animal. If TMN is less than TN the extra undegraded dietary amino acid N(UDN) requirement is calculated from the deficit in amino acid N corrected for efficiency of utilization of absorbed amino acid N and apparent absorption in the small intestine. Thus UDN requirement (g/d)

$$= \frac{\text{TN} - \text{TMN}}{\text{efficiency of utilization of absorbed amino acid N x apparent absorption of amino acid N}}$$

$$= \frac{\text{TN} - 0.526\ \text{M}_E}{0.75 \times 0.70} \qquad = 1.91\ \text{TN} - 1.00\ \text{M}_E$$

The minimum N requirement of the animal is then the sum of RDN and UDN.

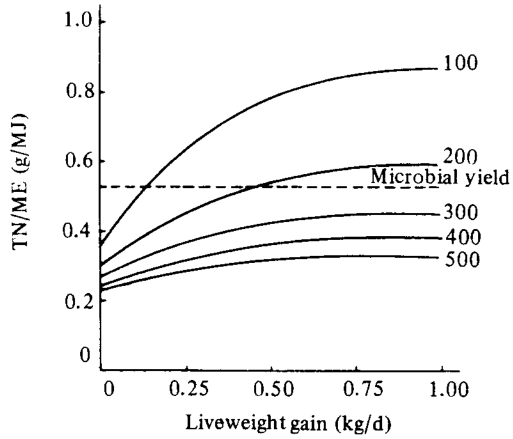

FIG. 3

Relationship between live-weight gain of steer at various live-weights given a diet of 11 MJ ME/kg DM to meet energy needs and tissue N requirement/MJ ME. Also the the predicted microbial contribution (0.53 g N/MJ) is shown.

To formulate a diet to exactly meet the minimum N requirement would involve selection of ingredients of varying dietary N degradability so that the mixture exactly supplied both RDN and UDN requirements. However, feedstuffs will primarily be selected for their energy contribution and voluntary intake. If the basal feeds are found to be more than adequate in UDN but inadequate in RDN then the cheapest supplement is likely to be a source of non-protein N such as urea. The efficiency of conversion of urea to microbial N will vary according to the method of feeding and the nature of the basal feeds. Feeding urea little and often in conjunction with rapidly fermentable starchy diets can give high rates of utilization. However, to cover the less than ideal situation an apparent efficiency of conversion of urea N to microbial N of 0.80 has been adopted instead of 1.0 used for degraded dietary protein. Thus the weight of supplementary urea required (g) = $\dfrac{\text{deficit of RDN}}{0.80 \times 0.46}$

where 0.46 = N content of urea (g/g)

and 0.80 = efficiency of conversion of urea N to microbial N.

Where the basal ingredients are deficient in UDN, protein supplements are required. The amount needed depends on the degradability in the rumen. Much less is required of a protein of low degradability (provided it is still well digested in the small intestine) than one of high degradability. This is illustrated in Figure 4 which shows the influence of protein degradability upon the calculated required crude protein content of the diet for different levels of milk production. At low milk yields the requirement for RDN predominates. The minimum CP concentration is 86 g/kg DM when all the dietary CP is available for microbial metabolism i.e. a degradability (dg) of 1.0. The microbial protein yield is calculated to be adequate for maintenance plus 7.5 kg milk. As the dg decreases the CP requirement increases if the RDN requirement is to be met but the consequent additional UDN supplements the microbial protein so that higher yields of 11 and 18 kg at dg of 0.9 and 0.8 respectively should be sustained. At a dg of 0.7 the required dietary CP is 123 g/kg DM to supply ruminal needs and the UDN will be sufficient to allow for yields up to 40 kg milk. However, if the dg is less than optimum the requirement for CP to sustain high milk yields increases very rapidly. For the high yielding dairy cow and for the rapidly growing young lamb or calf the degradability of the dietary protein is the most important factor influencing the determination of the optimum CP concentration in the diet.

The calculations in Figure 4 are based on the energy supply exactly equalling needs so that there is no change in body weight. High yielding cows are seldom in this condition, but usually lose weight in the important first weeks of lactation and regain the weight in the latter part of lactation. During weight loss the UDN requirement is increased since inadequate protein is mobilised from the tissues to match the energy mobilised from fat depots. Indeed there is evidence that the mobilisation of energy reserves is stimulated by the supply of additional protein (Ørskov & Grubb, 1977; Journet & Vérité, 1977) so that correct protein supplementation in the initial weeks may be vital to the attainment of high peak yields (Satter & Roffler, 1977; Vérité & Journet, 1977).

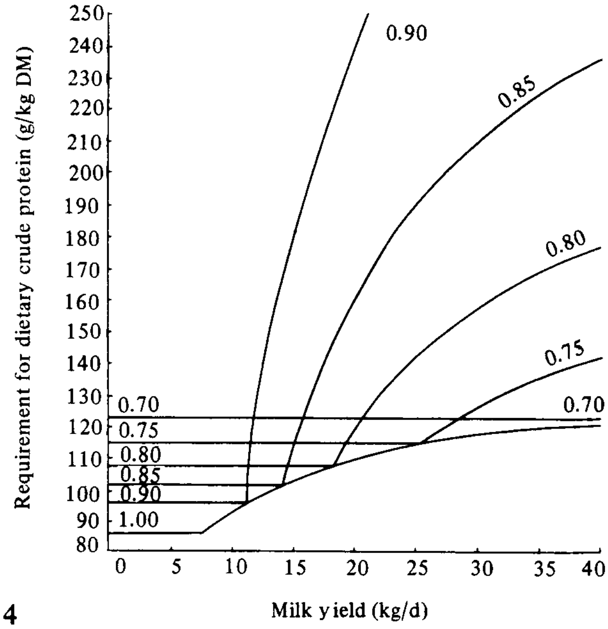

FIG. 4

Requirement between milk yeild of Friesian (600 kg) given a diet q=0.6 (ME 11 MJ/kg DM) to meet energy needs, rumen degradability (0.7-1.0) of dietary protein and required protein concentration in the diet.

In Tables 1 and 2 I have listed the published *in vivo* estimates of dietary protein degradability determined with sheep. Clearly much more work is required in this area since where nominally similar materials have been tested by different workers, divergent results have sometimes been obtained. At least part of this variability may be due to the analytical methods used but part may also reflect level or method of feeding and true differences between differently prepared samples. Nevertheless a number of principles appear to emerge. Fresh forages appear to be extensively degraded but the proportion is close to the predicted optimum to meet the high producing animals requirement and the high protein content and voluntary intake will ensure more than adequate supplies of both RDN and UDN for the grazing animal. Drying and pelleting of forages causes a reduction in degradability probably because of the reduced particle size and faster transit time through the rumen. Conservation as silage increases degradability. This is to be expected since the soluble NPN content of the forage increases during ensilage. However, the addition of formalin at 6.4 l/t fresh weight during ensilage probably over protects the protein. Barley protein is extensively degraded. Wheat and oats are probably similarly degraded but maize, as expected from its zein content, is less degraded. Heat processing the cereals reduces the degradability of the protein. The protein concentrates differ markedly in degradability. The unspecified fish meal tested by Hume is believed to be a pilchard meal of S. African origin, and it seems meals prepared from the oily species are particularly resistant to degradation. Soya bean meal that has been toasted to reduce trypsin inhibitors and other deleterious factors appears to be less degraded than other solvent extracted oil seed meals such as groundnut and cottonseed meal that have not been subjected to excessive heat.

So far the data on which the predictions of requirement and degradability of dietary protein are based come from detailed metabolic studies of the ruminant mode of digestion. Clearly such predictions must be checked against actual production trials. So far no trials have been designed specifically to test the new predictions. Therefore, the ARC Working Party on Nutrient Requirements of Ruminants has surveyed the published literature on milk yield and growth responses to dietary protein and compared the practical results with the current predictions (Miller, Balch, Ørskov, Roy & Smith, 1977).

TABLE 1
Degradability in the rumen of crude protein from forages

Fresh forage	**Degradability**	**Reference**
Ryegrass	0.67–0.73	Ulyatt et al, 1975
White clover	0.72–0.73	Ulyatt et al, 1975
Red clover (frozen)	0.71*	Harrison et al, 1973
Dried legume forage		
Subterranean clover, green	0.73	Hume & Purser, 1975
Subterranean clover, wilted hay	0.43–0.53	Hume & Purser, 1975
Red clover, dried, pelleted	0.34	Harrison et al, 1973
Lucerne, high temp. dried, chopped	0.38*	Coelho da Silva et al, 1972a
Lucerne, high temp. dried, cobbed	0.44*	Coelho da Silva et al, 1972a
Lucerne, high temp. dried, pelleted	0.23*	Coelho da Silva et al, 1972a
Lucerne, dried	0.86*	Harrison et al, 1973
Lucerne, dried, cobbed	0.72	Mathers & Miller, 1977b
Lucerne hay	0.79	Pilgrim et al, 1970
Lucerne hay	0.61	Nolan, 1975
Sainfoin	0.26*	Harrison et al, 1973
Dried grass		
Ryegrass, high temp. dried, chopped	0.92*	Coelho da Silva, et al, 1972b
Ryegrass, high temp. dried, pelleted	0.68*	Coelho da Silva, et al, 1972b
Grass, pelleted	0.49	Mathers & Miller, 1977a
Rygrass hay, barn dried, pelleted	0.77–0.94*	Harrison et al, 1973
Silage		
Ryegrass, no additive	0.85	Beever et al, 1977
Ryegrass, HCHO	0.22	Beever et al, 1977

*Values calculated from authors data.

Practical lactation trials give very conflicting estimates of protein requirement; diets containing 125 g CP/kg DM were satisfactory in some cases whereas in other experiments significant responses were obtained by increasing protein content to 140, 160 or even 180 g/kg DM. The ARC proposals indicate the possibility that these variations could be accounted for by changes in the degradability in the range 0.70 to 0.85. In general high milk yields were achieved with diets of low CP concentration when the ingredients were maize silage, ground maize and soya, all of which would be expected to have degradabilities in the range 0.6 - 0.75. Responses to higher CP concentrations were obtained where grass silage (expected degradability 0.85) was the main basal feed.

Two illustrations are given from recent trials of the importance of dietary protein in lactation. Treacher (1977) compared urea with groundnut plus white fish meal as supplements to a diet of barley straw, lucerne nuts, barley and wheat. The complete diets contained approximetely 140 g CP/kg DM and were given from the beginning of lactation. The milk yields are shown in Figure 5. Yields of cows given the urea diet reached a peak of 28 kg at week 4-6 and then began to decline whereas the protein supplemented group peaked at 30 kg and did not start to decline until week 9 and were significantly higher throughout weeks 10 to 20. Figure 6 shows the estimated requirement and supply of rumen degraded protein (RDP) and undergraded protein (UDP) for weeks 2-10 and 11-20. Undergraded protein intake is calculated to be limiting for the urea diet in the first period and, when body weight loss was taken into account closely predicted the milk yield achieved. In the second period undegraded protein intake was a little greater than that required for the milk yield achieved but still less than that necessary to sustain milk yields equal to those of the protein group. Thus the milk yields achieved were close to predictions.

TABLE 2

DEGRADABILITY IN THE RUMEN OF CRUDE PROTEIN FROM CONCENTRATES

Cereals	Degradability	Reference
Barley	0.81*	Ørskov et al, 1974
Hay and barley	0.92	Sutton et al, 1975
Barley	0.89	Mathers & Miller, 1977b
Barley, cold rolled	0.96	Papasolomontos & Wilkinson, 1976
Barley, steam flaked	0.87	Papasolomontos & Wilkinson, 1976
Barley, micronized	0.75	Papasolomontos & Wilkinson, 1976
Maize, cold rolled	0.70	Papasolomontos & Wilkinson, 1976
Maize, steam flaked	0.51	Papasolomontos & Wilkinson, 1976
Maize, micronized	0.60	Papasolomontos & Wilkinson, 1976
Protein concentrates		
Fish meal	0.29	Hume, 1974
Fish meal, Peruvian	0–0.31	Miller, 1973
Fish meal, White	0.61–0.63	Ørskov et al, 1971b, 1974
Soya bean meal	0.39	Hume, 1974
Soya bean meal	0.59*	Ørskov et al, 1971a
Groundnut meal	0.63	Hume, 1974
Groundnut meal	0.78	Miller, 1973
Lupin	0.65	Hume, 1974
Sunflower seed meal	0.72–0.81	Miller, 1973

*Values calculated from authors data.

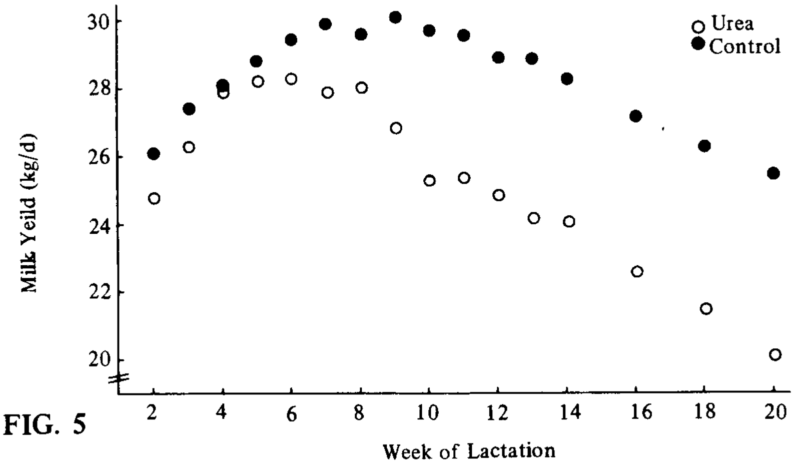

FIG. 5

Milk yeild of cows given from calving isoenergetic diets in which the concentrate contained either urea or groundnut meal plus white fish meal.

Data from Treacher (1977).

Milk protein yield is highest shortly after calving and declines with progress of lactation. Food intake, and therefore protein intake, is low after calving and then increases to a peak at around 12 weeks. Vérité & Journet (1977) have tested the effect of both giving extra protein in the initial weeks of lactation and of protecting that protein with formaldehyde to increase even further the supply of undegraded protein. The basal diet consisted of rationed amounts of maize silage supplemented with urea and minerals. The concentrates consisted of

1) 10 parts soya bean meal, 10 parts rapeseed meal, 80 parts maize

2) 50 parts soya bean, 50 parts rapeseed at calving, then diluted steadily with maize to give the same as 1 during the 7th week

3) as for 2 but with formaldehyde treated soya and rapeseed meals.

The lactation curves are shown in Figure 7. The experiment clearly demonstrates the importance of matching supply of undegraded protein with requirement in the crucial first few weeks of lactation, especially where energy intake is rationed.

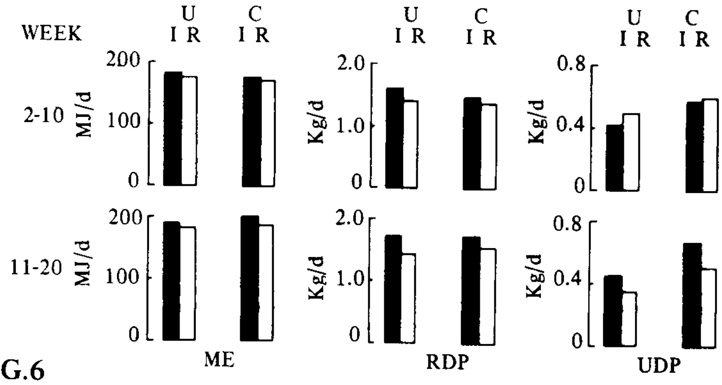

FIG.6

The calculated intake (I) and requirement (R) of metabolisable energy (ME) rumen degradable protein (RDP) and undegraded dietary protein (UDP) in the 2nd-10th or 11th-20th week of lactation of cows given concentrates containing either urea (U) or groundnut plus fish meal (C).

Data from Treacher (1977)

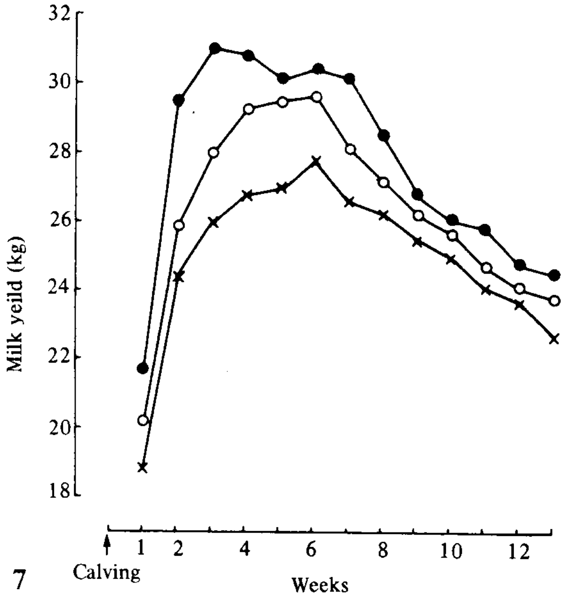

FIG. 7

Milk yield from calving of cows given isoenergetic supplements of normal protein concentrate 20% maize 80% throughout (X); normal protein concentrate 100%, at week 1, reducing to protein 20%, maize 80% by week 7 (0); HCHO-treated protein concentrate 100%, at week 1, reducing to protein 20%, maize 80% by week 7 (●).

Data from Verite & Journet (1977)

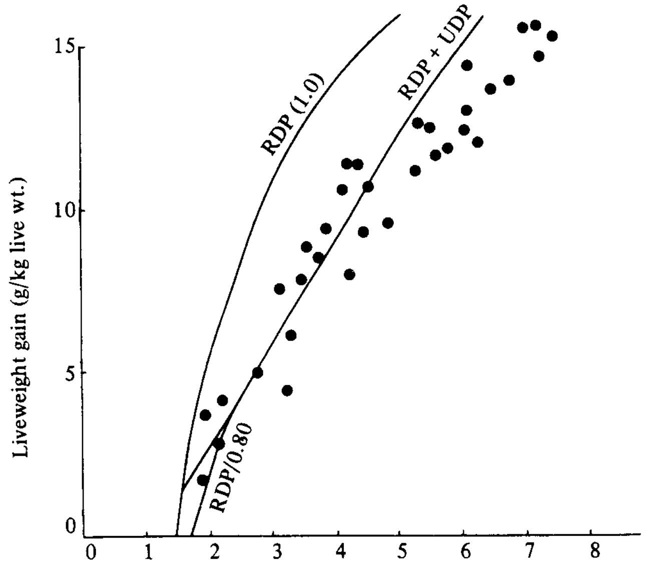

FIG. 8

Weight gain of cattle of 50-100 kg (mean 87 kg) given diets believed to be limiting in crude protein. Minimum intake of crude protein to supply required RDP or RDP + UDP are also shown (Q=0.55).

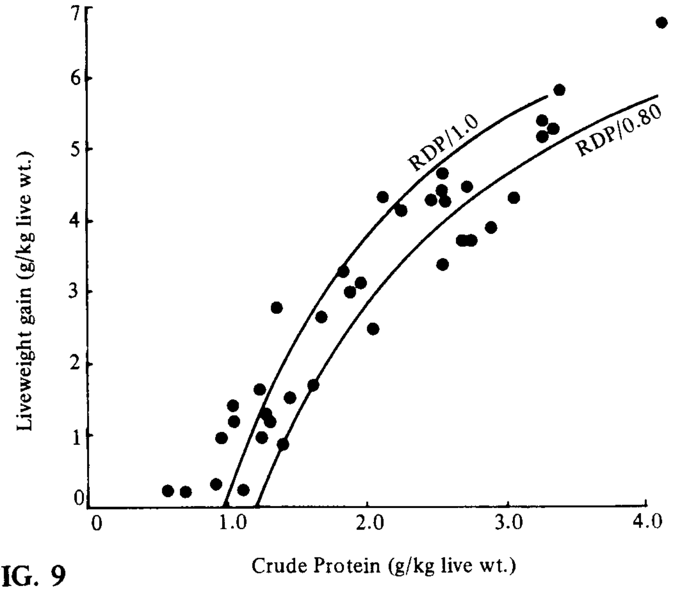

FIG. 9

Weight gain of cattle of 200-300 kg (mean 259 kg) given diets believed to be limiting in crude protein. Minimum intakes of crude protein to supply required RDP at dg of 1.0 or 0.8 are also shown (Q=0.55).

Figures 8 and 9 show the growth rates achieved by young cattle on diets which appeared to be limiting in protein. Also shown are the requirements for CP to meet the minimum need for RDP (dg 1.0) or RDP + UDP or RDP at degradability of 0.80. For the 50-100 kg calf the supply of minimum RDP on its own is clearly inadequate whereas the line of RDP + UDP requirement fits close to the data. Points lying to the right of this line may still represent protein limiting diets if the dietary protein degradability is greater than the optimum. For the 200-300 kg calf, the CP requirement to supply the estimated RDP at a degradability of 0.8 is in keeping with the practical observations. Since most mixed diets probably have a degradability of 0.85 or less the data is consistent with the hypothesis that basal diets for this weight range require no supplementary undergraded protein but may need supplementary NPN to meet the needs of the rumen microbes.

The requirement of the early weaned calf (50-100 kg) for supplementary undegraded protein is clearly shown in Tables 3 and 4. Table 3 shows the response when urea is replaced by white fish meal and Table 4 shows a response to supplementary sunflower seed meal to a basal diet already well supplemented with urea and an increased response when the sunflower seed meal is 'protected' by treatment with glutaraldehyde.

TABLE 3

EFFECT OF REPLACING UREA WITH WHITE FISH MEAL ON GROWTH RATE AND FEED CONVERSION OF CALVES FROM 50 TO 110 kg LIVE WEIGHT

Diet variables*				
White fish meal (%)	–	6.3	13.9	
Urea (%)	3.0	1.6	–	
Bruised oats (%)	33.3	28.9	23.7	
Minerals/Vitamins (%)	4.3	3.0	1.1	
Crude protein (% of DM)	19.26	19.40	19.55	
Production				
				Standard error
Feed intake (kg/d)	2.04	2.34	2.27	0.311
Live weight gain (kg/d)	0.53	0.71	0.80	0.113
Feed: gain ratio	3.98	3.32	2.89	0.297

*Other ingredients: flaked maize 39, molassine meal 12.6, grass meal 8.8%.

Data from Kay, MacLeod, McKiddie and Phillip (1967).

Similarly the growth rate of young lambs has been shown to increase as urea is replaced by fish meal as the supplement to barley diets. Table 5 gives data from such a trial at Cambridge. Ørskov *et al* (1974) have obtained similar growth responses to fish meal and have also drawn attention to improvements in digestibility of starch and organic matter of the diet when urea is added to low levels of fish meal. This clearly indicates the dual nature of the animal's requirements. Low levels of fish meal contribute important amounts of undegraded protein to meet the tissue needs, but on high energy cereal diets do not supply sufficient N for the rumen micro-organisms. A combination of undegraded or 'protected' protein with a cheap NPN source is the most efficient method of meeting the dual requirements.

Having established that the value of dietary protein is best determined in terms of its degradability and not its overall apparent digestibility, it is clear that rapid laboratory method for predicting degradability are urgently required. While changes in solubility of protein in buffer solutions or rumen liquor have accompanied processing treatment of a single material (Beever *et al*, 1976) there does not appear to be a consistent relationship over all feedstuffs. Furthermore solubilities may differ markedly with pH and type of solvent. An alternative method is *in vitro* ammonia production in an artificial rumen but here care must be taken to equate energy supply so that differences in uptake of ammonia for

TABLE 4

EFFECT OF TREATMENT OF SUNFLOWER SEED MEAL WITH GLUTARALDEHYDE ON THE LIVE WEIGHT GAIN AND FEED CONVERSION OF EARLY WEANED CALVES FROM 6 TO 12 WEEKS OF AGE

Diet variables* (g/kg DM)	Basal	L_1	L_1P	L_2	L_2P	
Sunflower, control	–	100	–	200	–	
Sunflower-treated	–	–	100	–	200	
Barley Straw	222	167	167	112	112	
Starch	178	133	133	88	88	
Analysis						
Crude Protein in DM (g/kg)	140	174	174	209	209	
Estimated ME in DM (MJ/kg)	10.9	10.9	10.9	10.9	10.9	
Results						SEM
Live weight gain (kg/d)	0.67	0.72	0.80	0.74	0.84	0.036
Feed conversion	3.73	3.60	3.33	3.40	3.24	0.150
Plasma Urea (mmol/l)	3.27	4.20	3.10	5.55	5.33	0.333

*Constant ingredients Barley 498, Urea 22, Molassine Meal 50, Minerals and Vitamins 30.

Unpublished data of J. A. Stedman & E. L. Miller.

microbial growth do not mask differences in rates of production of ammonia. A most promising method is to follow the rate of disappearance of N from a sample of feed placed inside a polyester bag placed within the rumen. A detailed examination of the technique has been made recently by Mehrez & Ørskov (1977), and has already been used to assess degradability in a number of laboratories. Figure 10 gives N disappearance curves for some protein concentrates, most of which had already been tested for in vivo degradability (Mathers, Horton & Miller, 1977). For these materials short incubation times

TABLE 5

EFFECT OF REPLACING UREA WITH FISH MEAL ON GROWTH RATE AND FEED CONVERSION OF LAMBS FROM 15 TO 25 kg LIVE WEIGHT

Diet variables*							
Fish meal (%)	–	5.0	–	2.5	5.0	10.0	
Urea (%)	1.25	–	2.50	1.87	1.25	–	
Starch (%)	3.75	1.0	7.50	6.13	4.75	2.0	
Crude protein (% dry matter)	15	15	18	18	18	18	
Production							Standard error
Live weight gain (kg/d)	0.29	0.28	0.25	0.30	0.33	0.35	0.024
Feed intake (kg/d)	1.05	0.97	1.00	0.98	1.00	0.93	0.065
Feed: gain ratio	3.66	3.56	3.99	3.32	3.11	2.68	0.292

*Other ingredients: Molassine meal 4, trace element and vitamin 2.8, steamed bone flour 0 to 2, barley 86.2 or 81.2%.

Unpublished data of Miller (1967).

of 4-6 h gave the best prediction of *in vivo* values. For cobbed lucerne-barley mixtures 11-12 h incubation gave the best fit. Ørskov & Mehrez (1977) proposed determining the extent of degradation when 90% of the digestible DM has also disappeared from the bag, while Mohamed & Smith (1977) have proposed that a rate constant of disappearance should be calculated from a logarithmic plot. Clearly the method holds considerable promise and is under intensive investigation. So far values in each laboratory rank the feedstuffs similar to the *in vivo* values given in Tables 1 and 2. However, many more experiments in which *'in vivo'* and *'in sacco'* values are determined simultaneously will have to be carried out to calibrate the latter for use in quantative prediction.

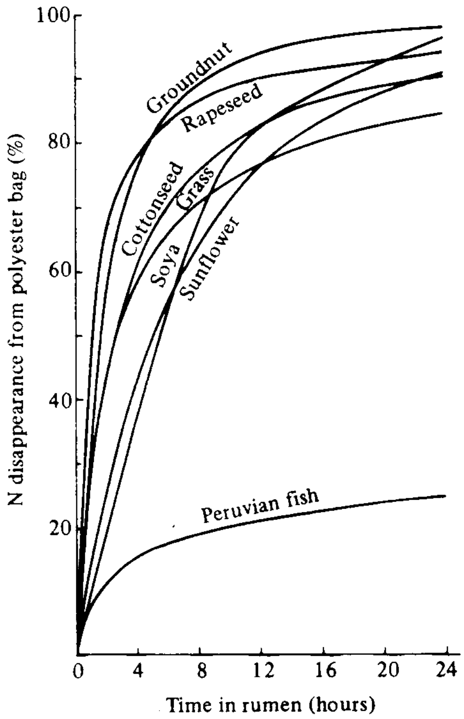

FIG. 10

Disappearance of feedstuff N from polyester bags suspended in the rumen of sheep. From Mathers, Horton & Miller (1977).

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