ROLE OF SUPPLEMENTS IN THE UTILISATION OF LOW QUALITY FEEDS

T.J. KEMPTON*

SUMMARY

Feed supplements, for use under grazing conditions to increase ruminant production from low quality feeds should be formulated to

(i) be palatable to the animal:

(ii) increase the outflow of microbial protein from the rumen;

(iii) meet the protein requirements of the animal and balance the ratio of absorbed nutrients:

(iv) increase ME intake; and

(v) increase the efficiency of utilisation of absorbed nutrients.

The cost-effectiveness of feed supplements will depend on the extent to which the material satisfies each of these factors and hence increases production.

INTRODUCTION

In Australia, the majority of ruminant production is from native and improved pastures, and at times, because of variable pasture quality throughout the year or between years, the only pasture available is dry material of low digestibility and low protein content. Since the rate of production of ruminants grazing these diets is restricted by a shortage of nutrients during these periods, various supplementation strategies have been developed in an attempt to offset these effects. The nutritional principles on which these strategies have been based are also applicable to ruminant production systems from low quality agroindustrial by-products. The aim in developing production feeding systems for ruminants from low quality diets is to use judicious amounts of supplements to alleviate nutritional'deficiencies in the basal diet, to maintain or increase intake of the basal diet,. to increase the efficiency of utilization of nutrients, and to increase production. However, not all feeds added to a diet will act as a true supplement, since often the feed added will substitute part of the nutrient supply from the basal diet.' Ideally a supplement should maintain or increase intake of the basal dietary material. The important 'distinction therefore is whether the feed material has a *supplementary* effect or a *substitution* effect.

CONDUCT OF FEEDING TRIALS TO ASSESS PRODUCTION RESPONSES TO POTENTIAL FEED SUPPLEMENTS

Feeding trials provide a relatively simple, and yet effective experimental means for defining production responses in animals to specific feed supplements. A production. response in a feeding trial however reflects the complex interaction between many intrinsic and extrinsic factors, and unless the experiment is well designed and conducted, the observed responses may be unrelated to treatment effects.

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* Department of Biochemistry and Nutrition, The University of New England, Armidale, NSW 2351

Results from feeding trials must therefore be interpreted in relation to the methods used in that particular experiment. Although the approach adopted in a feeding trial must be modified according to the specific objectives of each experiment, there are several basic principles which must be applied to all feeding trials to ensure the results are applicable to production systems.

(i) Type of animal In feeding trials designed to define production responses to a particular supplement, animals must be chosen which have a potential for increased production.. The potential for an animal to increase the rate of production is not constant and varies with age and physiological status, previous nutritional history, genetic potential and mature bodyweight of that particular breed. For example, 25 kg finewool Merino lambs would have a lower potential for further growth than would Merino x Border Leicester lambs of similar bodyweight.

(ii) Preparation of diet In feeding trials in which granulated supplements are mixed with roughage diets, it is relatively easy for the animals to select against the supplement. This' is particularly evident with non palatable 'supplements such as urea,' or protein meals such as meatmeal or fishmeal. This problem is often overcome by pelleting the complete ration, however, it is then difficult to determine if the observed response is to the supplement or to the effects of pelleting. Also the heat generated during the pelleting process can reduce the degradability of dietary proteins and change the site of nutrient digestion (Coelho da Silva et al. 1972, Thomson 1972), both effects which can increase production.

An alternative approach has been to spray water soluble supplements such as urea onto the basal dietary material. The addition of water to straws however can increase DM intake by reducing the effects of dust on palatability (Chaturvedi et al. 1973). The rate of ammonia release may also be reduced by spraying urea onto the basal diet. As a result, the efficiency of NPN utilisation for microbial protein synthesis may be considerably increased by providing a continuous source of soluble N in the rumen as opposed to a single dose of urea (Meggison et al. 1979 a,b). Although these factors may ultimately be beneficial to production, they introduce further effects which will confound the interpretation of the observed results in feeding trials. Ideally, the supplements should be offered in the same manner in which they are intended to be used, i.e. as single daily meals, or as meals to be consumed continuously over the day.

(iii) Level of feeding In most ruminant production feeding systems, the basal material is available ad libitum, and the supplements are either mixed with the basal diet, or given as a single meal. If a production response is being monitored, then the animals must be given free access to the basal diet to enable them to express their appetite and growth potential.

Skilful management, attention to detail, and patience are the bases for inducing animals to eat to appetite. The animals must be accustomed to animal house routine before an experiment commences, and they must be fed as close as possible to the same time each day. It is essential that clean water be provided continuously, that feed refusals, be removed each day and that feed troughs be cleaned regularly to remove saliva and feed contaminants.

Animals can be enticed to express their voluntary intake of a diet if the experiment is commenced with the animals consuming restricted amounts of the basal diet and the amount of food offeredis increased slowly over the experimental period. The amount of food offered should be fixed for at least a three day period. If the animal consumed all the feed offered for that period, then the amount of food offered can be increased by 50 - 100 g/d for sheep, or 300 - 500 g/d for cattle.. When sheep are eating to appetite, the refusals should only be 50 - 100 g/d. It has been observed in this laboratory that animals in feeding trials will occasionally refuse to maintain food intake for no apparent reason, and if the amount of food offered is not immediately reduced to an amount less than the previous day's intake, their food intake will be reduced further and it will take longer for them to return to appetite.

(iv) Measurements It is necessary to conduct feeding trials for at least 40 days with lambs and 80 days with cattle to obtain realistic' estimates of food intake and liveweight responses to the treatments- If gut fill is not a random effect but is related to treatment effects, then the variance introduced by gut fill cannot be included in the error term in the statistical model of analysis. Variation associated with gut fill can be reduced to some extent if animals are'weighed after a 16 hour fast at the beginning and end of the feeding period. If the primary aim of a feeding experiment is to define the production response to a particular treatment, then interference with the animals by taking blood or ruminal fluid samples must be avoided if possible.

SUPPLEMENTATION OF LOW PROTEIN DIETS GIVEN TO SHEEP WITH NPN AND BYPASS PROTEINS

The nutritional principles for the use of NPN and bypass protein supplements in ruminant diets have been discussed in detail by Miller (1973), Kempton et al. (1977), Lenq et al. (1977), Kempton and Nolan (1978) and Egan (1981). The portion of a dietary protein that is not degraded in the rumen and passes intact to the intestines is termed a bypass protein, which is synonymous with undegraded dietary protein (UDP) adopted by Roy et al. (1977). A summary of the pen feeding trials with crossbred lambs, conducted at UNE since 1973 to evaluate the relative roles of NPN and bypass protein supplements to low protein diets is given in Table 1.

(i) NPN supplements Supplementation of a low protein cellulosic diet with 2.5% urea (calculated to provide 30 gN/kg OM apparently digested in the rumen) increased liveweight gain by 67 g/d and increased intake of the basal diet by 21%, although this was not significant (Experiment 1). 'This is a typical response to urea supplementation of low quality diets in pen feeding trials (see review Loosli and McDonald 1968).

(ii) Bypass protein supplements Supplementation of a low protein cellulosic diet with a source of soluble protein (casein) did not increase liveweight gain or food intake above that supported by a NPN supplement (Experiment 1). However., treatment of the casein with 1% formaldehyde (Ferguson et al- 1967) such that the protein was resistant to hydrolysis in the rumen and passed intact to the intestines (Kempton et al. 1979), increased liveweight qain by 60% (Experiment 1). It was necessary however for the NPN and bypass protein supplements to be provided together to support this production response. These experiments indicated

TABLE 1

Experiment 1 Basal diet	Treatment	Liveweight gain (g/d)	Intake Basal diet (g/d)	Total DMI(g/d)
Oat hulls, solka Floc (70:30) (Kempton & Leng 1979) (42 days) n = 5	Basal	-40^{a}	507	507^{a}
	+2.5% urea	29^{b}	614	630^{ab}
	+7.5% HCHO-casein	67^{b}	609	654^{b}
	+7.5% casein	71^{b}	610	657^{b}
	+2.5% urea +7.5% HCHO-casein	112^{c}	732	807^{c}
	+2.5% urea +7.5% casein	55^{b}	582	642^{ab}
	SEM	14	45	47
Experiment 2				
Oat hulls, solka Floc (70:30) +2.5% urea (Kempton & Leng 1979) (42 days) n = 8	Basal	14^{a}	634	634
	+15% casein	60^{ab}	606	695
	+10% casein + 5% HCHO-casein	88^{b}	634	726
	+5% casein + 10% HCHO-casin	141^{c}	724	830
	+15% HCHO-casein	109^{bc}	676	776
	SEM	18	48	49
Experiment 3				
Oaten chaff (56 days) n = 4	Basal	10^{a}	493	493
	+2% urea	33^{b}	525	536
	+2% urea + 10% casein	23^{ab}	463	519
	+2% urea + 10% HCHO-casein	50^{c}	553	620
	+2% urea + 5% casein +5% HCHO-casein	59	509	570
	SEM	13	41	43
Experiment 4				
Bagasse, sugar (50:50) (35 days) n = 5	Basal	40^{a}	452	451^{a}
	+12.5% fishmeal	170^{c}	592	665^{bc}
	+25% fishmeal	192	587	734^{c}
	+12.5% rice bran	64^{a}	442	497^{a}
	+25% rice bran	127^{b}	498	622^{b}
	+12.5% rice bran + 12.5% fishmeal	197	583	728^{c}
	SEM	13	31	31

Experiment 5

Basal Diet	Treatment	Liveweight gain (g/d)	Intake Straw	Total DMI(g/d)
Barley straw + 2.5% urea	Basal	20^{a}	393^{a}	415^{a}
Abidin & Kempton (1981) (42 days)	+ 6% protein pellet*	33^{a}	404^{ab}	456^{ab}
	+12%	50^{ab}	433^{ab}	513^{abc}
	+18%	76^{bc}	449^{ab}	565^{bcd}
n = 7	+24%	84^{bc}	501^{b}	657^{d}
	+30%	102^{c}	503^{b}	693^{d}
	+36%	83^{bc}	421^{ab}	627^{cd}
	SEM	4	28	35

Experiment 6

Barley straw + 2% urea	10% protein pellet*	71^{a}	627	724^{a}
Abidin & Kempton (1981) (35 days)	20%	106^{b}	622	784^{b}
	30%	125^{c}	629	856^{c}
n = 6	SEM	6	15	16

* Protein pellet (g/kg) cottonseed meal (800), meat meal (80), soyabean meal (100), NaCl (10), minerals (10).

that on these low protein diets, there was a need to supplement the diet with 1) NPN to maximise the outflow of microbial protein from the rumen and 2) a source of bypass protein to augment the supply of amino acids from microbial protein and to meet the amino acid requirement of the animal for production. The increased production associated with these supplements was attributed to an increased food intake.

Although the protein supplemented diets in Experiment 2 were isonitrogenous, liveweight performance of the lambs was considerably different indicating that food intake and growth rate in ruminants. is not primarily a function of the crude proteincontent of the diet, but rather a function of the total supply of amino acids at the intestines.'

In other growth trials in which lambs were given various low protein, cellulosic diets and supplemented. with either HCHO-casein or various bypass protein meals, growth rate was increased by 50 - 150 g/d and intake of the basal material was either maintained, or increased by 12 - 60% by NPN and bypass protein supplements (see Experiments 3, 4, 5 and 6).

EFFECT OF NPN AND BYPASS PROTEIN SUPPLEMENTS ON FERMENTATION AND NUTRIENT SUPPLY

1. Rumen fermentation and microbial protein synthesis

Detailed metabolic studies in lambs given the low protein cellulosic diets used in Experiments 1 and 2 have shown that the effect of supplementation of these diets with NPN and an undegraded dietary

protein was directly attributable to an increased food intake. Concomitant with the increased food intake was an increase in the production and absorption of fermentation end products. Digestibility of the basal material was not increased by supplementation (Kempton and Leng 1979).

Supplementation of the low protein cellulosic diet with NPN increased the outflow of microbial NAN(gN/d) from the rumen, (by 4 - 7 g N/d) above that on the basal diet. Although microbial NAN flow to the duodenum was increased by NPN and'protein supplementation, the net efficiency of microbial synthesis (microbial N outflow from the rumen/kg FOM) was not different between the basal and supplemented diets (21 gN/kg FOM) (see Figure 1).

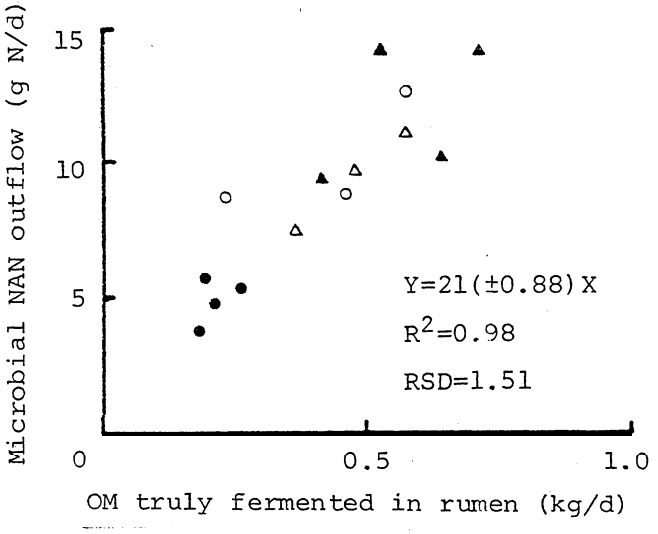


Figure 1. Outflow of microbial NAN in relation to OM truly fermented in the rumen of lambs given low protein cellulosic diets supplemented with NPN and a bypass protein (from Kempton et al. 1979).

That the efficiency of microbial protein synthesis was not increased by any of the supplements, even though voluntary food intake was 80% greater in those lambs receiving the diet containing urea and HCHO-casein, indicates that the supply of microbial protein to the animal was directly related to food intake.

2. Nutrient supply to the animal

Supplementation of the low protein cellulosic diet with 20 g N/d from a soluble protein did not markedly increase the outflow of microbial NAN from the rumen, and so the majority of the supplementary N from the protein was absorbed from the rumen as ammonia. This absorbed ammonia would either be recycled back to the rumen via salivary inputs, or excreted as urea in the urine. Treatment of the soluble protein with formaldehyde to reduce the degradability of the protein in ruminal fluid increased the total supply of NAN at the duodenum from 14 - 34 g N/d, and reduced the loss of N from the rumen as ammonia by 10 g N/d (see Figure 2). It was apparent from these studies that supplementation of these low protein cellulosic diets with NPN and a bypass protein increased food intake and consequently increased the production of fermentation end products and the absorption of nutrients from the digestive tract. Furthermore, the primary factor limiting food intake and the growth of lambs given these diets was the quantity of amino acids of microbial and

dietary origin that were absorbed from the small intestines (see Kempton et al. 1979).

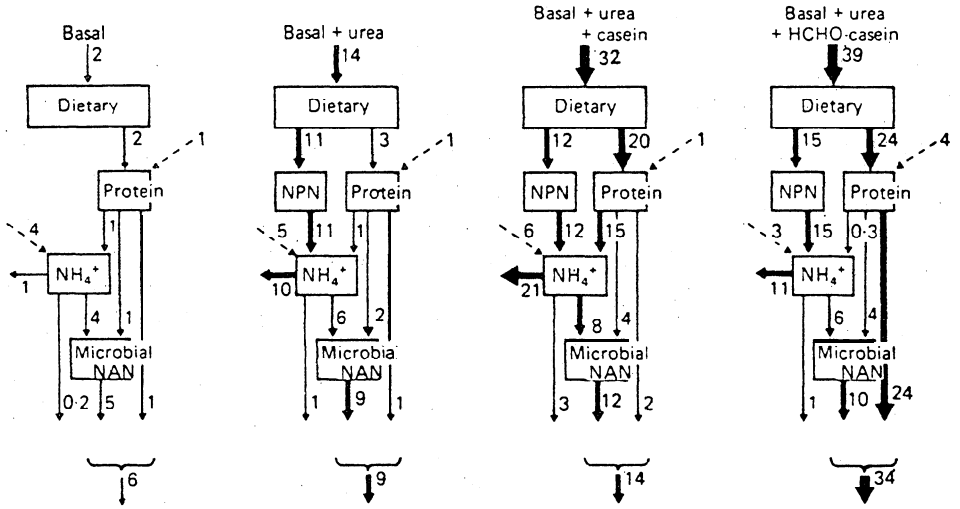


Figure 2. Flows of nitrogen (g N/d) in the rumens of lambs given a basal low protein diet (A), plus urea (B) and either urea plus casein (C) or urea plus formaldehyde-treated (HCHO)-casein (D). Only the major pools and pathways of N transactions in the rumen are shown. NAN, non-ammonia-N: NPN, non-protein-N (from Kempton et al. 1979).

FOOD INTAKE RESPONSES TO NPN AND BYPASS PROTEIN SUPPLEMENTATION

In the lamb growth experiments reported above, the extent to which the intake of basal material was increased by NPN and bypass protein supplementation varied from 0 - 60%. Although the intake of basal material was not increased to the same extent in all experiments by NPN and bypass protein supplementation, it is of major importancethat the intake of the basal material was not reduced by any of the supplements in these experiments. By definition therefore, the bypass proteins acted as true supplements, and, not substitute feeds. By comparison, inclusion of increasing amounts of rolled barley in a diet of field cured hay progressively decreased the voluntary intake of hay by the lambs (Lamb and Eadie 1979), the barley acting as a substitute feed rather than a true supplement.

In mature sheep given a variety of roughage diets, DM intake was directly related to the balance of absorbed nutrients (ie g protein digested in the intestines/MJ ME (Egan 1977). In the studies reported in Experiments 1 and 2, DM intake was increased when the ratio of protein absorbed/MJ ME was increased from 5.5 to 11.6 g/MJ ME by bypass supplementation (Kempton et al. 1979). In lambs given highly digestible diets such as barley grain, both DM intake and liveweight gain were considerably increased by supplementation with NPN and a source of bypass protein (fishmeal) (Ørskov et al. 1973). Taken together, these. studies suggest that in ruminants given diets of differing energy contents, there is an optimum balance of absorbed nutrients at which maximum intake of that diet is achieved.

The disestibility of low quality roughages is not increased by bypass protein supplementation (Kempton and Leng 1979, Hennessy 1981) and so the animal must derive additional energy to support production either from an increased intake of basal material, or. from catabolism of the

supplement (Abidin and Kempton 1981). With low protein, low digestible forages, NPN and bypass protein supplements increase the rate of particle breakdown in the rumen and the rate of clearance of undigested feed residues from the rumen enabling food intake to be increased (Egan 1974, 1977). However, the physical size of the rumen will restrict the extent to which the animal can increase the intake of low quality roughages.

EFFICIENCY OF FOOD UTILISATION FOR GROWTH

Food conversion ratio (kg DM/kg gain) is difficult to interpret in ruminants as it is affected by digestibility of the diet and the level of food intake relative to maintenance (Kempton and Nolan 1978). The efficiency of utilisation of digestible DM above maintenance however. can be determined from the relation (Figure 3) between digestible DM intake (g/d) and liveweight gain (g/d) for the results from the experiments presented above, and for lambs given barley based diets in the experiments of Ørskov et al. (1973), Ørskov et al. (1974) and Fraser and Ørskov (1974) . It was apparent from this relationship that even though DDMI and

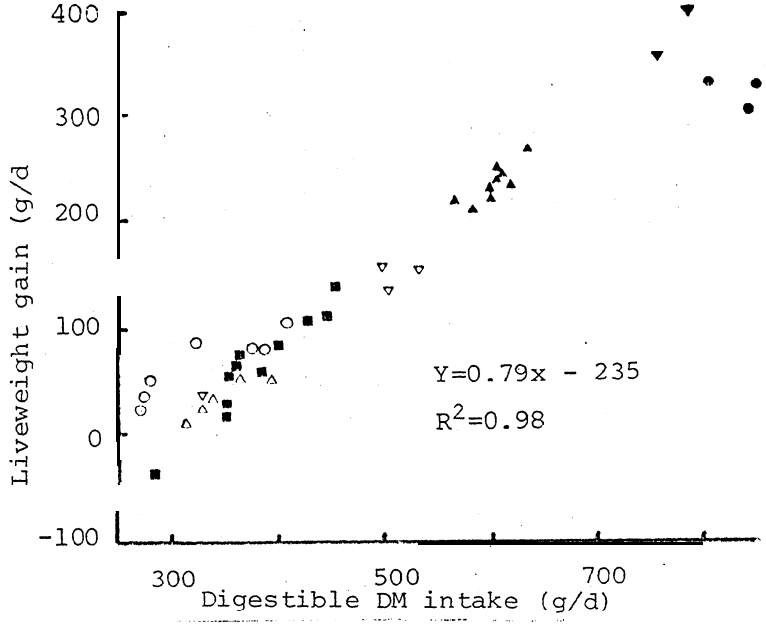


Figure 3. Digestible dry matter intake and liveweight gain of lambs given diets of different energy content, and supplemented with NPN and a bypass protein (■) Kempton and Leng (1979), (△) Experiment 3, (0) Abidin and Kempton (1981), (▲) Ørskov et al. (1974), (▼) Fraser and Ørskov (1974), (●) Orskov et al. (1973).

growth rates were higher in the barley fed lambs 1) the efficiency of utilisation-of DDM above maintenance was relatively constant for all diets and 2) liveweight gain is a function of total digestible nutrient intake and that for animals on each diet, there is a response in both food intake and liveweight gain to optimising the balance of absorbed nutrients by supplementing that diet with NPN and a bypass protein and 3) for production to be increased above that in response to the NPN and bypass protein supplements, the animal must further increase DDM intake. This may not be possible if the animal is consuming diets of low digestibility..

EFFICIENCY OF NUTRIENT UTILISATION FOR WOOL GROWTH

The rate of wool growth in sheep is principally determined by the supply of essential amino acids to the wool follicle, and in particular to the supply of sulphur containing amino acids methionine and cyst(e)ine (Reis 1969). In turn the supply of amino acids to the follicle is determined by (i) competitinq demands for circulating amino acids as determined by the physiological 'status of the animal i.e. the amino acid' requirements for tissue growth., concepta gain or milk production (Kempton 1979), (ii) efficiency of utilisation of absorbed amino acids for wool growth (at most only 10 - 15%) (Hogan et al. 1979), (iii) efficiency of absorption of amino acids from the small intestines (us&ally 75%), (iv) degradability of dietary protein in the rumen, (v) outflow of microbial protein from the rumen, and (vi) protein content of diet and total protein intake.

Although a wool growth response can be achieved by supplementing sheep at pasture with a bypass protein, (Beger, Leng and Hill 1981) , the response will mostly be uneconomic due to the low efficiency of incorporation of absorbed amino acids into the wool follicle.

FACTORS TO BE CONSIDERED IN FORMULATION OF FOOD SUPPLEMENTS TO MEET THE LIMITATIONS TO PRODUCTION ON LOW PROTEIN DIETS

Feed supplements should be formulated according to the order in which nutritional factors will limit production. The aim of supplementation should be to

(i) maximise the outflow of microbial protein from the rumen;

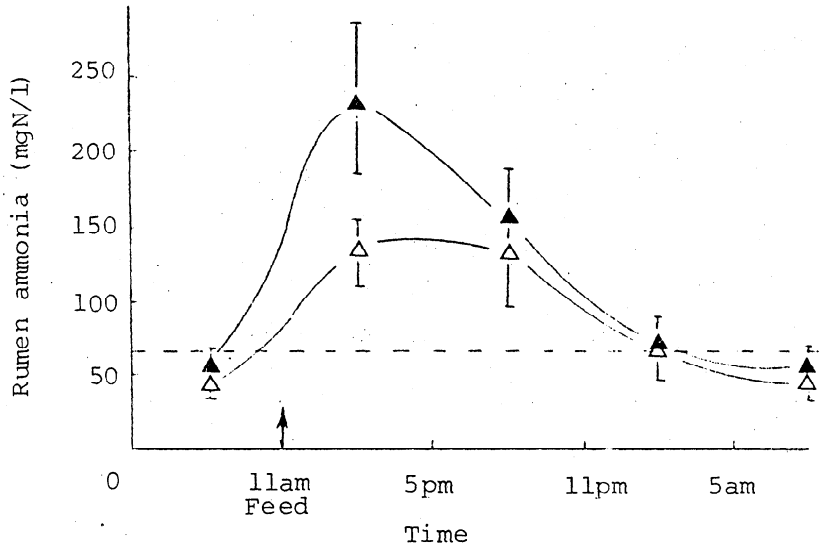
(ii) provide a bypass protein, if necessary, to augment the supply of amino acids from microbial protein to meet the protein requirement of the animal.

(iii) increase ME intake to meet the energy demands for the desired level of production.

(iv) increase the efficiency of absorption of nutrients from the rumen and intestines.

(i) Efficiency of microbial protein synthesis in the rumen The primary aim of supplementing any feed should be to maximise the outflow of microbial protein from the rumen. There is a critical level of ammonia in rumen fluid (20 - 50 mg N/l) below which microbial growth may be impaired or efficiency reduced (Satter and Slyter 1972, 1974). Whenever ammonia concentrations fall below 20-50 mg N/l, which can occur when animals consume low protein, low quality roughages, the rumen microorganisms may be ammonia deficient and may respond to NPN supplements.

Provision of readily soluble NPN supplements such as urea will increase rumen ammonia levels for a short period immediately post feeding, however the ammonia levels may be below the critical level for a period of time until the next intake of supplement (see Figure 4). Under these conditions the outflow of microbial protein may be considerably reduced (Helmer and Bartley 1971) and may contribute in part to the lack of response to urea in the majority of grazing studies (Leng et al; 1973). Initial studies have shown that the efficiency of utilisation of NPN for microbial protein synthesis' in sheep can be considerably increased by providing urea continuously in the rumen, as compared with providing



Fiqure 4. Duirnal variation in ammonia concentrations in ruminal fluid of Zebu bulls given a basal diet of derinded sugarcane and urea (A) and . supplemented with cottonseed meal and sweet potato foraqe (A). The animals were fed once per day. The dotted line represents the critical concentration of ruminal ammonia, below which microbial protein synthesis may be reduced (from Kempton, Nolan, Rowe, Gill, Leng, Stachiw and Preston, unpublished).

the same quantity of urea in a single dose (Meggison et al. 1979a,b). Considerable effort has therefore been directed to develop sustained release urea products which 'release NH_3 over a 12 - 24 hour period as energy is made available from fermentation (Helmer and Bartley 1971, Bartley and Deyoe 1975). Potential methods for controlling the rate of urea release include th use of clay-like materials such as sodium bentonite to absorb ammonia released during the hydrolysis of urea (Martin et al. 1969). Also, when starch and urea are heated together under pressure and fed to ruminants, rumen ammonia concentrations are markedly reduced and microbial protein synthesis increased (Helmer and Bartley 1971). Protein meals which are slowly degraded in the rumen may also act as a slow release source of ammonia. Formulation of supplements in which the rate of ammonia and carbohydrate release are synchronised with the rate of energy release in fermentation may give production responses where no previous response has been achieved to NPN supplements.

(ii) Protein requirements for production The protein requirements of ruminants varies with the physiological status of the animal such that during early growth, late pregnancy and lactation, the supply of amino acids from microbial protein will not meet the amino acid requirements of the animal (Ørskov 1970). In these cases, it is often necessary to augment the supply of protein of microbial origin with a source of bypass protein. The need to supplement a diet with a bypass protein must be assessed from the supply of microbial protein and dietary protein in relation to the protein requirement of the animal and can be calculated by the methods of Roy et al. (1977).

The quantity of bypass protein containing meal to be fed to meet a protein deficit can be determined from a knowledge of the protein content and rumen degradability of the protein meal. The ruminal degradability of protein meals can be determined from the loss of N from the meal in solvents (Craig and Broderick 1981), or from nylon bags suspended in the rumens of the sheep or cattle (Mehrez and Ørskov 1977, Kempton 1980).

(iii) ME requirement for production

The energy requirements of ruminants for maintenance, or for a desired level of production, can be calculated with a degree of precision from the relationships outlined by the Ministry of Agriculture, Fisheries and Food (MAFF) (1975). These calculations however make no allowance for the effects of supplementary feeds. For instance there are no allowances made for substitution or supplementary effects of feeds on food intake; nor are there allowances for the increased efficiency of utilisation of energy for production when the energy supplements are digested postruminally (Preston and Leng 1980). At present,, therefore, it is necessary to calculate the ME requirements for production from methods such as outlined by MAFF (1975), and then to use the nutritional principles of supplementary feeding to formulate feeds which will increase ME intake to the extent required to support the desired level of production.

As discussed above, the intake of low protein roughages with a low ME content (7 MJ ME/kg DM) can be maintained or increased by supplementation with NPN and a bypass protein. However, the animal may be unable to consume sufficient DM to provide the required amount of ME to achieve maximum production, unless the digestibility of the basal diet is increased, or the energy density increased by including an energy supplement in the diet.

Digestibility of low quality roughages can be increased by grinding or pelleting, or treating the roughage with materials such as alkali (NaOH, or NH_3, see Jackson 1977) or SO_2 (Ben-Ghedalia and Miron 1981). Although these techniques increase digestibility, ME intake and production, they have limited practical application to the grazing ruminant industry in Australia.

Alternatively the basal diet can be supplemented with NPN, a bypass protein and a source of energy which when feremented does not inhibit intake of the basal material. The growth responses obtained to heat treated plant protein meals (Hennessey 1981, Abidin and Kempton 1981) may in part relate to the additional energy provided by the supplement, since the plant protein meals used in those studies, contained at most only 40 - 50% protein. 'The protein in these meals would be sufficient to maintain or stimulate intake of the basal diet, whereas the energy in the supplement would support increased production.

In a preliminary experiment to differentiate the effects of various supplements on food intake and production, lambs were given a basal diet of oaten chaff, sugar and urea (60:37:3) and supplemented with isocaloric amounts of various supplements. Each supplement was calculated to provide equivalent to that in 100 g meat meal. Supplementation with meat meal increased intake of the basal diet and increased growth rate by 73 g/d (Figure 5). Conversely supplementation with cereal grains (maize, sorghum, oats) reduced intake of the basal diet and vet maintained the same growth rate as in the control animals indicating ME intake was

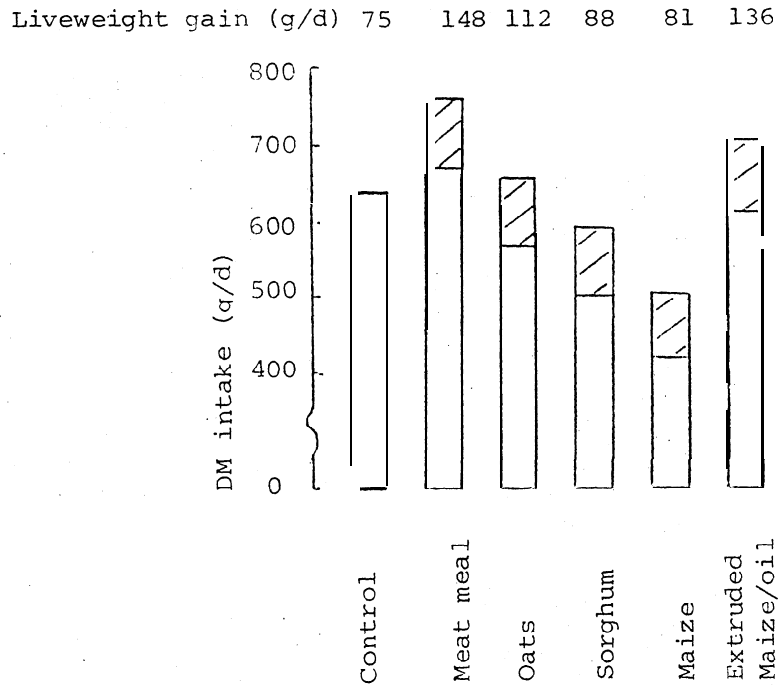


Figure 5. Dry matter intake and liveweight gain of lambs given a low protein diet of oaten chaff, sugar and urea and supplemented with isoenergetic amounts of various feed supplements.

unchanged by supplementation. By comparison, feeding of ground maize, treated with 4% oil and extruded at 150° maintained intake of the basal material and increased ME intake as indicated by the additional 61 g/d growth rate in lambs on this diet. These results suggest that the meat meal acted as a bypass protein supplement and that the cereal grains were substitute feeds.

The substitution effect of these cereal grains on intake apparently is a function of the increased, volatile fatty acid production and absorption associated with the fermentation of these grains in the rumen, since Baile and Mayer (1970) have demonstrated that the quantity of feed eaten by ruminants can be reduced by a concentration change of acetate in ruminal fluid. By comparison intravenous injections of equicaloric amounts of acetate had no effect on appetite indicating the presence of intake controlling receptors in the rumen wall which are receptive to concentration changes in acetate in ruminal fluid. Therefore, provision of energy supplements which do not increase the concentration of acetate in ruminal fluid will enable ruminants to maintain intake of the basal material. The extruded maize/oil supplement used in the experiment reported above was apparently less degradable in ruminal fluid than was whole maize, and therefore maintained intake of the basal material, increased ME intake and increased production. Further research is necessary however to define production responses to providing energy postruminally and to develop processing means to reduce the ruminal fermentability of energy containing supplements.

(iv) Buffering of intestinal digesta

Provision of energy yielding nutrients such as starch postruminally may require specific buffering of intestinal digesta to induce amylase

activity. This is indicated by the studies of Wheeler et al. (1981) in which steers were given high starch diets and supplemented with various levels of calcium carbonate. Inclusion of up to 1.5% $CaCO_3$ with a high acid neutralising capacity increased growth rate, pH of intestinal digesta, faecal pH and reduced faecal starch content (Wheeler and Noller '1977, Ferreira et al. 1980, Wheeler et al. 1981). Evaluation of other buffers such as sodium bentonite and the site of action of these buffers need to be defined to enable formulation of supplements which contain a buffer suitable to increase the efficiency of utilisation of the supplementary nutrients.

CONCLUSION

The rate of production of ruminants from low protein diets is restricted by the low intake of digestible nutrients. Supplementation with a source of NPN and bypass protein will increase amino acid supply to the animal and increase food intake. Intake of low quality diets is ultimately restricted by the physical size of the rumen such that the animals may be unable to consume sufficient DM to meet the energy requirements for maximum production. Since the efficiency of microbial protein synthesis in the rumen (g N/kg FOM) and the efficiency of nutrient utilisation for growth (g gain/g digestible DM intake) is not increased by supplementation, ME intake must be increased by alternate means. Under these conditions ME intake can be increased by increasing the digestibility of the basal dietary material, or by supplementing with an energy form which does not suppress intake of the basal material.

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