Ruminant Nutrition and Production in the Tropics and Subtropics

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Preface

Nitrogen metabolism has been extensively studied in animals fed at a level adequate to maintain moderate or high levels of production. Much less attention has been given to events in the digestive tract of animals struggling to maintain some productivity or in some instances having difficulty surviving because of the low plane of nutrition available to them. Yet for part of every year this is the fate of ruminants in subtropical and tropical regions which support the bulk of the worlds' population both of humans and of herbivores. These animals depend almost entirely on nutrients obtained from natural pastures which rise and fall in nutritional value according to the season. As the rainy season is replaced by a dry period soil moisture becomes inadequate to support plant growth.

Reliance on animal power to produce human food creates a demand for ruminant animals in the countries of these regions. These animals may ultimately become human food and present unique nutritional problems that exacerbate generally low animal productivity. These regions are characterised by low income per household and a high proportion of farming households where the burden of farm debts is often high and the financial returns from animal products relatively low. It is therefore these regions that have the greatest potential for the improvement of animal production but the least financial capacity to adopt known technologies. These regions must therefore accept the reality of quite different production targets based around animals perhaps with lower productive potential than imported breeds but with greater ability to adapt to the stresses of the environment. Best use must be made of the feeds adapted to that environment and increased efficiency of production achieved by the application of established nutritional principles.

This monograph was commissioned by the Australian Centre for International Agricultural Research to collate information pertinent to the feeding of ruminant animals in these regions. In the past half century scientific research into the nutrition of ruminants has resulted in the development of feeding systems pertinent to animals bred for temperate and Mediterranean climatic zones and fed on diets both produced in those zones and designed to achieve production targets approaching the genetic potential of individual animals. It is the aim of this monograph to establish:

- the relevance to tropical cattle fed tropical grasses of the nutritional principles of nitrogen metabolism developed in temperate regions; and
- the applicability of nutritional principles to the use of non-protein nitrogen and protein as supplements to improve the efficiency of animal production.

The first section of this monograph is intended to explore the principles of nitrogen metabolism in ruminants, to describe the ways in which important measurements are made, to discuss the relationship between nitrogen and energy metabolism, to indicate relatively simple ways in which deficiencies of nitrogen can be diagnosed and to explore practical ways to overcome such deficiencies. The second section presents information from animal production scientists in tropical and subtropical countries on the systems of animal production, the nutrition of animals and the use of nitrogenous supplements in those countries.

Feeding Systems: a Preamble

J. HOGAN

T HE advances made in the last half century in our understanding of the principles of ruminant nutrition have led to the production of feeding systems or models describing the nutrient needs of different classes of animals. These systems find direct application with animals maintained in barns or feedlots; in these situations it is possible to compute the production responses to be expected from the supply of a given amount of feed of known quality and hence to formulate least-cost rations to achieve a production target.

This system is clearly less applicable for the vast proportion of the world's ruminants that obtain most of their nutrients by grazing or browsing. Nutrient needs of many of these animals vary from those of their pen-fed counterparts to an extent dictated by environmental stresses. Similarly the quality of the diet available, while subject to improvement through selective grazing, is apt to be far more variable and dependent on climatic conditions.

In the dry summers associated with Mediterranean climates and in the tropical dry winters when plant growth largely ceases, the diet of the grazing animal soon advances in maturity and declines in quality to an extent not envisaged in most of the published feeding systems. These are the conditions under which the ability of the animal to derive nutrients from the diet are restricted, not only by the highly refractory nature of plant fibre to microbial attack, but also by the decline of protein and minerals to inadequate levels for both the fermentative microbes and the tissues of the animal. As a consequence, all aspects of animal production are dominated by climate.

Natural pastures exist as a result of adaptation to the climate, but adaptive ability is often associated with decreased nutritional value. Introduced pasture species will survive only if they are capable of similar adaptation. The choice of ruminant species and especially of cattle is determined to a large extent by ability to adapt to climatic stresses but as with pasture species a penalty must be paid in terms of lower potential productivity. However as indicated earlier, the most direct effect of climate relates to its restriction on animal management practices. The inability of a pasture to grow for more than a few months of the year restricts the grazing pressure that can be applied during that period. Hence grazing cannot be used to maintain the pasture in a vegetative state and even during the period of adequate rainfall the diet of the animal increases rapidly in maturity. Maturation advances even more rapidly as soil moisture becomes

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increasingly inadequate until the death of the plant occurs. The diet of the animal until the next effective rain then consists of seed pods or dead aerial material which declines in value either as the grazing animal selects the more nutritious parts of the plant or more disastrously through leaching or mould formation following the receipt of small amounts of moisture as showers or dew.

In the tropics animal production is dominated by the reliability and length of the wet season and this determines the nature of the animal production enterprise. Weight gain in Zebu × Shorthorn cattle in northern Australia is about 1 kg/day of the wet season and hence areas with a relatively short wet season are better suited to cattle breeding than fattening enterprises. However in both situations only a relatively low annual productivity can be expected as the feed available changes in quality from supra-maintenance to maintenance and finally sub-maintenance. A short wet season is of course associated with a long dry season during which the decline in feed quality may cause weight loss of such magnitude as to threaten the life of the animal. The reliability of the wet season which reflects the probability that the normal dry season will extend into drought further affects animal management. Drought risk often dictates the composition of the herd which usually comprises relatively small numbers of the most vulnerable animals, the breeding females, in association with a high proportion of relatively slow growing castrate male progeny.

Tropical animal production, dependent on the climate-regulated supply of feed, has developed into a relatively inefficient, low cost, low return system. Profitability permits the expenditure of only minimal amounts of money on supplements and hence the aim is to maximise the intake and digestibility of roughage by supplying limiting nutrients. These usually comprise minerals and sources of ammonia such as urea for rumen microbes. If the animal continues to lose weight at a rate faster than desired, protein to supply amino acids to the tissues is then added to the supplement and if that is not adequate, additional sources of energy must be provided. However energy supplied as grain or molasses is generally expensive and has the further disadvantage of acting partly as a substitute rather than as a supplement for roughage.

Supplementary feeding of tropical ruminants must then be seen as a least-cost system which is integrated into the management of an enterprise with low stocking rates tolerating some annual weight loss and expecting a relatively low reproduction rate and annual weight gain. Within such a management system provision must be made to feed only those animals with the greatest need and to ensure the safe and uniform distribution of supply to the target animals. Finally, care must be taken that supplementary feeding does not lead to the overgrazing of part or all of the feed resource with irreversible damage to what is generally a fragile ecosystem.

Part 1. Principles of Ruminant Nutrition

Methods for Studying Ruminant Nutrition

J. HOGAN

Pastures represent the cheapest source of ruminant feed and sustain most animal production systems worldwide. Production of animal feed is driven by the three climatic variables—temperature, light and moisture—and by properties of the soil. In tropical regions, as Fitzpatrick and Nix (1970) indicated, temperature and light generally do not limit plant production. However effective soil moisture, in a region where potential evaporation exceeds precipitation every day of the year, is the dominant factor determining the rate of pasture growth and the period of the year over which the growth of green feed extends. Recent modelling (Jones et al. 1990) shows a linear relationship between 'green days' and annual weight gain in cattle. The slope of this relationship presumably varies in climatic regions where temperature and light rather than moisture limit plant growth and where the contribution of temperate rather than tropical pasture species might be more important. The physical and chemical properties of the soils in any climatic zone will determine the relative quantity of pasture produced but deficiency of particular minerals may reduce both quantity and nutritional value of pasture.

In pastoral systems the aim is to achieve the most efficient conversion of pasture to animal products with minimal damage to the environment. This requires knowledge on which to base management systems that determine the amounts of pasture removed at different times of the year. Management systems too must take into account the probability of droughts, that is, the extension of the annual dry season or seasons for weeks, months or even years. The pasture scientist can contribute by introducing better pasture species, by identifying and correcting mineral deficiencies and by developing grazing strategies to achieve maximum production with minimal environmental damage. Most importantly, by measuring such aspects of animal production as annual weight gain and reproductive performance, the scientist can determine whether and when productivity is less than might be expected. It then becomes the particular province of the animal nutritionist to contribute to the solution of the problem.

In the present context of determining the nature and timing of nitrogen supplementation to ruminants there is need to define research approaches to ruminant nutrition. These are represented by six broad categories (Fig. 1). The

first two involve production studies with grazing animals or with animals fed specific diets in pens, and the others, more detailed studies of nutrient balance and of diet digestibility, of release of nutrients in the digestive tract, and of the metabolism of nutrients in the tissues.
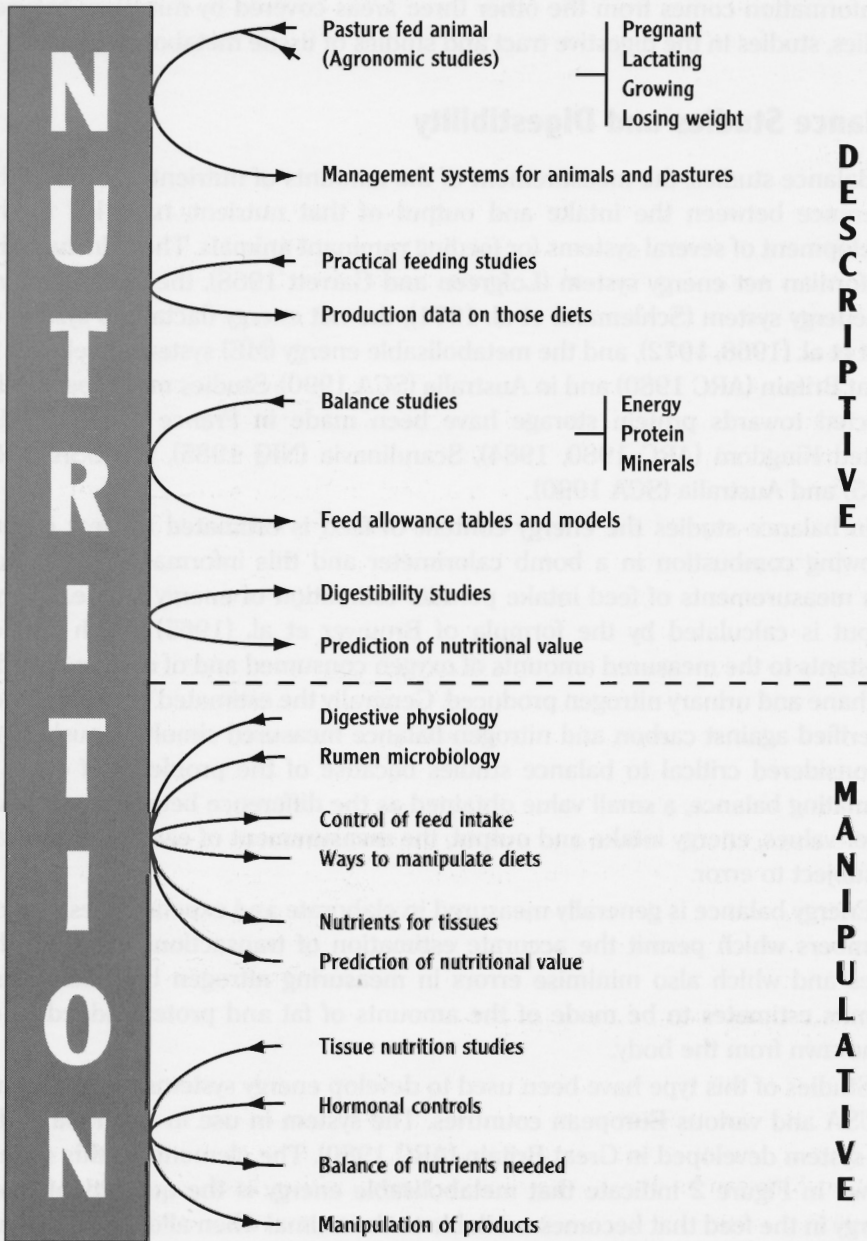
Grazing

As most ruminants, apart from intensively fed dairy cows, derive most of their nutrients from pasture, the grazing animal is central to the whole animal production system. Studies of such animals have led to

· the development of models based on soil and pasture variables to predict forage production;
· from this the prediction of animal production, and where observed values are less than predicted, the indication of nutritional problems;
· improved animal nutrition through the provision of pasture species of higher nutritional value or through better animal and pasture management;
· the development of techniques to increase production efficiency by the application of information developed with nutritional research; and
· the development of management systems to maximise the conversion of pasture to animal products in a sustainable way.

This is a system in which it is difficult for the nutritionist to work. There is little control over the nutritional value of the diet selected and, provided the amount of herbage available exceeds some minimal value, no control over the amount eaten. Techniques to measure the amount of feed eaten are also imprecise. Accordingly, while principles relating to animal × pasture interactions can be deduced it is difficult to use the grazing animal to develop principles of nutrition. These can best be developed under more controlled feeding conditions with animals held in pens and then applied to improve the efficiency of conversion of pasture into animal products.

Studies with Pen Fed Animals

The advantage of working with animals in pens is knowledge of the intake and composition of feed offered. Hence data can accumulate on the productivity of animals in response to particular diets and from these data general relationships can be drawn regarding diet composition, level of feeding and such production responses as milk production and weight gain. Hence studies of this kind form the basis of ration compounding for high production dairy cows and cattle being fattened in feedlots. They are accurate for the type of feed used. However as with the grazing animal, the pen-fed animal does not provide a great deal of information either on the mechanisms by which improved use of feeds

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Pasture fed animal
(Agronomic studies)

Pregnant
Lactating
Growing
Losing weight

D E S C R I P T I V E

Management systems for animals and pastures

Practical feeding studies

Production data on those diets

Balance studies

Energy
Protein
Minerals

Feed allowance tables and models

Digestibility studies

Prediction of nutritional value

Digestive physiology

Rumen microbiology

Control of feed intake

Ways to manipulate diets

Nutrients for tissues

Prediction of nutritional value

Tissue nutrition studies

Hormonal controls

Balance of nutrients needed

Manipulation of products

M A N I P U L A T I V E

Figure 1. Six broad approaches to the study of nutrition, indicating the nature of research inputs and the knowledge generated by those approaches.

may occur or conversely on reasons for unexpectedly poor productivity. This type of information comes from the other three areas covered by nutrition; balance studies, studies in the digestive tract and studies of tissue metabolism.
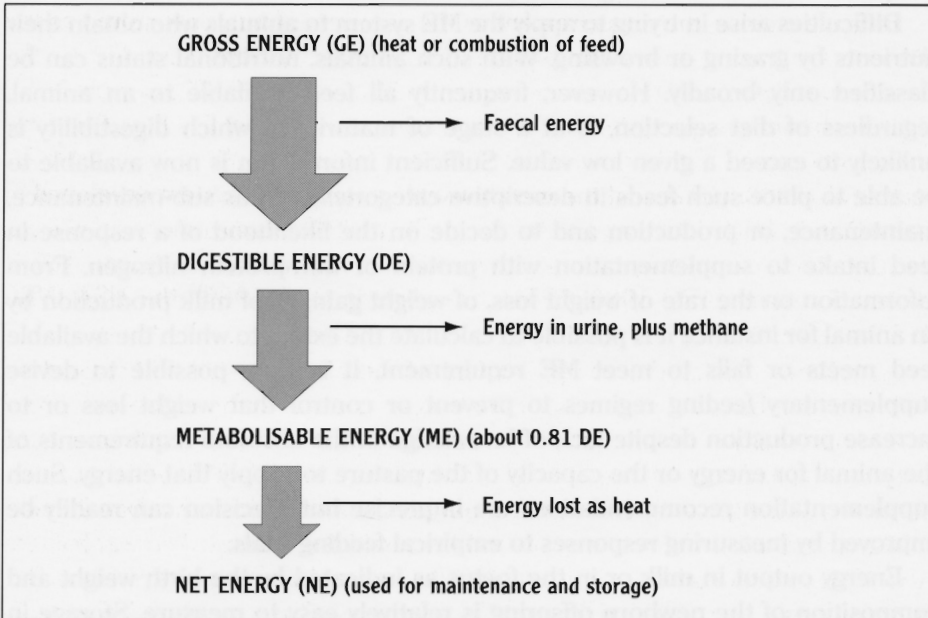
Balance Studies and Digestibility

Balance studies, the measurement of the amounts of nutrients stored as the difference between the intake and output of that nutrient, have led to the development of several systems for feeding ruminant animals. These include the Californian net energy system (Lofgreen and Garrett 1968), the East Germany net energy system (Schiemann et al. 1971), the net energy (lactation) system of Flatt et al. (1968, 1972), and the metabolisable energy (ME) system developed in Great Britain (ARC 1980) and in Australia (SCA 1990). Studies more specifically directed towards protein storage have been made in France (Verité 1979), United Kingdom (ARC 1980, 1984), Scandinavia (NKJ 1985), the USA (NRC 1985) and Australia (SCA 1990).

In balance studies the energy content of feed is estimated as heat output following combustion in a bomb calorimeter and this information combined with measurements of feed intake permits estimation of energy intake. Energy output is calculated by the formula of Brouwer et al. (1965) which applies constants to the measured amounts of oxygen consumed and of carbon dioxide, methane and urinary nitrogen produced. Generally the estimated energy balance is verified against carbon and nitrogen balance measured simultaneously. This is considered critical to balance studies because of the problems of error in estimating balance, a small value obtained as the difference between two much larger values, energy intake and output, the measurement of each of which can be subject to error.

Energy balance is generally measured in elaborate and expensive respiration chambers which permit the accurate estimation of transactions involving the gases and which also minimise errors in measuring nitrogen balance. It also permits estimates to be made of the amounts of fat and protein added to or withdrawn from the body.

Studies of this type have been used to develop energy systems for ruminants in USA and various European countries. The system in use in Australia is the ME system developed in Great Britain (ARC 1980). The elements of this system shown in Figure 2 indicate that metabolisable energy is the quantity of gross energy in the feed that becomes available to the animal when allowance is made for wastage in the faeces and urine and in the fermentation gases. The complication arises when consideration is given to the efficiency with which ME is used. It is appreciated that ME is used with greater efficiency for the maintenance of body weight than for production purposes such as storage in

weight gain, the developing foetus, or in milk, because during these processes varying amounts of ME are dissipated as heat. It is also appreciated that the efficiency of use of ME varies with the quality of the diet. Corrections to take this latter variability into account include a 'quality factor', q, which is calculated as ME/GE, where GE is the gross energy of the diet.

GROSS ENERGY (GE) (heat or combustion of feed)

→ Faecal energy

DIGESTIBLE ENERGY (DE)

→ Energy in urine, plus methane

METABOLISABLE ENERGY (ME) (about 0.81 DE)

→ Energy lost as heat

NET ENERGY (NE) (used for maintenance and storage)

Figure 2. Descriptions of feed energy.

In the absence of the sophisticated equipment needed to estimate energy balance in respiration chambers, valuable information on ME requirements can be obtained by the 'regression method'. In this approach long-term weight change is plotted against feed intake. The calculated amount of feed required to maintain zero weight change is then regarded as the maintenance requirement. When this has been established, the efficiency of conversion of surplus energy to products can readily be calculated.

Reasonable estimates of ME intake can also be made from the simpler measurement of intake of digestible organic matter (DOM), a variable calculated as the difference between organic matter (OM) intake and faecal OM output. The calculation assumes that the OM in forage diets contains approximately 19.2 MJ gross energy, that the digestibility of OM equals that of energy and that ME is equivalent to 0.81 digestible energy (DE). On this basis 1 kg DOM is equivalent to about 15.6 MJ ME.

A forage with OM digestibility of 60% would then provide 0.6 kg DOM/kg OM or $0.6 \times 19.2 = 11.5$ MJ/kg DE. As ME = 0.81 DE, the ME value would be $11.5 \times 0.81 = 9.3$ MJ/kg OM.

This calculation can be made with data derived from studies of feeds incubated in fibre bags in the rumen or incubated in vitro provided control samples of known in vivo digestibility are included as controls.

Difficulties arise in trying to apply the ME system to animals who obtain their nutrients by grazing or browsing. With such animals, nutritional status can be classified only broadly. However, frequently all feed available to an animal, regardless of diet selection, is at a stage of maturity at which digestibility is unlikely to exceed a given low value. Sufficient information is now available to be able to place such feeds in descriptive categories such as sub-maintenance, maintenance, or production and to decide on the likelihood of a response in feed intake to supplementation with protein or non-protein nitrogen. From information on the rate of weight loss, of weight gain, or of milk production by an animal for instance it is possible to calculate the extent to which the available feed meets or fails to meet ME requirement. It is then possible to devise supplementary feeding regimes to prevent or control that weight loss or to increase production despite lack of knowledge of the absolute requirements of the animal for energy or the capacity of the pasture to supply that energy. Such supplementation recommendations are imprecise but precision can readily be improved by measuring responses to empirical feeding trials.

Energy output in milk or in the foetus as indicated by the birth weight and composition of the newborn offspring is relatively easy to measure. Storage in the animal is more difficult because of variations in the proportions of fat, protein, and water stored in weight gain. Techniques to estimate these components are based either on the analysis of carcass composition after slaughter or on predictions from the dilution of reference substances 'markers' that after injection are mixed with one or other of the major components. Both approaches have limitations. The slaughter technique permits only one observation per beast and derives information on the composition of weight gain from differences between groups of animals slaughtered before, during, and at the end of an experimental period. Errors can be caused by the inadequate choice of animals in groups, by losses during the analysis of carcass samples, and by analytical errors. Indirect techniques depend on an inverse relationship between water and fat in the carcass and on the storage of a relatively fixed proportion of minerals in body weight change. Reference substances such as tritiated water or deuterium oxide injected into an animal are allowed to equilibrate over perhaps six hours when it is assumed that the injected molecules have mixed intimately with all the water molecules in the animal. Analysis of the water in samples of blood permits estimation of the extent of

dilution of the reference substance in the animal and hence calculation of total body water. The proportions of fat and protein are then estimated from regression equations previously obtained by carcass analysis. This technique permits repeated measurements to be made on the same animal. However there are concerns about the possible errors involved in applying regression equations developed with a particular species and genotype in a given body condition and on a particular feed ration to other genotypes in quite different body condition. This is particularly true of animals suffering severe depletion of body protein and fat as a result of undernutrition. The regression relationship attempts to take into account variations in the amount of water in the digestive tract. Attempts are made to minimise variability by imposing a feed- and water-free period of perhaps 16 hours on the animal before injection of the reference substance. However, calculations from Weston (1985) indicate that with diets of varying quality, cattle may have water in the rumen, expressed as g/kg body weight, free of reticulo-rumen digesta, ranging from 105 to 183; this is equivalent, in a 350 kg beast, to 37 to 64 L. Regression equations developed with an animal held under the first set of dietary conditions would be in some error when applied to the other.

The most serious problem with use of the indirect techniques comes in the assessment of composition of body weight gain. Again errors occur in measuring the composition of relatively small weight changes as the differences between two larger quantities. For instance to assess the amount of fat and protein stored in animals growing from 350 to 400 kg, it is necessary to make estimates of protein and fat content of the animals at the two body weights and then to subtract them. The difference is subject to the errors in the two estimates. They may cancel out, they may be additive, or they may represent some combination of the two. The results should obviously be treated with caution. It is equally clear that for the most accurate predictions the change in body weight over which composition is measured should be as large as possible. Some of the variability in estimates is illustrated by the data in Table 1. In six Merino wethers the proportions of protein and fat were reasonably consistent in relation to body weight but were much more variable in weight gain.

Studies based on nutrient balance are therefore clearly subject to errors but despite limitations they have provided a framework on which to build an understanding of animal performance against nutrient intake. There are clearly inadequacies in the information available on mature forages but studies of the type made in Malaysia (e.g. Devendra and Wan Zahari 1981; Liang et al. 1988) will help to fill the gap in knowledge. Balance studies, too, do not adequately explain intermediary processes occurring in the animal and information on these must be sought by the nutritional investigations conducted in the digestive tract and the tissues.

Table 1. Estimated levels of fat and protein in the weight gain in Merino wethers fed roughage ad libitum for 180 days. (Body weights are 48-hour fasted and fleece-free.)

Sheep	Body weight (kg)		Body fat (g/kg)		Body protein (g/kg)	
	Initial	Final	Initial	Final	Initial	Final
1	44.1	51.3	217	256	135	130
2	45.5	57.4	237	296	133	126
3	43.5	48.1	225	287	135	127
4	43.6	52.7	169	263	140	129
5	44.6	51.6	229	274	134	128
6	45.2	50.4	322	302	124	125

Source: T.W. Searle and J.P. Hogan (unpublished data)

Events in the Digestive Tract

Although ruminant feeding systems have been based largely on balance studies they include many factors derived from quantitative studies of events in the digestive tract. Pertinent information has come from estimates of the site and extent of digestion of carbohydrates and especially of lignocellulose and of the extent of release and variation in proportions of volatile fatty acids. Significant to the present context, are the studies that have been made of the breakdown of dietary proteins, the subsequent synthesis of microbial proteins in the rumen, and the fate of those proteins in the intestine. In addition an understanding has been achieved of the fate of lipids and of minerals in the digestive tract.

Some of the work involving, for instance, the rate of production of volatile fatty acids and the contribution of microbes to the proteins leaving the stomach depends on techniques involving the dilution of radioisotopes of carbon, hydrogen, sulfur, or phosphorus, or of the stable isotope of nitrogen.

Most studies of the fate of proteins or fibre in the ruminant digestive tract are made by determining the difference between the amounts entering or leaving a given section of the tract. The accuracy of estimates of a relatively small value obtained by the difference between two larger values again is subject to unknown but potentially large errors. The precautions needed to help obtain accurate estimates and the reactions pertaining to bacterial growth are discussed in later sections.

Protein nutrition in the tissues of the ruminant differs very little from that in monogastric animals. Ruminant tissues are not able to synthesise some amino acids which are accordingly called 'indispensable' or 'essential' and must rely on

their absorption following protein digestion in the small intestine. Further, the amounts of both essential and 'non-essential' amino acids supplied to the tissues must be adequate to match the metabolic reactions that are driven primarily by the supply of energy. If this does not occur the diet is said to be imbalanced.

Protein to energy imbalance may first affect the rumen microbes through an inadequate supply of ammonia. Microbial cells contain 50 to 60% protein and with many rumen bacteria this protein can be synthesised from ammonia. Cellulolytic bacteria responsible for the initial attack on plant fibre appear to require ammonia in concentrations no greater than 40–50 mg N/L. Other bacteria in the rumen seem to have higher ammonia requirements. Ammonia concentrations in the rumen with animals fed temperate forages can be predicted from the ratio of digestible organic matter intake (DOM) to crude protein intake (CPI). A DOM:CP ratio above about 7:1 which would correspond to a forage of 50% digestibility with a crude protein content of 7.1% would indicate that ammonia levels might need to be increased by the provision of nitrogen supplements. A similar situation could be anticipated with tropical grasses with which the DOM:CP ratio exceeded 5:1.

The protein that passes in the digesta to the small intestine is derived largely from two sources. With forage diets at least, a relatively small part is plant protein that has passed through the rumen unfermented; the greater part represents cells synthesised in the rumen. With forage diets of a particular type a relatively fixed proportion of protein escapes fermentation. The microbial component can be predicted from the intake of DOM. The mixture of proteins that passes to the small intestine comprises about 80% amino acids and about 75% of these are absorbed during passage through that organ. Hence amino acid supply can be predicted from knowledge of DOM and CP intakes.

Studies of Tissue Metabolism

Animals maintain body function and produce saleable products by metabolising the nutrients derived from the digestive tract in the tissues. This is the second major area in which the nutrition of the animal can be manipulated. The broad principles by which energy is released as high energy phosphates from carbohydrates, the pathways involved in the catabolism of the main metabolic fuels for the ruminant, acetate, propionate and butyrate, and the processes involved in the conversion of amino acids to protein are well known. Of more importance to the nutritionist is the development of techniques to manipulate the relative proportions of nutrients and the effectiveness of their use to improve the efficiency of conversion of nutrients to animal products. Studies of the rates of synthesis of animal products can be made by

measurements on carcase meat, on wool, or on milk. However in the living animal the most significant measures are those aimed to determine the fate of amino acids.

The techniques involve the intra-arterial infusion of amino acids labelled with ^{15}N, ^{3}H, ^{14}C or ^{35}S and the determination of the uptake of those amino acids as the arterial blood passes through the tissues. Frequently the hind limb of the animal is used for this work as this permits access to an isolated mass of muscle in which the blood supply can be monitored and measured. Hence the labelled amino acids can be provided to the muscle and the quantities of reaction products in the blood draining the muscle measured. In this type of preparation the expired air can also be monitored for ^{14}C carbon dioxide.

From studies of this type has come the realisation that the amount of protein stored each day in weight gain represents the difference between the amount synthesised and that catabolised. These transactions may be quite extensive compared with net protein storage. MacRae and Lobley (1991) for instance indicated that a net storage of 125 g protein/day came from the synthesis of 2556 g protein and the catabolism of 2431 g. The net rate of protein storage can be improved by increasing synthesis, decreasing breakdown or both. This was illustrated by MacRae and Lobley (1991) in three examples. In the first, trenbolone acetate administered to steers had no effect on protein synthesis but reduced catabolism. In the second the administration of growth hormone increased protein synthesis to a greater extent than it increased breakdown. In the third situation, clenbuterol increased synthesis and decreased degradation. Agents such as anabolic steroids are used to stimulate growth in cattle. Under northern Australian conditions cattle gaining 100 kg live weight/year should add a further 8-15 kg in response to a long-acting hormone growth promotant implanted subcutaneously. The use of such chemicals is not permitted in some countries. Although not scientifically justified, the ban is serving a useful purpose in stimulating research to develop 'natural' growth promoting substances. Vaccines to stimulate the slightly increased secretion of growth hormone, for instance, could be acceptable to countries opposed to the use of anabolic steroids. Attempts have also been made to achieve the same end by manipulation of the genetic structure of animals. Transgenic animals capable of secreting increased amounts of growth hormone have been produced. With rats and mice this has resulted in major increases in growth rates but attempts with pigs and sheep have been less successful. Nevertheless as knowledge of the genetic control of growth increases, transgenesis may have a major impact on research into animal growth.

These advances will require reconsideration of nutrition. At present most animals dependent on forages produce at levels appreciably below their genetic potential because of inability to derive adequate nutrients. If the genetic

potential is increased without a corresponding improvement in feed, intake or the release of nutrients from that feed, the gap between potential and actual production will widen. In addition, changes in tissue metabolism may have unexpected consequences for the animal. For instance it was observed by Hunter and Magner (1990) that the reduction in protein catabolism by trenbolone acetate reduced urea recycling to the rumen and thus caused a decline in feed intake. Protein catabolism was reduced and additional nitrogen as urea had to be supplied to the rumen to maintain feed intake. This is an important observation. Inadequate supply of N to the rumen was shown earlier to be predictable from an unsatisfactory DOM:CP ratio in the diet. The observation of Hunter and Magner (1990), serves as a warning that the diversion of amino acids to other uses or the manipulation of amino acid transactions within the tissues can induce a deficiency of ammonia for rumen microbes. Hence in animals receiving growth promoting agents DOM:CP ratio to predict ammonia levels should be used with caution.

Conclusion

It is clear that, while our understanding of the nutrition of ruminant animals is far from complete, the research of the past half century has provided a reasonable basis on which to build. Recommended feeding allowances are reliable for European breeds of cattle fed on forages grown in temperate and Mediterranean environments. They must be used with care when applied to tropically adapted animal breeds fed on forages also adapted to tropical regions, mainly because too few studies have been made of that situation. However the general principles underlying energy, protein, and mineral nutrition appear to apply and the development of accurate feeding systems will certainly follow when more measurements have been made.

For the present it is possible to diagnose the presence of nutrient imbalances and to devise supplementary feeding strategies to overcome them. When this has been done it appears that tropical grasses are used by sheep and cattle in a similar way to temperate species.

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Measurement of Nitrogen Transactions

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Progress in understanding protein nutrition depends on ability to measure transactions in the animal involving nitrogen. These transactions include the balance between intake and excretion of nitrogen, events concerning nitrogen metabolism in the ruminant stomach and intestines, and ultimately amino acid metabolism in the tissues. The reliability of conclusions drawn depends on the accuracy with which measurements are made. This chapter comments on points of technique and sources of error observed in making these measurements.

Nitrogen Balance Studies

Studies of nitrogen balance made in conjunction with energy balance were discussed in the previous section. They are generally made with careful attention to accuracy because any errors in nitrogen balance will cast doubts on estimates of energy balance made by other means. Less care is usually taken with balance studies made as part of an estimate of digestibility of feed and the results obtained have correspondingly greater chance of error. Sources of error with animals held in metabolism pens include

·   inadequate mixing and sampling of feed;
·   spillage of feed into pen, with some spilled feed included in estimate of nitrogen in excreta;
·   losses of faeces from the pen, especially with sheep and goats;
·   incomplete collection and preservation of urine;
·   inadequate sampling and storage of faeces and urine; and
·   inadequate analysis of feed and excreta.

Much has been written about these various sources of error. The main point to be considered here is the volatility of nitrogen when it is converted into ammonia as readily happens in excreta.

Practical guides in estimating balance

Feed mixing. Bulky feeds such as hays are generally purchased in bales that may weigh 10 to 500 kg. Adequate mixing of feeds to ensure an even supply to the animal and accurate sampling for analyses is often difficult. With feed supplied

in the smaller packages, bales are removed at random from the stack. If the hay is fed without further processing, a small sample is removed from each bale to make up a composite sample for analysis. Often the hay is chopped and bagged before being fed in balance studies. The chopped feed can be mixed in mechanical mixers but this is difficult with big lots of roughage. Alternatively the bags can be poured out onto a clean floor in a large circle and mixed manually with shovels or forks before re-bagging.

The addition of finely ground material such as protein concentrates or minerals to chopped hay may also be made in a mechanical mixer. Minerals, and especially those given in small amounts, such as trace elements, can be brought into solution and sprayed or sprinkled into the roughage while mixing is in progress. If the amount of water added raises the moisture content of the roughage by only 1 to 2% no mould development should occur. Although most minerals exist in forms that can be brought into solution, not all can be mixed together as precipitation can occur.

A suitable mineral supplement for mature hay could be formulated to provide (mg/kg hay) $NaH_2PO_4.H_2O$ 1.5×10^4, $CaCO_3$ 1.0×10^4, Na_2SO_4 2.0×10^3, $MgCO_3$ 1×10^3 $(NH_4)_2SO_4.FeSO_4.6H_2O$ 2.0×10^2, $ZnSO_4.7H_2O$ 63, $CuSO_4.5H_2O$ 14, $MnSO_4.H_2O$ 10, $CoCl_2.6H_2O$ 6, $(NH_4)2$ MoO_4 6, KI 1.8, $Na_2SeO_4. 10 H_2O$ 1.4 (Weston and Hogan 1967). With this mixture the first four ingredients were added as dry powders or crystals, the remainder as solutions made up as (w/v) $(NH4)_2SO_4.FeSO_4.6H_2O$ 20%, $ZnSO_4.7H_2O$ 45%, $CuSO_4.5H_2O$ 20%, $MnSO_4.H_2O$ 1.75%, $CoCl_2.6H_2O$ 1.05%, $(NH_4)_2$ MoO_4 2%, KI 0.315%, Na_2 $SeO_4.10H_2O$ 10%.

For many purposes though, it is better to prepare a complete mineral mixture and add a weighed amount directly to the daily feed ration for each animal. Commercially formulated mineral preparations often must be used for large-scale feeding experiments. However for balance studies the scientist, unless prepared to analyse the commercial mixture, has to hope that the mixture was prepared in accordance with the ingredients stated on the label and that mixing was perfect. It is improbable that both conditions always prevail and artefacts can readily be introduced into experiments because the mineral mixture supplied contains too much or too little of one or more elements.

Concern is often expressed at the settling out in the feed trough of dry ingredients that lack ability to adhere to the roughage. The problem can sometimes be overcome by moistening the roughage slightly with water before adding the more powdery material. An alternative method involves the addition of small amounts of substances such as molasses to create both improved adhesion and also an attractant that assists the consumption of the additive. The amount of molasses added is generally so small as to have little effect on nutrient intake.

Sampling for feed analysis. All feed to be used during the balance period should preferably be weighed from the one batch into containers such as plastic bags at the start of the experiment. Every few containers, a small sample is set aside and this is composited to provide the sample for analysis. That material is mixed and a sub-sample immediately dried to provide an estimate of the content of dry matter in the feed during the balance period. When the feed is subsequently ground before estimation of nitrogen or other constituents, the dry matter estimate is repeated permitting the nitrogen content of the ground sample to be related back to the feed given to the animal.

The size of the error involved can be seen from an example. If a sheep is fed hay containing 20 g/N and 920 g dry matter/kg on the day of feed weighing but 940 g/kg dry matter on the day of analysis, the analyses would indicate that the sheep consumed an additional 20 g dry matter/kg feed intake. The additional 20g feed would have erroneously added 0.4 g/N to intake and this could be equivalent to a substantial part of the estimated nitrogen balance.

This problem is more acute with forages fed green, where sub-sampling and dry matter analysis must be carried out daily. Estimates made with browse plants add a further source of error caused by the need to decide which parts of the plant to include in the feed sample analysed. That decision must be made by inspecting the residues of previous meals and establishing a convention that parts of the plant above a certain diameter will be rejected by the animal and hence excluded from analyses.

Collection of faeces. The collection of faeces is most conveniently made by holding sheep in a metabolism pen of the type described by Till and Downes (1963). Faeces and urine pass through the metal grid that forms the floor and as they travel down a slope are separated for storage in different containers. This type of pen is made of a metal frame but all other components except the stainless steel urine–faeces separators are made of fibreglass to minimise adhesion of excreta.

Spillage of feed. In designing a metabolism pen it is important to minimise feed spillage. Animals frequently advance to the feed container, take a mouthful and then step back into the main part of the pen. As they do so, small portions of feed fall back from the mouth and drop through the floor of the pen into the excreta collection system.

This problem can be addressed by placing the feed container 15–30 cm forward of the excreta collection equipment and fitting a separate feed collector, for convenience a cloth bag, under the gap thus created. The size of the problem varies with the nature of the feed and the temperament of the animal. Chopped hay can readily be identified as a contaminant in the faeces collection but finely

ground protein concentrates are less readily identified and frequently finish up in the urine. The problem is more pronounced with timid animals.

Loss of faeces. Faeces from sheep and goats fed dry roughage are generally excreted as pellets containing 30% or more of dry matter. Some pellets on excretion bounce out of the metabolism pen onto the floor and mix with corresponding material from animals in adjoining pens. They must be collected and ownership established from the shape of the pellet. If the pellets are few in number and clean, they can be added to that days collection with little error. If dirty or more numerous they should be counted; the same number of pellets from the days collection should be weighed and that weight added to the total. This is the preferred technique when some faecal pellets escape the separation device and are found in the urine. The pellets and any debris are removed by filtration through gauze. Some leaching of nitrogen from the faecal pellets by urine probably occurs. Equally some nitrogen from urine may be lost by soaking into the faeces. These losses tend to be ignored, but it should be remembered that they appear as 'nitrogen stored' on the balance sheet.

The losses can largely be overcome by direct collection of faeces on excretion. Many devices have been developed to permit the quantitative collection of faeces; one of the simplest (Raabe 1968) consists of a plastic bag attached by clips to a piece of rubber tubing glued to the wool in a circle around the anus.

Urine collection. As indicated in the previous section there is a great potential loss of nitrogen from urea excreted in urine in the metabolism pen. Further, fine material from feed and faeces often finds its way into the urine container. Both types of problem can be overcome by diverting urine directly from the animal through a tube into a bottle containing preservative. Urine collecting devices are most readily fitted to male animals. They must not be rigid as such objects cause damage to the prepuce and penis when the animal lies down. However they must be strong enough to support the weight of the tube leading to the urine container even when it is trodden on by the animal. This type of collector can readily be removed for purposes of hygiene. Another type by Raabe (1968) moulded from rubber latex and glued onto the wool surrounding the prepuce relies on continuous suction delivered from a small compressor to remove the urine to a storage vessel.

Urine collection from female animals relies on devices glued to the skin around the vulva to separate urine from faeces. One made from a rubber surgical glove is described by Raabe (1968). A more elaborate device for female cattle (Magner et al. 1988) consists of a waterproof bag plus hose which can be readily removed and replaced.

Urine preservative. Preservatives must be added to the urine collection vessel to prevent both the microbial breakdown of nitrogenous components to ammonia and the discharge of the ammonia into the atmosphere. The most common preservatives contain acids. Some are relatively weak such as acetic to which a few crystals of thymol are added as a fungicide. Generally strong acids such as hydrochloric or phosphoric are used. The volume used should be kept to a minimum consistent with the maintenance of pH below about 4 at the end of the 24-hour collection period. Urine from ruminants fed herbage diets tends to be alkaline and often contains large amounts of potassium salts, especially bicarbonate. With such diets the amount of acid needed will be greater than with urine from animals receiving a higher proportion of concentrates.

While acids preserve nitrogenous components they may also create a problem by encouraging the precipitation of some urinary components and the crystallisation of others. The latter is particularly evident with tropical forages containing large amounts of phenolic acids; these substances on release in the rumen reach the liver as benzoic acid which is detoxified by the addition of the amino acid glycine to form compounds such as hippuric acid (Lowry et al. 1993). Such compounds crystallise out under the acidic conditions in urine collection devices. Their subsequent reincorporation into urine to obtain a representative sample for analysis may require neutralisation.

Storage of excreta. If circumstances permit excreta should be stored at -10 to $-15°C$ while awaiting analysis. An alternative would involve the drying of faeces with subsequent storage at room temperature. Well preserved urine can also be stored at room temperature though refrigeration even at $4°C$ is preferable. Drying of faeces before storage must be regarded as a poor alternative. With many diets faeces tend to be alkaline and drying will discharge any ammonia present. Further, a decision has to be made on the temperature to be used. Temperatures such as $95-100°C$ may bake the fibre constituents and introduce errors in subsequent analyses. This problem would be avoided at $40°C$ but slow heating at this temperature would permit microbial growth with the risk of loss of nitrogen as ammonia. Generally a compromise temperature of $50°C$ for about 48 hours is employed. Whatever the procedure, estimates should be made of the extent of nitrogen loss by analysis of fresh and dried faeces.

Analytical techniques. The estimation of nitrogen in feed and excreta is one of the most commonly used procedures in nutritional studies and probably the one most subject to error. There are two broad approaches. One, the Dumas method, converts any nitrogen in a sample to gaseous nitrogen which is then measured. The method is very precise but requires specialised equipment and is rarely used. The second method is based on the Kjeldahl method of oxidising organic

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matter with sulfuric acid. In the process, nitrogenous constituents are converted to ammonium sulfate. The ammonia is then estimated originally by distillation and titration or more recently by colorimetric methods.

The methods have been simplified and some of the original principles are now disregarded, to the detriment of accuracy. Many sources of error have been investigated by McKenzie and Wallace (1954). The Kjeldahl method required the digestion of an appropriately sized sample in pear-shaped flasks with long necks that were fitted into devices to extract most of the fumes including sulfur dioxide and sulfur trioxide liberated as the organic matter was oxidised. It was considered important to condense sulfuric acid in the flasks. To do so the angle at which the flask was held and the suction on the fume extractor were regulated to remove only the surplus fumes ensuring that a cloud of fumes remained at all times in the neck of the flask. From this cloud sulfuric acid condensed and ran back down into the body of the flask. The digestion process was assisted by the addition of potassium sulfate to raise the boiling point of the mixture and by a metal such as selenium to act as a catalyst. It was shown by McKenzie and Wallace (1954) that if sufficient sulfuric acid was removed to increase the proportion of potassium sulfate above 1 g/mL sulfuric acid the temperature of the digest could increase to the point where ammonium sulfate would be split with the discharge of gaseous nitrogen. To avoid this problem it was recommended that the initial digest should contain at least 2 or 3 mL sulfuric acid/g potassium sulphate. It was established that approximately 4 mL sulfuric acid was needed to oxidise 1 g organic matter but that about twice this volume of acid was needed to oxidise 1 g of either fat or phenol. The volume of sulfuric acid added to the digest was adjusted according to the nature of the material being analysed. The digestion process was the main source of poor recoveries of nitrogen; there were few problems with the final step of addition of surplus alkali, distillation of the released ammonia and titration.

The Kjeldahl technique has now been made fully- or semi-automatic, e.g. Kjelfoss equipment (Foss Electric Co. Denmark) or Tecator (Tecator AB, Sweden) but if the above principles are followed, excellent recoveries are obtained. More problems occur when the conditions of digestion are varied and when colorimetric methods to estimate ammonia replace distillation and titration. In an effort to digest large numbers of samples to keep pace with the capacity for colorimetric analysis of automatic instruments such as the Auto analyser (Technicon Co., Rahway, New Jersey, USA), block digesters holding relatively small tubes and heated on electric hot-plate heaters are often employed. There is little control over the escape of fumes and temperatures are often quite variable across the block. In consequence the heating temperature during digestion and amount of acid remaining at the end of digestion may vary appreciably from tube to tube. The amount of residual acid can affect

subsequent colour development and hence recovery of ammonia. If this system is to be used the effectiveness of the heating block must be checked by estimating recoveries of nitrogen not only from a standard solution of ammonium sulfate but also from mixtures of cellulose and casein composited to simulate feed samples. Special care must be taken in analysing samples of browse plants that contain high levels of phenolic compounds as the consumption of sulfuric acid could become excessive.

The conduct of a balance experiment

Apart from the technical problems mentioned what other factors must be considered in conducting a balance experiment? This can be reduced to a series of questions.
(a) How many animals should be involved?
(b) How long should they be on the diet before conduct of the experiment?
(c) For how many days should the experiment run?
(d) What happens if an animal loses digesta after losing a cannula plug?
(f) What is a convenient method to conduct the experiment?

Numbers of animals. This is determined by such factors as the availability of suitable animals, the degree of precision desired and the experimental design. For observations on a single forage fed at restricted level of intake four animals might be adequate. If the animals were fed ad libitum six animals might be needed to reduce variability associated with different levels of intake. Comparisons between diets might require a Latin square design with, for instance, four animals and four diets. It might be found necessary to have more than one animal per treatment cell.

Adaptation period. It was considered formerly (e.g. Staples and Dinusson 1951) that the time between diets need be only 3 or 4 days to allow all residues of the previous diet to pass through the animal. It is now realised that a longer time is required to permit adaptation of the rumen microbes to the new diet. The minimum period usually allowed is 14 days. If there is an abrupt change from a high quality roughage, the achievement of a reasonably constant ad libitum intake is a good indicator that adaptation is complete. This may require 21 days or more. For less abrupt changes, especially with animals to be fed at fixed intakes appreciably below ad libitum 14 days should be adequate.

Duration of experiment. A 10-day collection period is commonly used, though Staples and Dinusson (1951) with cattle fed hay and concentrates found no differences in estimation of crude protein digestibility with collection periods of 7 or 10 days. Animals fed roughages ad libitum tend to have a 3-or 4-day feeding

cycle with feed intakes substantially above and below the mean during these times. If balance data are sought with such animals a 10-day faecal collection period would be desirable.

Variations in feed intake. When making a faecal collection, the question may arise: 'How soon does a variation in one days feed intake affect faecal output?' As a working rule, 48 hours is a useful convention to follow. No problem arises if animals regularly consume the whole ration offered. However if intake varies appreciably from day to day, it should be accepted that the measurement period will extend over 12 days, with feed intake measured from days 1 to 10 and faecal output from days 3 to 12.

Loss of digesta. At times faecal collection periods coincide with measurements of flow of digesta from the stomach to the small intestine or from the terminal ileum to the large intestine. Such measurements involve the removal of digesta, part of which would normally have been excreted in the faeces. Allowance should be made from the knowledge that approximately one third of digesta nitrogen and 40% of organic matter that passes from the stomach to the intestines is excreted in the faeces; corresponding values for digesta passing from the small intestine are based on the assumption that nitrogen equivalent to 90% and organic matter equivalent to 80% of that passing the terminal ileum will be excreted in the faeces. The amounts involved in these corrections are generally small, especially when collections of digesta are made during 3 days and faecal collections during 10.

More serious losses of digesta may occur following the loss of the plug from a rumen cannula. The effect on faecal collection depends on the severity of the loss. If losses are less than about 10% of the digesta in the rumen, if the faeces are not contaminated with digesta and if the animal does not lose appetite, there is probably no need to suspend measurements on that animal. If the losses are more severe it may be necessary to stop the faecal collection for at least 3 days until the functioning of the digestive tract has returned to normal.

Method of conduct of balance experiment. There are many routines to be followed in conducting a balance experiment. Here is one example.
(1) Select animals and train them in metabolism pens. Place them on selected diet for two weeks.
(2) Mix feed thoroughly and weigh out 12 daily feeds for each animal. Put small sample for analysis aside for every three bags. Mix analytical sample and dry 100 g in duplicate at 95°C for 16 hours to establish dry matter content.
(3) At the end of the 2-week adaptation phase, clean metabolism pen and prepare animals for excreta collection. Commence feeding weighed feeds on Day 1.

(4) Commence excreta collection on Day 3.

(5) Starting on Day 4, pick up any fallen faeces and add to collection. Weigh faeces and pour into large plastic tub. Mix and remove 10-20% aliquot to be stored at -10°C as a composite sample for each sheep. Weigh or otherwise measure urine sample and store at -10°C appropriate aliquot of 1-2% of output as composite sample for each sheep.

(6) Continue feeding and excreta collection until conclusion of metabolism period on morning on Day 13.

(7) Thaw out composite samples of faeces and mix. While still cold, weigh out duplicate 100 g samples for dry matter determination. With cattle faeces weigh into crucibles 10g samples for estimation of dry matter and of organic matter as loss in weight of dried material during 2 hours at 550°C. Weigh out samples for estimation of nitrogen, fibre or other components. Store remainder at -10°C. With sheep faeces thaw mix and subsample. Weigh duplicate 100g samples of pellets for dry matter determination. Weigh a further 100g pellets into blender, add 300 mL water and macerate to form slurry containing approximately 10% dry matter. Weigh out samples of slurry for estimation of dry matter/organic matter, nitrogen and other components. Store remainder at -10°C. Thaw and mix composite urine sample for each sheep. Measure or weigh samples for nitrogen. Take sub-sample and freeze.

(8) Grind feed through 2 mm screen. Weigh out samples for analysis of dry matter/organic matter, nitrogen and other desired components.

(9) Calculate balance data as follows: Use information from total feed intake and dry matter based on 'large' samples to calculate dry matter intake. Estimate nitrogen intake, taking into account the dry matter and nitrogen content of the ground samples. Apply similar calculations to faecal analysis to estimate nitrogen output. From urine volume and nitrogen content calculate urinary nitrogen output. Nitrogen balance is then calculated as the difference between nitrogen intake and its excretion in faeces plus urine.

Quantitative Estimates of Digestion

Quantitative estimates of the amounts of digesta that pass from one section of the digestive tract to another are of particular importance in estimating the amount of amino acids derived from dietary and microbial sources in the mixture of proteins digested enzymatically in the small intestine. Measurements originally required the diversion of digesta outside the animal with subsequent return further down the tract of the residue remaining after sampling. The techniques involved which were reviewed by MacRae (1975) have now been largely replaced by methods involving inert reference substances or markers. The ideal marker has physical properties similar to those of the substance being

marked. However it should be inert, i.e. not absorbed from the digestive tract nor adsorbed onto the wall of the tract. It should also not stimulate or inhibit the microbes or digestive enzymes in the tract. There can be no single ideal marker, as water and feed particles behave differently in the tract. Markers for the movement of water have included polyethylene glycol with a molecular weight of approximately 4000 (Hyden 1961). However more recently the complex of ethylene diamine tetra-acetic acid with chromium (Downes and McDonald 1964) or cobalt (Uden et al. 1980) have been preferred. Both are soluble and readily analysed.

Markers for feed particles have included the dietary component lignin but, with some diets, at least part of the 'lignin' appears to be removed during passage through the tract (e.g. Hogan and Weston 1969; Lowrey et al. 1993). However it is assumed that any losses of 'lignin' most probably occur in the stomach, and the amount of lignin excreted in faeces gives an estimate of the lignin passing from the stomach into the small intestine. More recently heavy metals such as cerium adsorbed onto feed particles (Ellis and Huston 1968), chromium mordanted onto particles (Udén et al. 1980), or a ruthenium–phenanthroline complex attached to particles (Tan et al. 1971) have all been used to mark the plant particle fraction. Chromium sesquioxide has been and is still often used, but its specific gravity is very much greater than that of any feed particle and the validity of its use to measure digesta flow has been questioned (Faichney 1972).

Measurements of digesta flow

The theory underlying the techniques is that if a marker is pumped into one section of the digestive tract continuously for a sufficient time to reach equilibrium, then on average, 100% of the daily dose of the marker will pass each subsequent section of the tract each day. Hence if samples of digesta are collected from a point distal to the infusion point, the flow of digesta may be estimated by dividing the rate of infusion by the concentration of marker.

The results obtained with one marker are valid for the whole of the digesta only if that marker moves in the same way as all the components of the digesta. In practice, in many sections of the tract, particles are retained longer than solutes. In addition, separation between these phases of digesta may occur during sampling. To overcome these difficulties, two markers are used, one of which travels with the liquid phase, the other with the solid phase (Weston and Hogan 1967; Hogan and Weston 1967). This discussion will involve the soluble marker chromium complexed with ethylene diaminetetra–acetic acid (Cr EDTA) (Downes and McDonald 1964) and the particulate phase marker, the phenanthroline complex of ruthenium (Tan et al. 1971).

In using two markers to measure digesta flow, part of the digesta is strained through gauze and analyses of the concentrations of the two markers are then made both on digesta and on the filtrate. Corrections are then made, if necessary, for deviation of the markers from ideal behaviour. From these analyses the composition and flow of 'true' digesta are calculated.

Experimental schedule

A schedule for measuring digesta flow in a sheep is as follows:

(1) Preparation of markers. ^{51}Cr is complexed with ethylene diaminetetra−acetic acid (Downes and McDonald 1964). The complex ^{51}CrEDTA is diluted to permit the daily infusion of about 50 Ci^{51}Cr with a specific activity no greater than 1 µCi/mg Cr. ^{103}Ruthenium is complexed with phenanthroline (^{103}RuP) (Tan et al. 1971), with a specific activity no greater than 0.4 µCi/mg Ru, and diluted so that when infused with ^{51}CrEDTA the sheep will receive 10 µCi^{103}Ru/day.

(2) Sheep prepared with ruminal and intestinal fistulae are placed in metabolism cages and preferably offered feed in equal amounts at not more than 3-hourly intervals.

(3) When the sheep have spent at least 10 days to become adapted to the ration, the collection of faeces is commenced (Day 1).

(4) On Day 3, samples of intestinal digesta are collected for preparing counting standards. The infusion of the mixed solution of markers is then started, a priming dose of approximately 60% of the usual daily dose being given to bring the concentration of marker in the rumen more quickly to the final equilibrium concentration.

(5) On Day 8, the collection of rumen and abomasal samples begins. With sheep offered feed at 3-hourly intervals, three samples are taken to correspond to 30, 90 and 150 minutes after the sheep have been offered the 0800, 1100 and 1400 hour feeds. The sampling procedure is repeated on Days 9 and 10. On each occasion equal amounts of digesta are removed and bulked. Part of the digesta is strained through nylon or terylene gauze with apertures about 100×200 microns and equal amounts of the resulting filtrate are also bulked. Strained rumen fluid samples are similarly bulked. During Days 9 and 10 urine is collected to permit correction for marker absorption while subsamples of faeces are set aside to check that the ratio of ^{51}Cr to ^{103}Ru in the faeces is as expected. On Day 11 faecal collection ends. The infusion of markers is terminated, but rumen samples are taken each two hours to provide data, from changes in ^{51}Cr and ^{103}Ru levels, on the volume and mean residence time of liquid in the rumen. With sheep fed forages as described here, sampling can be discontinued after 12 hours. With concentrate diets it may have to be continued for 24 hours.

Calculations

(1) Calculate the daily infusion rates of ^{51}Cr and ^{103}Ru; express concentrations in samples as fraction of the daily infusion rate.

(2) From urine analysis, estimate the amounts of the two markers that were absorbed from various sections of the tract. Urinary losses of ^{103}Ru above about 0.5% of the daily dose are unusual. By contrast, losses of ^{51}Cr up to 4% of the daily dose often occur. Evidence has been obtained that a little less than 50% of this absorption occurs from the stomach, and about 10% from the small intestine, and the remainder from the large intestine (Faichney 1975b). Losses of ^{51}Cr above 4% of the daily dose with forage diets can often be traced to leakage from the rumen cannula.

(3) Count the activity in samples of abomasal digesta, abomasal filtrate and rumen liquor, and analyse for organic matter, nitrogen, ammonia and other desired components.

(4) Calculate flow as follows:

Flow of liquid from rumen = 1/Rumen liquor ^{51}CrEDTA (1)

From the concentrations of the two markers in abomasal digesta and filtrate, calculate the 'reconstitution factor', 'R', that is, the amount of filtrate that must be added to or removed from one unit of the collected digesta sample to obtain 'true digesta' (Weston and Hogan 1967; Hogan and Weston 1967).

R = [Digesta^{103}RuP – Digesta^{51}EDTA]/[Filtrate^{51}EDTA – Filtrate^{103}RuP] (2)

then

True digesta^{51}CrEDTA = [Digesta^{51}CrEDTA + (R × Filtrate^{51}CrEDTA)]/1 + R (3)

Digesta flow = 1/True digesta^{51}CrEDTA (4)

The concentration of any constituent in true digesta is calculated by substituting its concentrations in collected digesta and filtrate for those of 51CrEDTA in equation (3). Rate of flow of the constituent is then calculated as True digesta flow the concentration of that constituent in true digesta.

Advantage of technique. The technique involves relatively simple surgery. One technician can sample many animals. The technique is applicable to grazing animals (Corbett 1980) and following infusion of markers through a rumen catheter (Faichney and Colebrook 1979) to animals subsequently slaughtered. With the latter, of course, care must be taken to avoid post mortem shedding of

mucosa of the upper small intestine into the digesta (Badawy et al. 1957; Faichney 1975a).

Difficulties. The method relies on markers to correct errors in sample collection and requires either reasonably steady-state conditions or a sampling protocol to cover the several days that may be regarded as a feeding cycle in animals fed ad libitum.

Estimation of rumen volume

The volume of liquid in the rumen, under steady-state conditions, may be calculated from the dilution rate of ^{51}CrEDTA following the cessation of marker infusion (Weston and Hogan 1967). In a steady-state system

$$F = 0.693V/T_{0.5} = V/1.44T_{0.5} = V/Tm = kV \tag{5}$$

where F is the flow rate from the rumen, V the volume of liquid present, $T_{0.5}$ the time for the marker concentration to decline by one half, T_m the mean time spent in the rumen by marker molecules, and k, the reciprocal of T_m, the disappearance rate of ^{51}CrEDTA.

Data in Equation (5) can also be calculated from study of the dilution rate of a known amount of ^{51}CrEDTA given as a single dose into the rumen. The data follow the relationship

$$C_t = C_0e^{-kt} \tag{6}$$

where C_0 and C_t are the concentrations of marker at times zero and t, and k is the dilution rate. Then

$$V = Dose\ of\ ^{15}CrEDTA/C_0 \tag{7}$$

and

$$Tm = 1/k \tag{8}$$

Advantages. This technique provides a useful measure of the volume of water in the rumen, and can be extended in some circumstances (Faichney 1980) to estimate the total weight and composition of rumen digesta. It also gives some indication of the dynamics of the movement of solutes and small particles such as bacteria from the rumen.

Problems. Departures from steady-state caused by major changes in the volume of water in the rumen through drinking (Warner and Stacy 1968) or the intake of large amounts of green forage could cause appreciable errors.

Estimation of the passage of rumen microbes

This technique assumes that when ^{35}S-sulfate is infused into the rumen, all the organically bound ^{35}S that leaves the abomasum will be present in microbes (Mathers and Miller 1980).

Method. On Day 8 of the experiment schedule above, ^{35}S-sulfate (150μ Ci/day) is added to the marker infusate. During Days 9 and 10 several representative samples of bacteria and protozoa are separated from rumen fluid; abomasal digesta samples are also collected. Estimates are made of the ratio of ^{35}S to non-ammonia nitrogen (NAN) in the microbes and digesta. From these results,

Microbial NAN:Digesta NAN = ^{35}S:NAN in digesta/^{35}S:NAN in microbes   (9)

From the ratio of NAN to other constituents in microbes, the rate of passage of microbial organic matter and its components can be calculated. This in turn permits the estimation of the amount of non-microbial organic matter, mainly of dietary origin, in the digesta leaving the stomach.

Similar calculations of the bacterial component alone may be made using the bacterial amino acid, diaminopimelic acid in place of ^{35}S.

Advantages. These methods are relatively simple and can readily be included with measurements of digesta flow.

Problems. The methods depend on the assumption that bacteria adherent to the rumen wall, free-floating in rumen liquor, or attached to particulate matter, are either all representatively sampled in the microbes analysed, or do not differ substantially in chemical or radio chemical composition from those that do.

Conclusion

It is not currently possible to estimate absolutely the errors involved in measuring flow of digesta from one organ to another with either the total collection or marker techniques. Large errors can be expected when the result sought is a relatively small figure derived as the difference between two much larger measured values such as digesta flow into and out of the small intestine. With subsequent calculations such as the amount of microbial organic matter synthesised per unit organic matter apparently digested in the rumen, the errors

may be magnified. In that calculation, if the rate of flow of digesta is over-estimated by 10%, so is the flow of microbial organic matter; however the extent of apparent digestion of organic matter will be under-estimated because that calculation depends on the difference between intake and the over-estimated flow from the stomach. The final calculation may thus over-estimate the efficiency of synthesis by much more than 10%.

However, concern over possible errors in the present techniques for measuring digesta flow should not inhibit their use in increasing our understanding of forage digestion. Such concern should be taken both as an indication of the need for the greatest care and precision in applying existing methods, and also as an encouragement to develop new and better methods for future use.

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Nutritional Needs of Rumen Microbes

J. HOGAN

In the past 50 years ruminant nutrition has moved through the various phases with feeding standards first based on the results of empirical feeding experiments then reinterpreted in the light of balance studies and finally modified as knowledge accumulated from quantitative studies of the events occurring in the rumen, the intestines, and the tissues. During this time the interactions of the different groups of microbes, especially in the rumen, have received increasing study and we are now seeing the development of the next phase, that concerning the appreciation of the role of individual species of the bacteria, protozoa, and fungi in the catabolism and anabolism of polymers in the rumen and of the possibility that these activities can be regulated to improve the efficiency of feed conversion and hence of the nutrition of the animal.

The importance of plant fibre as a source of nutrients for the animal is shown in Figure 1. With temperate grasses the contribution that digested fibre makes to digestible organic matter clearly reflects the level of fibre in plant organic matter; fibre digestion is proportionally less significant with temperate clovers and with lucerne (*Medicago sativa*). A similar situation appears to apply with tropical grasses fed to cattle and buffalo though recently discovered analytical artefacts in estimating the fibre content of tropical grasses (Lowry et al. 1994) make interpretation of the observations difficult. However microbial fermentation of fibre is obviously critical to the ruminant and hence ruminant diets should first aim to provide adequate nutrients for the microbes involved.

The two main types of microbes involved in the fermentation of plant fibre are the cellulolytic bacteria and the anaerobic fungi. Before an animal takes in the first feed of the day, the bacteria and the motile forms of the fungi, the zoospores, are found in the rumen liquid. After feed has been taken into the rumen, these microbes become closely associated with the swallowed feed. The bacteria may attach themselves by means of an outer mantle or else alter their shapes to conform closely to the shape of a plant particle. The fungal zoospores attach to broken plant surfaces or to stomata in the leaf and develop hyphae that penetrate the plant tissues. Both types of microbe produce an array of enzymes comprising cellulases, hemicellulases, and pectinases. The molecules released through their activity are either further metabolised by the microbes themselves or pass into the liquid in the rumen for metabolism by other microbes.
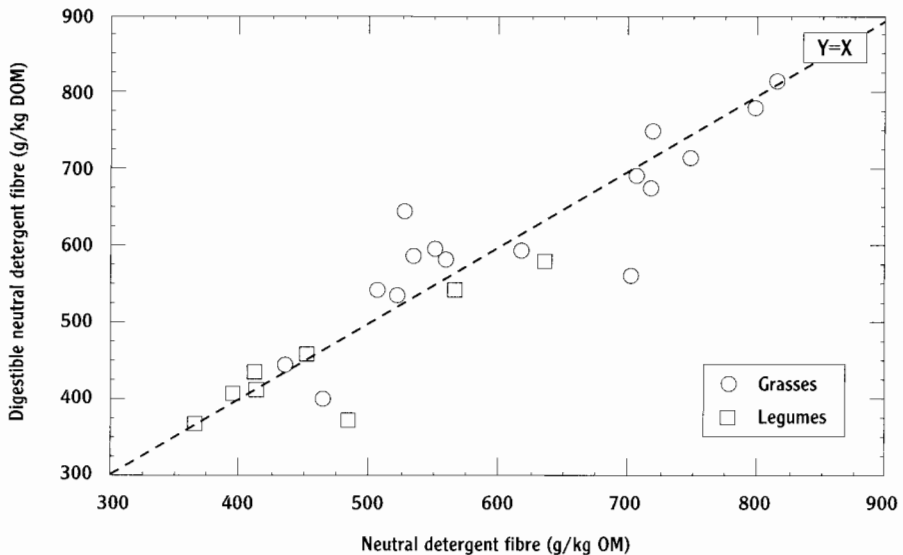
Figure 1.   The level of neutral detergent fibre (NDF) in forage reflects the contribution of digestible fibre to digestible organic matter (DOM). Data of Weston and Hogan (combined experiments).

The microbes involved in fermentation of cellulose and hemicellulose form a relatively small proportion of the rumen population. In recent work with sheep fed a diet of 3 parts barley straw and 1 part lucerne hay, Gordon and Phillips (1993) observed the following numbers of microbes in rumen liquor-fungal zoospores 7.6×10^3/mL, ciliate protozoa 3.8×10^5/mL, viable cellulolytic bacteria 0.4×10^8/mL and total viable bacteria 0.8×10^9/mL. Hence fungal zoospores were relatively few in number compared with protozoa while cellulolytic bacteria comprised only about 5% of the total viable population. The total fungal biomass-zoospores, fruiting bodies and hyphae-would be appreciably larger than that indicated by the zoospores alone, but probably would not exceed 5% of the total microbial biomass (D.E. Akin, pers. comm.). These cellulolytic microbes, though relatively few in number are critical to the ability of the host to extract nutrients from fibre or to weaken the fibre to such an extent that it more readily passed from the rumen. However they are probably at a nutritional disadvantage compared with the major part of the bacterial population and with the protozoa, as these organisms live largely in the rumen liquor and hence are better able to take advantage of nutrients and metabolites released into that medium. The minimal nutritional needs of the 'free swimming' population are probably higher than those of the microbes attached to plant material and hence if the nutrients reaching the rumen are adequate for the 'free swimmers', the needs of those microbes so critical to fibre fermentation are also

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largely met. One exception to this is possibly sulfur for anaerobic fungi. Those microbes disappeared from the rumen with a forage containing 1.1 g S/kg, but were maintained with the same forage fertilised to contain 1.7 g S/kg (Akin and Hogan 1983), suggesting that whereas some bacteria could survive at the lower sulfur level, the fungi could not.

It is clear that nutrient supply influences the microbial ecology of the rumen. To provide a sound basis for supplementary feeding of the animal it is therefore necessary to consider the steps needed to achieve nutrient balance for the microbes.

Nutrient Balance For Microbes

The factors that determine nutrient adequacy for rumen microbes are:
·   the requirement for a particular nutrient relative to other nutrients;
·   the total amount entering the rumen;
·   the proportion of the total available to the microbes;
·   the minimum concentration needed in the rumen; and
·   the concentration that can be maintained in the rumen.

Nutrient requirements of microbes

Energy. The main nutrient needed by rumen microbes is energy, and the adequacy of supply of other nutrients must be assessed in relation to energy supply. Hence consideration of the provision of supplements to the animal's diet must start with an assessment of the energy that becomes or can become available to the rumen microbes.

It is accepted that anaerobic bacteria require sources of energy associated with high energy phosphate like adenosine triphosphate (ATP). Early studies suggested that the yield of bacterial cells per mole ATP (YATP) was fairly constant and perhaps this is true for the amount of energy needed for a bacterial cell to divide and to produce two fully developed daughter cells. However yield is not usually measured in this way but rather as the bacterial mass that can be harvested leaving the rumen or more generally, leaving the stomach. YATP then reflects the length of time that cells remain in the rumen using energy for maintenance rather than growth; and the proportion of synthesised bacterial cells that survive predators and death in the rumen to pass as identifiable bacteria from the stomach.

This source of energy is released in the general reactions associated with anaerobic fermentation:

carbohydrates ➜ *volatile fatty acids + fermentation gases + ATP + heat*

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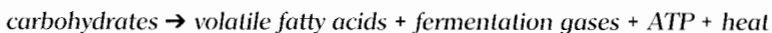
Calculations on the production of the bacterial mass in the rumen are based on the following observations that:

- during the fermentation of fibre in the rumen about 2 moles ATP are produced per mole volatile fatty acids (VFA) (Walker 1965);
- VFA production from forage diets is equivalent to approximately 8.5 moles/kg digestible organic matter (DOM) (e.g. Weston and Hogan 1968, 1986);
- in theory ATP release in the rumen is equivalent to 17 moles/kg DOM;
- the yield of microbial dry matter/mole ATP can range from about 8 to 30. The lower values probably reflect nutritional imbalance, for instance associated with inadequate levels of ammonia, where it is thought the use of ATP is 'uncoupled' and the energy wasted;
- in studies made using 35S or 15N to measure microbial synthesis (SCA 1990) in sheep or cattle grazing or fed cut forages, yield of microbial crude protein (g/kg DOM) ranged between 87 and 184 (mean 140) with sheep and 100 to 236 (mean 178) with cattle. Consideration of all values in the literature including diets with protein protected against breakdown in the rumen gave values for microbial protein (g/kg DOM intake) of 121.1 and 146.1 for sheep and cattle respectively (SCA 1990).

Corresponding values in U.K. (ARC 1984) and in France (Verité et al. 1979) were 130 g/kg DOM and 135 g/kg DOM respectively;

- studies with sheep fed dried or fresh forages (Hogan and Weston 1981) indicated that crude protein (CP) passing from the abomasum (g CP/day) conformed to the relationship

$y = 0.36$ *CP intake* $+ 0.16$ *DOM intake* $+ 6$

implying that
- 36% of dietary protein escaped degradation in the rumen;
- microbial protein synthesis was equivalent to 160 g/kg DOM; and
- addition of CP to the abomasum from endogenous sources was 6 g/day.

The relationship between DOM intake and microbial growth provides a basis for estimating minimal nutritional needs of rumen microbes. The composition of bacterial cells varies widely, but 1 kg dry weight of cells could contain approximately 100 g N, 14 g P, 3 g Mg, 9 g Ca, 10 g S, 20 g K and 20 g Na. As seen above, energy to support the synthesis of this quantity of microbial nitrogen would require the ingestion of about 4 kg DOM; this equates with forages of 40, 50 and 60% digestibility to the provision of nitrogen equivalent to about 10, 12..5 and 15 g/kg OM. Many mature tropical grasses do not provide these levels of protein. The adequacy of nitrogen then depends on recycling to the rumen, as will be discussed later.

A further corollary to these observations is the limit placed by the intake of DOM on the amounts of microbial protein that can be derived from the rumen. Voluntary consumption of forages of 40, 50 or 60% digestibility by sheep of 40 kg body weight might provide 0.25, 0.41 and 0.62 kg DOM which could support the synthesis of 40, 66 and 99 g microbial protein. As microbial protein represents perhaps 80% of the protein that passes from the stomach to the small intestine it can be seen that as forages mature the amounts of protein that become available as amino acids to the tissues are seriously curtailed.

Phosphorus. The requirements by bacteria for P can be expressed in relation to DOM intake in the same way as requirements for N. It has been suggested (Komisarczuk-Bony and Durand 1991) that the average N:P ratio in rumen bacteria is 7:1; on their assumption of microbial protein synthesis equivalent to 122 g/kg DOM or 19.5 g N/kg DOM, the need for P would be met by 2.8 g P/kg DOM. However, if as suggested earlier (Hogan and Weston 1981), microbial protein synthesis was equivalent to 25.6 g N/kg DOM, the requirement for P would be correspondingly higher. Further Komisarczuk-Bony and Durand (1991) indicate that the needs of cellulolytic bacteria for P are higher than for other bacteria and those authors suggest that the supply of available P should be at least 5 g/kg DOM. If this requirement was to be met totally from the feed, the content of P for feeds of 40, 50 and 60% digestibility would need to be 2.0, 2.5 and 3 g/kg OM. In reality, mature tropical grasses appear to meet requirements if total P content is 1.2–1.5 g/kg OM (Winks 1990) and it is clear that the nutrition of the rumen microbes depends substantially on the recycling of P in saliva.

There does not seem to have been any study made of the effects of P deficiency on the ecology of rumen microbes. Total P content of rumen microbes may vary between 20 and 60 g P/kg DM and the requirement for P of different types of microbes varies appreciably. It might be assumed then that a deficiency of P would alter the relative proportions of bacterial types. There is no evidence though that the correction of a P deficiency alters the digestibility of forages (Winks 1990) so perhaps a lack of P reduces the whole population but maintains adequate numbers of the main groups to ensure a reasonable level of fibre fermentation.

Sulfur. Sulfur requirements can be assessed on the basis of N:S ratios of 15:1 (Komisarczuk-Bony and Durand 1991). However a significant part of the bacterial population appears to have N:S ratios less than that and a value of 10:1 is probably closer to reality. Assuming that the requirement of microbes for N is 25.6 g/kg DOM, the need for sulfur could be approximately 2.6 g/kg DOM. With forages of 40, 50 and 60% digestibility, this should correspond to 1.0, 1.3 and 1.6

g/kg OM. However these figures in practice appear to understate requirements probably because not all S is available to the microbes. Presumably this is the reason why unfertilised *Digitaria pentzii* containing 1.1 g S/kg did not support an anaerobic fungal population whereas a fertilised forage with 1.7 g S/kg did (Akin and Hogan 1983). Deficiency of S may thus alter the balance of microbes in the rumen with those such as the fungi that are dependent on the provision of sulphide by bacteria being rapidly affected.

Magnesium It has been suggested (Komisarczuk-Bony and Durand 1991) that the requirement of rumen microbes for magnesium is met by the provision of 1.5–2.5 g Mg^{++}/kg DOM. This would correspond, with forages of 40, 50 and 60% digestibility to the provision of available Mg^{++} equivalent to 0.6–1.0, 0.75–1.25 and 0.9–1.5g/kg OM. Availability of Mg^{++} depends on the extent to which it can be extracted from dietary sources and possibly on interactions with NH^+_4 and K^+ in the rumen.

Calcium. Although some bacteria require calcium for growth, others appear not to do so (Durand and Kawashima 1980). There is also some interchangeability of Mg^{++} and Ca^{++} within bacterial cells and requirements for Ca may thus be affected by the supply of Mg. Durand and Kawashima (1980) suggest that media for bacterial growth in vitro should contain 2 to 25 mg Mg/L and 10–40 mg Ca/L. On the basis of the suggested dietary supply of Mg^{++} above, available Ca^{++} for forage diets of 40, 50 and 60% digestibility might need to be 1–3 g/kg OM.

In practice, the high demands of ruminants for calcium in the metabolism of bone and other tissues and in milk secretion suggest that the main needs of the animal for calcium relate to the tissues rather than the rumen microbes.

Trace elements. Trace elements including Cu, Co, Fe, I, Mn, Se and Zn are required for various aspects of microbial activity (Durand and Kawashima 1980) including the synthesis of vitamin B_{12}. As the name implies, requirements for these minerals are minute by comparison with those for the major minerals. Deficiencies generally depend on availability of the minerals in soils and on the capacity of plants to take up those minerals. As Table (1) indicates, unless available minerals are very low in soils, those trace elements such as Mn and Zn for which the plant has a higher requirement than the animal should be in adequate supply whereas others such as I, Co and Se are always potentially deficient.

The amounts of various trace elements required by microbes in rumen liquor and in the diet are presented in Table 2. The dietary requirements suggested by Durand and Kawashima (1980) and Grace (1991) differ appreciably, and as the latter author indicates, should be regarded merely as guidelines subject to

interactions within the feed and in the rumen. Diagnostic standards of deficiency or adequacy based on analysis of plasma or tissues presented by Judson et al. (1987) further emphasise the difficulty in diagnosis. For instance, levels of selenium in the blood of less than 250 n.mol/L are regarded as deficient and more than 500 as normal but adequacy between 250 and 500 is not certain.

Table 1. Mineral interactions between plants and animals.

Plant compared with animal	Effects on animal
Requirements much higher (K, Mn, Zn)	Generally adequate
Requirements low or zero (Na, Cl, I, Co, Se)	Potentially inadequate
Requirements equal (P)	Potentially inadequate
	Fertilizer may increase plant growth without changing mineral level
Tolerates higher levels (Se, Cd, Mo, Pb)	Potential toxicity
Little accumulation (As, I, Be, F, Ni, Zn)	Toxicity unlikely

Source: Reid and Horvath 1980.

Table 2. Suggested trace element content of the rumen fluid and diet.

	Fe	Mn	Zn	Co	Cu	Mo	I	Ref
In rumen fluid (mg/L)	1–10	1–10	0.2–1	0.1–0.5	0.01–0.25	1–10		Durand & Kawashima (1980)
In diet (mg/kg DM)	120	120	50	0.5–1	5–10	?	?	Durand & Kawashima (1980)
	30–40	25	25	0.08–0.11	5–10	?	0.5	Grace (1991)

The small amounts of trace elements needed for normal function expose the rumen microbes to the dangers of intoxication through excessive levels. The capacity of plants to accumulate some minerals (Table 1) is involved. Levels associated with chronic toxicity in part at least affecting the microbes have been presented by Grace (1991). Toxicity is of course related to availability, and reduction in availability can occur through interactions with other minerals in the rumen. The best-known example is that between sulfur and molybdenum to form thio-molybdate which renders copper unavailable; in so doing it also affects the availability of both molybdenum and sulfur so that variable toxicity may be observed between feeds containing the same levels of a toxic mineral depending

on its interactions with other minerals present. It is therefore difficult to generalise but toxicity should be considered when the level of any trace element is 5 to 10 times above requirements.

Nutrients entering rumen

The diet is the main source of nutrients for the microbes and the supply of nutrients will be largely determined by the level of feed intake set by the animal and by the amounts of nutrients contained in and extractable from that feed. However such critical nutrients as N, P, S, Na and K also reach the rumen microbes by processes of recycling from the blood, either directly across the rumen wall or in saliva.

The recycling of nutrients into the rumen is a complex series of interactions that involve not only the rumen epithelium and the various salivary glands but also the kidneys. Control by the kidneys is particularly important with urea which is synthesised in the liver from two main sources; ammonia from the digestive tract, and amino-N derived from tissue catabolism. The relative contribution to urea synthesis from the two sources has not been established. It is significant though that the reduction in tissue catabolism following the application of the growth promotant Trenbolone reduced urea recycling sufficiently to cause an ammonia deficiency in the rumen (Hunter and Magner 1990). When dietary nitrogen is deficient the kidneys may virtually stop excreting urea in the urine. When protein is consumed in greater amounts the kidneys influence the level of urea maintained in the plasma and also the mean time that a molecule of urea spends in the body before excretion in the urine. Both factors are important to nitrogen recycling. The concentration of urea in the plasma influences the rate of movement of urea across both the rumen epithelium and the salivary gland. The mean retention time for urea in the body determines the number of times per day that a molecule of urea may be presented for passage to the rumen, deamination to ammonia, absorption, resynthesis to urea in the liver and representation to the rumen. This mechanism is particularly important for animals receiving supplemental urea in the diet, because it extends the time over which urea ingested in one meal can influence the amount of ammonia available in the rumen.

The role of salivary proteins in supplying amino acids to the rumen is often under-estimated. With sheep at least the protein-rich saliva from salivary tissue in the palate may not be included in samples of saliva collected from the mouth. These proteins can provide valuable amino acids, especially for animals fed on low quality forages.

Sulfur is only a minor component of saliva but microbes supported by diets low in sulfur benefit from the addition of both salivary sulphate and sulfur amino acids contained in salivary proteins.

Of the minerals, phosphorus, sodium and bicarbonate are secreted in substantial amounts. As Ternouth (1991) indicates, ruminants can concentrate plasma P 3–8 fold in saliva, largely through the parotid gland. This relationship appears to be maintained even during P deficiency when plasma P levels may decline from 160 to 20 mg/L (Wadsworth et al. 1990). Appreciable amounts of P are therefore recycled to the rumen even with diets deficient in P but they may not be adequate to meet microbial requirements as there is consequent depression of feed intake (Winks 1990).

Parotid saliva which supplies most of the liquid that enters the rumen contains about 3.5 g/kg sodium and 0.2 g/kg potassium. There is usually ample sodium for the microbes whereas any possible deficiency of potassium is met by the generally high potassium content of forages. A dietary deficiency of sodium is followed by a decline in the level of that element in saliva to approximately 1g/kg and an increase in the content of potassium to about 4 g/kg. With the decline in salivary sodium levels, the kidneys begin to conserve that mineral under the influence of the hormone aldosterone and excretion of sodium in the urine ceases (McSweeney and Cross 1992). The effects of changes in salivary sodium and potassium on rumen microbes have not been reported.

With other minerals of nutritional significance such as calcium, magnesium, manganese, zinc, cobalt and copper, recycling is not sufficient to provide much benefit for the nutrition of microbes. Hence, any deficiency in the diet must be met by supplementation.

Availability of nutrients

Soluble carbohydrates and smaller molecule oligosaccharides contained in plant cell contents provide energy sources for rumen microbes soon after forages are ingested. This energy permits the microbes to use ammonia and amino acids derived from readily available nitrogenous components in the cell contents, while the copious flow of saliva that occurs in response to eating ensures not only buffering capacity to control rumen pH but also a supply of recycled nutrients. This is a period of lavish supply of nutrients and is reflected in the rapid expansion of microbial populations.

When the most readily available nutrients from the feed have been fermented the microbes are dependent on fibre as the main nutrient source. There is generally a delay in the fermentation of fibre as microbes develop sites for fermentation. Even when the microbes are fully active the rate of fermentation of fibre from all but the most immature forages is relatively slow. The cellulolytic microbes can presumably obtain their own nutrients at a satisfactory rate from fermenting fibre but the bulk of the population, dependent on the smaller molecules released by cellulolytic microbes, experience nutrient deficiency and

there appears to be a heavy bacterial mortality with lysis of cells and the use of cell components by other microbes. This is the period during which the demand for ammonia exceeds the rate of supply and ammonia levels fall. It is the period during which recycling of nutrients becomes critical and when supplementation has its greatest benefit.

After varying periods in the rumen, the feed particles are reduced sufficiently in size and achieve the appropriate specific gravity to be propelled from the rumen. These feed particles may contain carbohydrate potentially susceptible to fermentation but not degraded because the enzymes had insufficient time to react. In addition they contain varying proportions of the plant nitrogen locked in vascular structures inaccessible to the microbes or associated with lignin. Some plant sulfur is similarly not available to the microbes, probably because of its presence in structures in association with nitrogen. It is probable, too, that many of the minerals are bound to particulate material strongly enough to be unavailable to microbes. There is little quantitative information on the proportions of nutrients in a forage that are available to microbes. In considering the need to supply supplementary nutrients it is therefore necessary to make a conservative estimate of the nutrients likely to become available from the feed and to consider ways in which the additional nutrients can be delivered at the times of day when need for them is greatest.

Minimal nutrient levels

When a nutrient is released into the rumen liquid it may be transferred across the rumen wall, pass with the digesta through the omasum or be taken up by the microbes. The relative rates of movement of nutrients in these three directions favour uptake by the microbes. The movement of nutrients across the wall of the rumen may involve active transport but is heavily influenced by the concentration of the substance in the rumen and by factors such as pH and osmotic pressure. At low concentrations, uptake by microbes is probably much faster than transfer across the wall. The mean time spent by molecules in the rumen before transfer may range from 20 minutes for sulfide to 1–2 hours for ammonia and volatile fatty acids. The corresponding time before passage to the omasum may range from 6 to 24 hours. The microbes therefore have access to molecules for an appreciable time before their removal from the rumen. The processes of nutrient uptake by rumen microbes are not well understood but some of the principles involved have been established from studies on the mechanisms underlying the uptake of ammonia.

Nitrogen. Protein metabolism by most rumen microbes commences with the uptake of ammonia. Two major enzymatic systems are involved in reactions that lead to the formation of glutamate and subsequently by transamination

processes to other amino acids. The first of these reactions involves the enzyme glutamate dehydrogenase and can be described (Hespell 1984) as

2-keto glutarate + NH₃ → glutamate
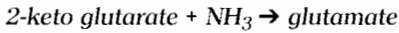
The second process, which requires ATP, consists of two enzymatic reactions catalysed by glutamine synthetase and glutamate synthase. The reactions are

glutamate + ATP + NH₃ → glutamine

2-keto glutarate + glutamine → 2 glutamate
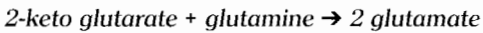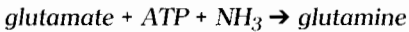
The various co-factors needed in these reactions are described by Hespell (1984). The particular system employed depends on the level of ammonia. The affinity for ammonia of the enzyme in the first reaction, glutamate dehydrogenase, is very much less than that of glutamine synthetase. Accordingly the second pathway becomes important especially at ammonia levels of 1 mM or less. Many rumen bacteria possess both types of enzymes and it seems probable that the second pathway, with its demand for ATP, takes part in assimilation even at high concentrations of ammonia. The extent to which this may reduce YATP is not clear. With one bacterial strain grown under nitrogen limiting or non-limiting conditions about half of a 20% decline in YATP was attributed to the need for the glutamine synthetase pathway (Hespell 1984).

These observations explain in part the reduction in the size of the microbial population at low levels of ammonia in the rumen. The cellulolytic bacteria seem to have a relatively low requirement for ammonia as their activity appears to require no more than 40–50 mg N/L (Satter and Slyter 1974). By contrast there are probably higher requirements, perhaps as high as 200 mg N/L for maximum activity in those groups of bacteria that ferment simpler carbohydrates. Much of the information available in this area is derived from studies of the effects of metabolite levels on voluntary feed intake and will be discussed in more detail in a later section. However they indicate that there is need to maintain rumen ammonia at levels approaching 200 mg/L where possible.

The levels of ammonia required by the other major groups of rumen microbes are less clear. Protozoa appear to derive most of their nitrogen from rumen bacteria and are excreters of ammonia into the rumen. The nitrogen requirements of anaerobic fungi are not well understood. The one species extensively studied, Neocallimastix patriciarum, was able to grow with ammonium ions as the source of nitrogen in medium comprising largely inorganic salts, but grew much better in a more complex medium that included amino acids (Orpin and Ho 1991). It appears that bacteria are the main initiators of protein hydrolysis in the rumen. Presumably this process proceeds

through large and small peptides and amino acids to ammonia. There is little evidence of peptides in rumen contents while the levels of free amino acids are low; either, as indicated above, those bacteria requiring peptides and amino acids acquire them during release from proteins or, with amino acids at least they must be taken up from solutions of low concentration. With low protein media, microbial protein synthesis can be inhibited by lack of branched-chain amino acids but these can be replaced by appropriate branched-chain fatty acids. However the response of animals to supplementation with branched-chain fatty acids is variable even with mature grasses of low protein content and probably depends on the variation between animals in the ability to return protein to the rumen in saliva.

The major minerals. In view of the difficulty in determining the availability of minerals for rumen microbes, the minimal levels required by the microbes cannot be described with any certainty. However data collated from Durand and Kawashima (1980) (Table 3) suggest that the levels found normally in the rumen are generally in excess of requirements.

Sulfur. Studies on the sulfur requirements of rumen microbes suggest that bacteria can meet their needs from solutions containing as little sulphide as 1 mg S/L (Bray and Till 1975), though Kandylis (1984) reported that for maximal growth, microbes required 3.8 mg sulphide S/L. Presumably these levels meet the needs of all rumen microbes, as anaerobic fungi depend on bacteria to reduce sulfate to sulfide, while most protozoal S is derived from bacteria.

Trace elements. An indication of desirable levels of trace elements to be maintained in the rumen is presented in Table 3. The wide range quoted for these minerals also gives an indication of the uncertainty surrounding the trace element nutrition of rumen microbes. Concerns about toxicity expressed by Grace (1991) also indicate a further problem that exists in compounding supplements to meet any suspected trace element deficiency.

Maintaining concentration in the rumen

As indicated earlier the levels of nutrients available to the rumen microbes may range from excessive to inadequate during intervals between episodes of eating. Recycling of nutrients modifies the severity of these periodic nutrient deficiencies. However with diets supplying low levels of nutrients, supplementary feeding is needed to ensure that the levels of specific nutrients are maintained.

In devising such supplements it is clearly desirable to develop systems by which nutrients are ingested at intervals during the whole day or by retarding the

rate of nutrient release or fermentation, permit the microbes to have access to nutrients during the whole day.

Table 3. Levels of major minerals considered desirable in rumen liquor compared with those commonly found.

Mineral	Suggested level	Commonly found level
P (mg/L)	100	50–1300
Mg (mg/L)	2–25	70–150
Ca (mg/L)	10–40	75–450
K (g/L)	0.5–1.5	0.9–2.7
Na (g/L)	0.5–1.5	1.9–3.6

Source: Durand and Kawashima (1980).

Conclusion

The prediction of the adequacy of diets to support a population of rumen microbes is clearly imprecise. However the broad principles have been discovered and there is much research in progress, worldwide, to obtain greater precision. For the present, an estimate of the content of the major minerals in relation to the digestibility of organic matter gives a basis for determining whether a nutrient deficiency is probable. The existence of other mineral deficiencies can then be indicated by simple measurement of the level of voluntary consumption of the diet without and with a complete mineral supplement.

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Feed Intake

J. Hogan

T he amounts of nutrients that an animal acquires each day depend on the
quantity of feed consumed and the nutrients released per unit of feed as it
passes through the digestive tract. With temperate forages, digestibility ranges
during the year between about 80 and 50% and with tropical forages between
65 and 40%. However, feed intake may vary even more widely. From the data
of Gardener et al. (1988) and Murray et al. (1988) for instance it can be seen
that the digestibility of organic matter (OM) in the diet selected by tropical cattle
in the wet, wet–dry and dry seasons declined from 66.6 to 59.4 and 55.3%,
whereas OM intake decreased from 9.2 to 6.7 and 6.0 kg. Feed intake is thus
a major determinant of nutrient supply to the animal and the manipulation of
feed intake provides a significant mechanism to assist the nutrition of the
animal. It is therefore important to understand the factors that control feed
intake in ruminants. The subject has been reviewed extensively, e.g. Forbes
(1980), Minson (1982), Weston (1982, 1985), De Jong (1986), Hogan et al.
(1987) and Standing Committee on Agriculture (SCA) (1990) and only those
factors pertinent to the need for nitrogen supplementation will be discussed
here.

The most important nutrient for any animal is energy and in seeking to satisfy
the demands of the tissues for energy the animal eats food. In the monogastric
animal that generally eats highly digestible feed, the amount of feed consumed
tends to reflect energy demand, if adequate levels of amino acids, minerals and
minor nutrients are available. The animal thus starts eating when the central
nervous system receives signals indicating a deficit in energy. When that deficit
has been met, further signals of satiety induce the animal to stop eating; eating
is resumed only when satiety gives way to energy deficit again, and the time
required for this to occur depends on the rate at which energy is metabolised in
the tissues. Energy use expressed per unit of metabolic body size ($W^{.75}$) is
probably lowest in the ageing castrate male and intake ($g/W^{.75}$) is also low
compared with young animals with high metabolic rates. The more rapid
metabolism of energy, as in the young animal with high basal metabolism or in
lactating females creates more frequent energy deficits that reduce the intervals
between bouts of eating and ultimately lead to a higher daily feed intake.

The monogastric animal offered highly comminuted feed frequently has the
physical capacity to process additional feed through its digestive tract. If the

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concentration of energy in feed is low the animal can eat more feed to maintain constant energy intake. This situation may not prevail with the forage-fed ruminant which has to harvest and comminute fibrous feed often with poor digestibility. In the situation in which energy yield per unit of feed is low the animal will attempt to satisfy its energy demand by increasing feed intake but may be prevented from doing so completely by inability to pass sufficient feed through the digestive tract. Signals of pseudo-satiety arising from distension of parts of the digestive tract will then cause the animal to stop eating (Fig. 1) (R.H. Weston, pers. comm.).

FEED INTAKE

MEAL EATING

+ | | −

C N S

FEEDBACK SIGNALS

METABOLISM	**GASTROINTESTINAL TRACT**	**ENVIRONMENT**	**SPECIAL SENSES**
Capacity to use energy	Capacity to handle digesta	Capacity to withstand stresses	
genotype	particle processing in rumen	heat	palatability
diet	propulsion	cold	
essential nutrients	water removal	psychic	
inhibitors	electrolyte removal	social	
physiological state		grazing fatigue	
pregnancy		Circadian rhythm	
lactation		Photoperiod	
age			
body composition			
disease			
work			

Figure 1. Factors affecting feed intake in ruminants.

However, such signals can be in part over-ridden by signals of greater energy demand and the animal then consumes more feed, even though this requires the passage of greater quantities of digesta through the tract. Under increased nutrient demands during lactation for instance, feed intake may increase by 50% or more over that shown by the non-pregnant non-lactating animal. It appears that the lactating cow can increase feed intake even with the most mature forages (Weston 1995). In another situation of increased nutrient demand however, that of late pregnancy, the animal may be prevented from increasing feed intake by competition for space in the peritoneal cavity between the enlarging uterus and the rumen.

Much of the energy in ruminant diets is contained in fibre that requires fermentation by microbial enzymes. The microbes must have sections of the digestive tract in which to live and multiply and their enzymes require periods of time, on average exceeding 24 hours, in which to hydrolyse the component linkages in fibre. In all herbivores, there are adaptations of the digestive tract to provide a place in which the onward passage of fibrous residues is delayed while microbial fermentation proceeds. These adaptations achieve the greatest complexity in the ruminant with the development of the large fermentation chamber, the reticulo-rumen; the capacity to regurgitate feed to permit rumination chewing; the anatomical device at the reticulo-omasal orifice to delay the passage of feed; and then when enzymatic digestion has proceeded in the abomasum and small intestine, the development of a further fermentation system in the large intestine.

The need for such fermentation chambers and the consequent delay to the passage of unfermented feed leads to the accumulation of a significant load of digesta in the tract. This digesta load varies with feed quality but in cattle may range from less than 30 kg with immature feed to 80 kg or more with very mature roughage. Hence even though distension of the rumen constitutes a signal to stop eating, the digesta load that signals satiety is not fixed and the amount of digesta in the rumen that releases that signal can gradually alter (Weston 1985).

The rate of emptying of the rumen is dependent on such factors as the reduction of feed particles to physical dimensions consistent with passage further down the tract; this reflects the effectiveness of chewing and of microbial fermentation. Both are reduced by increasing maturity of the feed and result in slow passage of feed particles along the digestive tract and reduced feed intake.

The regulation of intake of a given sample of feed thus depends on many interactions between the animal and the feed. Intake will be maximised if that feed provides all the nutrients required by appropriate rumen microbes and by the tissues of the animal. Conversely feed intake will be reduced if nutrients are lacking (Hogan and Liang 1991). In considering the adequacy of nutrients for

rumen microbes it must be remembered that microbial growth is dependent on energy supply as indicated by DOM intake. Hence the amounts of nitrogen and minerals required from the diet must be related to the OM digestibility of the diet, the needs of the microbes for those nutrients, and the availability of plant nutrients to the microbes. Thus with a highly digestible feed, the amount of P needed for maximum intake could be 15 g/kg whereas with the same feed at a very advanced stage of maturity 7 g/kg could be adequate.

The Feed Year and the Animal Year

The animal dependent on forages is subject to variations in amount, stage of maturity, and nutritional value of the forage during the year. At the same time, the animal passes through different nutritional demands as it alters its physiological state through pregnant, lactating, non-pregnant, non-lactating and the young through pre- and post-pubertal development. An understanding of feed intake requires consideration of the interactions of feed quality, animal needs, and environmental factors as they affect feed intake.

The feed year

Advancing maturity of forages occurs as the wet season progresses. During this time the animal preferentially removes the most nutritious parts of the plant (Tables 1, 2), the leaf, flowers and seed, so that late in the wet season the feed on offer may comprise mainly stem, which contains high levels of fibre and low levels of protein (Table 3). Further the fibre becomes more highly lignified and thus more resistant to both chewing and microbial fermentation. Microbial activity is further reduced by protein deficiency. Hence an increasingly longer time is required to process such feed to permit its passage from the rumen, and feed intake falls. In the experiment of Hunter et al. (1976), with castrate male cattle fed native pasture without and with the legume *Stylosanthes* spp. (Stylo), weight gain ceased when the protein content of both diets fell to about 60 g/kg (Table 3). At this protein level, feed intake is often stimulated by supplementation with urea and hence it is at this protein level in the pasture that productivity ceases because of protein deficiency. As protein levels decline further, feed intake is further reduced and weight losses occur.

Consequences of soil infertility on pastures

Significant sections of the northern Australian cattle industry depend on pastures grown on soils deficient in P, Na, S or trace elements. Hence even in the wet season when the nitrogen content of pastures reaches its maximum the plant may provide inadequate levels of other minerals to support maximum

intake. With severe P deficiency for instance the effect on feed intake is indicted by the observation (Winter et al. 1990) that growth rates of cattle during the wet season were less than half those of comparable cattle adequately supplied with P. Similar effects of Na and S deficiency were reported by Hunter et al. (1983), again indicating a reduction in feed intake when the pasture was at its highest quality during the wet season.

Table 1. Changes in diet (percent brown leaf, green leaf and stem) available to cattle grazing a pasture of *Heteropogon contortus.*

	Brown leaf	Green leaf	Stem
February	10	73	17
March	13	50	37
August	32	8	60

Source: W.F.Colebrook and D.B.Coates (pers. comm.).

Table 2. Changes in diet (percent brown leaf, green leaf and stem) available to cattle grazing a pasture of *Stylosanthes hamata* cv. Verano.

	Brown leaf	Green leaf	Stem
March	31	11	58
May	5	19	76
August	0	0	100

Source: W.F.Colebrook and D.B.Coates (pers. comm.).

Nitrogen is generally at a low level in tropical soils but the consequence is often a reduction in the quantity of grass produced rather than in its protein content. However tropical grasses grown even on fertile soils generally have appreciably lower protein levels than temperate grasses at the same stage of maturity and as indicated earlier, the protein levels tend to fall rapidly with advancing maturity. Hence while other minerals may limit feed intake during the wet season, nitrogen is likely to be the main factor limiting intake during the dry season.

The animal year

Superimposed on changes in forage maturity and nutritive value as the season progresses from wet to dry are the changes in the physiological state of the animal. This can be illustrated by considering the breeding cow and its

castrate male progeny. The cow generally conceives early in the wet season and hence under northern Australian conditions, late pregnancy and lactation, the times of greatest nutrient demand, coincide 7–11 months later with the time at which pastures are at their lowest nutritional level and air temperature is high. In consequence feed intake is inadequate for maintenance and the cow may lose 50–80 kg in weight in late pregnancy with, depending on the time of arrival of the following wet season, a further substantial loss of weight during lactation. The extent of weight loss affects the chance of conception by the cow during that wet season.

Table 3.   Composition of diet selected by steers (g/kg DM)

	Native pasture		Stylo/native pasture	
	CP[a]	NDF[b]	CP	NDF
Late Feb.	144	691	150	700
Late March	156	721	169	590
Mid-Apr	103	754	131	715
Mid-May	83	783	96	753
	→ Zero growth			
Early June	64	790	58	769
			← Zero growth	
Mid-June	46	814	58	780

[a] CP = crude protein
[b] NDF = neutral detergent fibre
Source: Hunter et al. (1979)

Weight regain during the wet season can be very rapid. The feed is at its highest level both in nutritional value and in ease of processing through the rumen. In addition the animal experiences additional enhancement in feed intake associated with compensatory gain. This process, which is not well understood, occurs when the animal is rebuilding tissues that were depleted during weight loss. It results (SCA 1990) in weight gain containing more protein and water but less fat than normal weight gain. Presumably after the period of compensatory gain the animal reduces its feed intake to correspond to that of animals undergoing normal weight gain with that particular forage.

Weight loss and compensatory regain are annual features in the growth of castrate male animals. With such animals feed intakes tend to be very high during the wet season and appreciably lower in the dry season. It may be calculated from Gardener et al. (1988) and Murray et al. (1988) that OM intakes

for 450 kg castrate male cattle (g/kg $W^{.75}$) ranged from 94 to 68 and 61 in the wet, wet–dry and dry seasons.

Compensatory gain benefits the depleted animal to such an extent that by the end of the wet season its body weight is often similar to that of its non-depleted peer. This phenomenon is of great benefit for animal production but is also has implications for supplementary feeding. There is little economic advantage in feeding an animal to prevent modest weight loss if the depleted animal can subsequently make good that weight loss by compensatory gain.

Definition of Nitrogen Deficiency Affecting Feed Intake

Nitrogen Needs of Rumen Microbes

It is not possible to consider in detail the methods to define the requirements of microbes for all minerals. Much of the information needed for this purpose was presented in the previous section. The present discussion will involve requirements for N, and to some extent with S because the effective use of N by microbes also requires adequate amounts of S.

The prediction of nitrogen needs is apt to be imprecise because of variation in the availability to the microbes of N in different forages; the capacity of individual animals to recycle nutrients; and the needs for nitrogen of the dominant bacterial species in the rumen.

For this reason it must be accepted that only very general practical rules can be applied when attempting to predict the need for supplementation of forage of a known chemical composition. With forages suspected of being deficient, small scale supplementation feeding trials are recommended. With this proviso, the following general suggestions are advanced as rough guidelines to alert the nutritionist to the need for supplementation.

· Forages containing less than 10 g N/kg dry matter are likely to be deficient.

· With very low protein forages, feed intake can be increased by provision of non-protein nitrogen (NPN) to raise the levels of rumen ammonia to about 50 mg N/L, which appears to meet the needs of cellulolytic bacteria.

· Continuous infusion of urea to increase ammonia levels to 130–200 mg N/L increases feed intake (Boniface et al. 1986, Krebs and Leng 1984), probably by increasing protein supply to the animal by encouraging greater protein synthesis by non-cellulolytic bacteria (Morrison et al. 1976).

· In practice it is difficult to raise rumen ammonia levels above about 50 mg N/L, even when the animal has frequent access to urea. Hence consideration of the effect of higher ammonia levels on feed intake is of little practical value.

· Temperate grasses with a ratio of digestible organic matter to crude protein

(DOM:CP) of more than 7:1 that is about 23 g N/kg DOM or less will probably supply less than adequate levels of rumen ammonia.

· Tropical grasses with DOM:CP ratios greater than 5:1 probably also supply less than adequate amounts of ammonia. A grass of 40% digestibility would thus need to supply in theory 80 g CP or 12.8 g N/kg to provide adequate ammonia. In practice, a feed intake response to urea supplementation is not seen until the nitrogen content is lower than this. Although some of the nitrogen in forages is unavailable to the rumen microbes, a deficiency may be counterbalanced by nitrogen recycled from the blood to the rumen.

· The uptake of ammonia by microbes requires the supply of adequate amounts of sulfide. The needs of bacteria are probably met by diets that supply N:S in a ratio of 10:1. A diet of 40% digestibility would thus need to provide 1.28 g S/kg. In practice, the level of S required is probably 1 g S/kg or less because some S is recycled to the rumen and there is also some exchange of S within the rumen.

Amino acid needs of the tissues and feed intake

For efficient use of energy, animals require adequate amounts of other essential nutrients and especially amino acids. Any deficiency in one or more amino acid will cause metabolic disturbances that result in reduced feed intake. It is difficult to elucidate the mechanisms involved because the provision of the deficient nutrient, for instance glucose or a glycogenic amino acid, may bring about unexpected changes in hormones and alter metabolic pathways.

It is clear that the requirements of the animal for amino acids relative to energy alter with physiological state. The calculations presented in Table 4 indicate that a cow at maintenance level of feeding may need 3.5 g amino acids/MJ ME compared with 5.9 with even moderate lactation. In consequence amino acid imbalance for a particular diet would be more severe in the lactating animal than the animal at maintenance. In such a situation it would be expected that the extent of depression in feed intake would reflect the severity of the deficiency and in consequence that the relief of the most severe deficiency would be accompanied by the greatest increase in feed intake.

In studying imbalance in the tissues it is first necessary to provide adequate nutrients, especially N and S to the rumen microbes and then, having measured feed intake, to observe any increases in feed intake following the provision of protein treated to ensure the release of additional amino acids in the small intestine.

Some examples of this, presented in Table 5 indicate that:

· With oaten hay with nitrogen content below 7 g/kg, feed intake increased with NPN but did not increase further in response to protein supplement.

· With mature tropical grasses such as *Heteropogon contortus* containing

3–7 g N/kg feed intake responded to NPN supply but increased further, though generally to a lesser extent, with the provision of protein.

· The response in feed intake to NPN in growing steers affected both Angus and Brahman but a further response to supplementary protein was observed only in the Angus. This presumably reflects a lower demand for amino acids by the Brahman and indicates that the severity of nutritional imbalance can vary between breeds.

· Increases in feed intake in response to protein supplementation were higher in young steers probably experiencing compensatory growth and in pregnant and lactating cows than in adult steers. If the response in feed intake reflects nutrient demand the process of adult growth appears to be less demanding of nutrients than the other physiological states.

· In the experiment of Lindsay et al. (1982) with pregnant cows there was evidence of glucose deficiency because the birth weight of calves, which is affected appreciably by glucose supply, was only two thirds of normal. The intake of an additional 2 kg feed in response to NPN supplementation restored calf birth weight to approximately normal. Even so the provision of intestinally digested protein promoted a further increase of almost 2 kg in intake of roughages.

Table 4. Suggested requirements for metabolisable energy (ME) and for amino acids absorbed from the small intestine (AA) for a 400 kg cow in various physiological states

Physiological state	ME (MJ/day)	AA (g/day)	AA/ME (g/MJ)
Zero weight gain	40	141	3.5
1 kg gain/day	70	341	4.9
280 days pregnant	72	337	4.7
5 kg milk/day	65	396	5.9

Source: Lindsay and Hogan (1987).

Diagnosis of amino acid imbalance in the tissues

The simplest and most positive method to diagnose an imbalance of amino acids and energy is to observe an increased feed intake following supplementation with a protein digestible in the small intestine but protected against fermentation in the rumen.

However it is possible to derive useful information regarding a potential amino acid imbalance from relatively simple data involving organic matter (OM) intake; OM digestibility; crude protein content of dietary OM.

Table 5. Changes in roughage intake (g DM/W75 day) in response to supplementation with non-protein nitrogen (NPN) and/or one or more levels of intestinally digested protein (P1, P2).

Breed	Intake	NPN	P1	P2	Comments	Reference
		% response				
Hereford	69	21	21		Heifers 288 kg	Redman et
					Oat hay 7.7 g N/kg	al. (1980)
Brahman × shorthorn	39	60	90		Steers 215 kg	Mullins et al.
					Native pasture 4 g N/kg	(1984)
Brahman × shorthorn	40	27	38		Steers 380 kg	Hunter and
					Heteropogon 6.7 g N/kg	Siebert (1980)
Angus Brahman	43	32	49		Steers 500 kg	Hunter and
	47	22	20		*Heteropogon* 3.2 g N/kg	Siebert (1987)
Brahman × shorthorn	49	69	87		Cows, last trimester 400 kg	Lindsay et al.
					Heteropogon 4 g N/kg	(1982)
Hereford	61		80	93	Lactating cows 310–380 kg	Lee et al.
					Axonopus 4.3 g N/kg	(1985)

From these variables it is possible to calculate the amount of protein digested in the small intestine (DCP_i) which is a measure of amino acid supply and the intake of digestible organic matter (DOM) which gives a measure of energy intake. Weston (1971), working with temperate grasses, suggested that the ratio of DCP_i to DOM provided a useful indication of the adequacy of amino acids for the amount of energy available. Experiments with growing lambs indicated that a ratio of DCP_i:DOM of 180 g/kg was adequate for growing lambs, whereas 140 g/kg was inadequate and no increases in growth were observed at 230 g/kg. The ratio could be predicted as

$$DCP_i/DOM = 117 + 5.2 \; CP \; content \; of \; feed$$

It must be remembered though that the Weston (1971) studies involved ground and pelleted diets that minimised physical limitations to intake. However, with roughage-fed young animals capable of rapid growth, nutrient imbalances are likely to occur only with mature forages and factors affecting the movement of feed through the rumen may limit any responses to the correction of an imbalance in the tissues.

It is risky with the Weston approach to extrapolate nutrient requirements from lambs to young cattle. The wool growing sheep has a high requirement for

the amino acid methionine which on conversion to cysteine is deposited in wool and this withdrawal from the circulation of an essential amino acid which has many functions in the tissues must increase the minimum required DCP_i:DOM ratio. No studies comparable to Weston (1971) appear to have been made with young cattle but it seems probable that for adequate growth in such animals the DCP_i:DOM ratio need be no greater than 130 g/kg. This would be consistent with the observations presented in Table 1, where according to Weston's (1971) formula, DCP_i:DOM for oaten hay would have been 142 g/kg, the various lots of Heteropogon 127–139 and Axonopus 131. Even though these different forages were of very low protein content the calculations suggest that at worst they were not greatly deficient in DCP_i:DOM balance. It is a common finding that cattle may show an intake response to a supplement of intestinally digested protein with one source of roughage but not with another of similar protein content. This probably reflects the variation from one forage to another in the availability of protein to the microbes or the host or from one animal to another in the extent of microbial protein synthesis in the rumen and on the subsequent release of amino acids in the small intestine as discussed in the previous section.

Hence as Weston (1981) indicated this simple formula has limitations but it also has great value to the nutritionist because it can warn of dietary situations in which an amino acid:energy imbalance in the tissues may limit feed intake and utilisation.

Conclusion

The needs of ruminants for energy vary with changes in physiological state during the year. The capacity of the animal to eat enough feed to satisfy energy demands also varies as the pasture undergoes its annual growth cycle and as the changing seasons produce varying environmental stresses. The producer faces the task of maintaining a desired level of production often when the quality of pasture is less than optimal and as pasture is likely to provide the cheapest source of energy it is important to maximise feed intake at minimal cost. Sufficient information is now available to decide the forms of supplementation needed to improve intake and hence to permit the producer to decide on the economics of supplementary feeding.

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Energy and Protein Interactions

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The nitrogen economy of the animal relates to the supply of amino acids relative to energy for the tissues. Understanding of amino acid supply is based on studies of the microbiological and physiological events that occur in the digestive tract. The principles of energy use are based quite differently. Although extensive studies of intermediary metabolism have been conducted, the practical application of energy matters comes from balance studies and as embodied in the metabolisable energy (ME) system depends on knowledge of ME requirements for maintenance and for various forms of production; the amount of ME supplied by a particular diet; and the efficiency with which that ME is used for maintenance and for production.

In considering protein nutrition and the amount and type of nitrogen supplementation that might be needed, it is necessary to combine the two approaches into a system that considers the demands of the animal for these nutrients, and the capacity of available feeds to supply those nutrients, the ways in which the needs for supplementation with non-protein or protein nitrogen can be calculated and the nutritional consequences of supplying that supplementation.

The first step in this process is to determine the amounts of amino acids absorbed from the small intestine in consequence of the movement of nitrogen from endogenous sources into the stomach and small intestine; protein metabolism in the rumen; and the release of amino acids in the small intestine and their absorption from that organ.

Endogenous Nitrogen Supply to the Digestive Tract

Nitrogen enters the digestive tract not only from the diet but also from numerous endogenous sources. The most important of these are nitrogen recycled to the rumen and that discharged as sloughed epithelium into the small intestine. Recycling processes in the rumen include the movement of additional nitrogen in saliva or directly across the rumen wall. In addition cells from the rumen epithelium slough off. Finally there is the re-use of nitrogen within the rumen as protein becomes catabolised following the death of microbes.

Recycling of N in saliva

Much of the study of recycling of nitrogen in saliva has been based on samples collected by suction from under the tongue or from sponges chewed by the animal. Both types of sample are dominated by secretions from the parotid gland and are valid for those metabolites, largely minerals, that are secreted in parotid saliva. They are much less valid for nitrogen because they do not include the secretions of the large amount of salivary tissue in the palate. Output of saliva is best studied in animals fitted with permanent oesophageal fistulae. It has been possible to obtain saliva of the same nitrogen content as that collected from a fistula only by applying suction through a tube placed over the back of the tongue. Results of studies (J.P. Hogan and P.J. Connell, unpublished data) in which the protein intake of sheep was increased appreciably by dietary supplementation with formaldehyde-treated casein indicated that:

·   With a basal diet that supplied 12 g N/day about two thirds of the salivary nitrogen was present as protein and most of the remainder as urea.
·   With increasing levels of protein intake the levels of plasma urea and of salivary urea rose. Salivary urea levels were about 65% of those in plasma.
·   Despite appreciable rises in the levels of amino acids in plasma no changes were observed in the protein content of saliva. There were negligible amounts of free amino acids in the saliva throughout the experiment.
·   The proportion of protein in salivary N fell and correspondingly the proportion of urea rose with increases in plasma urea.
·   Assuming that saliva production was within the range of 10−20 L/day, the return of nitrogen with the basal diet would have been 3−6 g/day.
·   Gains of nitrogen of this dimension have been observed in the rumen with sheep fed forage diets supplying this amount of nitrogen.

The transfer of urea across the rumen wall

There is uncertainty about the extent of transfer of urea across the wall of the rumen, or at least of the effectiveness of this procedure in increasing the quantity of ammonia available to the rumen microbes. When urea was pumped continuously and in increasing amounts into the abomasum (Weston and Hogan 1967) an increase in plasma urea from 40 to 200 mg N/L was accompanied by a linear increase in the levels of rumen ammonia from 10 to 100 mg N/L. However ammonia levels did not show any further increase even when plasma urea reached 400 mg N/L. Some additional urea undoubtedly returned to the rumen in saliva but some must also have traversed the wall of the rumen. The suggestion that urease activity in the rumen is largely confined to bacteria attached to the rumen epithelium (Chang and Costerton 1980) may hold the key to urea transfer. It has been suggested that higher levels of

ammonia in the rumen may depress urease activity so that urea passes freely into the rumen and is not hydrolysed to ammonia. Alternatively when rumen ammonia reaches a particular concentration, urea crossing the rumen wall is deaminated at the epithelium and the transport of ammonia back across the rumen wall into the plasma becomes equal to ammonia addition from plasma urea. Either way there appears to be an upper limit to effective urea recycling into the rumen.

Nitrogen cycling within the rumen

Hespell (1984) has drawn attention to the fact that only 10–30% of bacterial cells in the rumen are culturable. It is generally accepted that feast and famine conditions exist in the rumen-feast with the release of nutrients following ingestion of feed but then famine that follows the removal of those nutrients by the rapidly developing microbial population. Hespell (1984) suggests that the low viability of the population indicates a high death rate during the famine period. Within this life cycle, some microbes are likely to survive longer than others perhaps because they are slowly but continuously extracting nutrients from cell wall or perhaps because, like protozoa, they can predate the living or dead bacterial population. However it is clear (Nolan and Stachiw 1979) that there is substantial cycling of nitrogen within the rumen as microbial protein is synthesised, broken down and resynthesised, and those authors have indicated that total microbial production could be at least twice the net outflow.

Recycling of urea into the lower digestive tract

Urea from the plasma enters all sections of the digestive tract, but mostly occurs distal to the rumen (Nolan 1974). It is readily deaminated by ureases of bacterial origin. Bacteria reside in all sections of the tract but part at least of the urease activity in distal sections of the tract may originate in the rumen. Certainly in sheep dosed per abomasum with a broad spectrum antibiotic to remove bacteria from the intestines, the urease from rumen microbes continued to pass out of the abomasum and the levels of urease activity in the faeces fell by only one half (R.H. Weston and J.P. Hogan, unpublished data). Urea from plasma contributes to the ammonia found in all sections of the tract and in the venous blood draining the tract (Table 6).

The role of urea in the nitrogen metabolism of the ruminant depends on the extent of its conversion to microbial protein. Events in the rumen are discussed elsewhere, but the particular benefits of microbial protein are realised only after its digestion and absorption as amino acids from the small intestine. Urea entering the caecum ensures an adequate supply of ammonia to the bacteria in that organ, even with diets supporting levels of ammonia in the rumen adequate

for microbial activity. This is probably a factor with mature forages where an increased proportion of fibre fermentation occurs in the caecum. However caecal fermentation is believed to have little direct influence on the nitrogen economy of the animal because it is unlikely that significant amounts of amino acids are absorbed from that organ and any bacterial protein synthesised is largely excreted in the faeces.

Nitrogen recycling into the small intestine is largely a consequence of the need to replace the cells of the epithelium. These cells divide in the crypts and then pass to the tips of the villi before discharge into the intestinal lumen, bearing with them appreciable quantities of protein. This is mixed with nitrogen contained in bile, pancreatic and intestinal secretions, mucus, and small amounts of protein derived from plasma. It has been estimated that about 8 g/day plasma albumin pass into the small intestine (McFarlane et al. 1961) whereas protein from the other sources could amount to 50–200 g/day (McDougall 1966) depending on assumptions made. The entry of plasma proteins into the intestine increases with infestation by intestinal helminths such as *Trichostrongylus* spp., the extent of increase depending on the severity of the infestation and the nitrogen status of the animal (Steel 1974). Endogenous proteins could therefore greatly exceed the amounts of protein arriving from the abomasum.

Digesta spend 2–3 hours in the small intestine, mainly in the ileum, and hence that is the time available for the release and absorption of amino acids or small peptides from the mixture of proteins.

The nutritional consequences of secretion of endogenous proteins and especially of the renewal of epithelial cells are three-fold, two detrimental and one beneficial. Detrimental effects are protein catabolism and subsequent protein synthesis in new epithelial cells creates an inefficiency in amino acid metabolism; and there is a substantial energy cost in the process. Benefit, conversely, comes from the fact that the digestion of the numerous proteins that reach the small intestine ensures the supply to the liver of a mixture of amino acids of relatively constant composition; this improves the efficiency of protein synthesis in the liver and in peripheral tissues.

Protein Metabolism in the Rumen

Protein metabolism in the rumen involves the fermentation of part at least of the nitrogenous components of dietary and endogenous origin and the subsequent synthesis of microbial cells. From the nutritional viewpoint it is important to be able to establish and preferably predict the proportion of dietary protein that escapes degradation in the rumen; the extent of protein synthesis.

Escape of dietary protein

Proteins of different origin are degraded to varying degrees in the rumen. Some are naturally protected from microbial attack by tannins released into plant cells during chewing. Others, for instance in oil seeds are partially denatured by heat during the extraction of oils or are deliberately protected against attack by treatment with chemicals such as formaldehyde. Others, especially in tropical grasses, appear to be contained in plant structures not readily fermented. There are also proteins associated with lignin that appear to escape attack in the digestive tract and presumably when grasses become more highly lignified with increasing maturity, the proportion of protein protected against microbial attack also increases.

For these reasons the published estimates of the proportion of dietary protein passing through the stomach undegraded cover a wide range. Values expressed as g/kg dietary protein for temperate grasses and clovers were 360 (Hogan and Weston 1981) or for sheep grazing immature temperate pastures 130 (Corbett et al. 1982; Corbett and Pickering 1983). Median values calculated by Norton (1982) for temperate grasses and legumes were 220 and 190 whereas corresponding figures for tropical grasses and legumes were 350 and 300.

Protein synthesis in the rumen

It must be pointed out that most published measurements of the amounts of protein synthesised in the rumen are inaccurate. Data purporting to describe this variable generally describe the amounts of microbial protein that pass out of the abomasum. Hence they are net values because as indicated above some microbial protein is destroyed before it leaves the rumen.

Predictions of microbial protein 'synthesis' assume that synthesis is regulated, when nutrients such as ammonia are adequate, by the release of energy in useful form during carbohydrate fermentation according to the formula

$$\textit{carbohydrate} \rightarrow \textit{volatile fatty acids (VFA)} + \textit{methane} + CO_2 + \textit{heat} + ATP$$
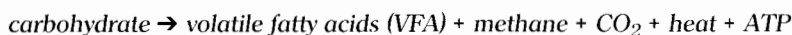
where ATP represents energy released in a form available to rumen bacteria, and presumably is proportional to VFA production.

This had led to the development of an association between microbial protein synthesis and organic matter (OM) apparently digested in the stomach. It was proposed, for instance by ARC (1980) that protein synthesis was equivalent to 30 g N/kg OM apparently digested in the stomach.

This estimate suffers the disadvantage that there is no simple method to measure the quantity of OM apparently digested in the stomach. However, it has

been observed that with many diets, OM apparently digested in the stomach is equivalent to about 65% of OM apparently digested in the whole tract. Hence the latter term, referred to as digestible OM (DOM) intake offers a more readily measurable predictor of microbial protein synthesis. The value of DOM as a predictor is further enhanced by the observations (Weston and Hogan 1968; 1986) that the production of volatile fatty acids with forage diets ranging widely in nutritional value was equivalent to 8.1–8.5 mole/kg DOM, suggesting a useful relationship between DOM intake and energy supply for rumen bacteria. Intake of DOM is therefore the main predictor used to estimate microbial protein synthesis.

Microbial protein yield, expressed as g/kg DOM with animals fed mixed roughage and concentrate diets has been reported to be 135 (Verité et al. 1979), 130 (ARC 1984), 121.1 for sheep and 146.1 for cattle (SCA 1990). These general values which include diets containing processed feeds probably understate the situation with forage-fed animals as a mean value of 160 was reported with sheep fed roughages ad libitum (Hogan and Weston 1981) and the mean value with sheep grazing temperate pastures was 182 (Corbett and Pickering 1983). Values with cattle ranged from 100 g/kg DOM with Kikuyu grass, *Pennisetum clandestinum* (Hart and Leibholz 1983) to 185–236 with immature perennial grasses and clovers (Beever et al. 1978).

The total amount of protein passing from the stomach then consists of a component of dietary protein that escapes fermentation, which is a function of protein intake, plus microbial protein which is related to DOM intake. In addition there is a small component representing endogenous nitrogen secreted into the abomasum. Protein flow from the stomach with sheep fed temperate forages was expressed (Hogan and Weston 1981) as equivalent to

0.36 *crude protein intake* + 0.16 *DOM intake* + 6

and this formula will be used for other calculations in this section.

However the variability indicated earlier in the factors representing undegraded protein and the extent of microbial protein synthesis indicate that the extrapolation of factors from one class of feed to another can lead to substantial errors. These errors are of significance only when the amount of protein predicted to pass from the stomach to the intestines is less than that needed by the animal, because that could lead to erroneous assessment of the need for supplementary feeding. The variability indicates the need to assess the validity of the above calculations with small scale supplementary feeding experiments.

Protein transactions with imbalanced diets

The calculations on protein flow to the intestines assume that microbial activity in the rumen is not limited by the supply of ammonia. With temperate forages, ammonia levels are predictable with reasonable accuracy from the ratio of DOM intake to crude protein (CP) intake (Weston and Hogan 1968). With temperate grasses a ratio above about 7:1 indicates a potential deficiency of ammonia. With tropical grasses with lowered availability of dietary nitrogen for the microbes, deficiencies of ammonia could occur with DOM:CP ratios greater than 5:1. Ammonia deficiency is suspected with forages containing less than 10 g N/kg OM, a situation observed frequently with cereal straws. Such diets have a DOM:CP ratio greater than 7:1 if OM digestibility exceeds 44%. Cereal straws range in digestibility between about 40 and 45%. A straw containing 10 g N/kg OM and 40% digestibility and thus with a DOM:CP ratio of 6.4:1 might be nitrogen-adequate whereas a straw of 45% digestibility with a similar nitrogen content and hence with a DOM:CP ratio of 7.2 could benefit from non-protein nitrogen (NPN) supplementation. There is thus the anomaly that the roughage of lower nutritional value might not respond to supplementation with urea whereas that of higher nutritional value would do so. This concept extends further because if the digestibility of straw is further increased through alkali treatment the demand for supplementary urea also increases.

The first consequence of deficiency of N in a forage is a fall in feed intake, presumably reflecting a reduction in the size of the microbial population in the rumen. The effects of low levels of ammonia on protein synthesis in the rumen are discussed in a previous section. In the present context, the question arises of the extent to which such a deficiency affects the energy:protein balance to the animal.

An example of this can be seen in the data of Freire et al. (1980) who fed sheep on mature spear grass, *Heteropogon contortus*. In this experiment the intakes of OM and CP were 282 and 6.0 g/day and corresponding faecal outputs 172 and 8.7 g/day. Intakes of DOM and CP were thus 110 and 6 g/day giving a ratio of DOM to CP of 18.3; this indicated a deficiency of rumen ammonia which accorded with the observed mean value of 21 mg N/L. However the DCP_i:DOM ratio 18.6:1 suggests that there was adequate balance between energy and protein even though the total amounts were small. In this situation amino acid supply might be considered adequate for the needs of the animal relative to energy, even though the animal experienced a severe deficiency of rumen ammonia. Supplementation with intestinally-digested amino acids should thus not increase feed intake. In practice it would not be possible to supply additional amino acids to the intestines without increasing the supply of ammonia to the

rumen by recycling and hence the question of nutrient imbalance is largely irrelevant.

Therefore despite significant variation in the degradability of forage proteins and in the efficiency of microbial protein synthesis the relationships that have been developed involving intakes of DOM and CP provide a useful basis for predicting the adequacy of nitrogen supply for rumen microbes and the probable supply of feed proteins and microbial proteins to the small intestine.

Estimation of Intestinal Digestion

From the viewpoint of the nutritionist the most useful estimate of protein supply is the loss of amino acids in the small intestine. This information is obtained as the difference between the quantities of amino acids passing from the abomasum into the duodenum and leaving the terminal ileum to enter the caecum. This calculation ignores the large amounts of protein that enter the small intestine from endogenous sources, where the components are largely digested and reabsorbed. Net loss in the small intestine therefore does not describe precisely the fate of proteins passing to that organ from the stomach, and it certainly grossly underestimates the total quantities of amino acids that pass each day to the liver from the small intestine. However it gives the best available estimate of the amino acid status of the animal as influenced by diet.

Observations on intestinal digestion indicate that:
· The amino acid composition is similar to that in forage proteins, though generally the proportion of lysine is higher. Variability has been observed in the proportions of lysine, threonine and the sulfur amino acids that is probably greater than analytical error (Hogan and Weston 1981) suggesting that by the manipulation of rumen microbes it might be possible to improve the supply of specific amino acids to the animal.
· The crude proteins passing out of the small intestine to the caecum contain only about 60% amino acids.
· The proportions of individual amino acids in this mixture are reasonably similar to those entering the duodenum; cysteine is present in higher concentration but this may reflect the addition of endogenous proteins rich in cysteine.

Estimates of 'true digestibility' of protein in the small intestine are based on the calculation

Protein truly digested = Protein entering duodenum − Protein leaving ileum
+ Endogenous protein leaving ileum

Endogenous protein passing from the ileum in sheep has been estimated by two different methods to be 6−10 g/day (Lindsay et al. 1980). True digestibility

of crude protein in the small intestine was estimated to be 73%. Further, for every 100 g crude protein that passed from the abomasum, 33 g crude protein, including the endogenous component, passed to the large intestine and probably made little further contribution to the nitrogen economy of the animal.

The true absorption of essential amino acids was generally above 70%, but cysteine appeared to be only 52%.

Digestion in small plus large intestine

There is little evidence that the animal's protein economy benefits greatly from the fermentation that occurs in the large intestine. Only small differences have been observed in the amounts of nitrogen entering the large intestine and excreted in the faeces, unless the animal was simultaneously supplied with additional starch or sugar to provide energy for microbial protein synthesis in the caecum.

The estimated value of the endogenous nitrogen appearing in the faeces, generally referred to as metabolic faecal N, is considered important in estimating 'true digestibility' of dietary crude protein in the whole tract and values of about 5 g N/kg DM intake are generally quoted (SCA 1990). 'True digestibility' is a meaningless expression because it cannot take into account either excessive wastage of protein absorbed as ammonia from the rumen or increases in protein flow from the stomach above dietary intake as a result of microbial protein synthesis in the rumen. Of greater significance is the amount of protein digested in the intestines estimated by the formula:

Protein digested in the intestines = Protein leaving stomach − Faecal protein
+ Endogenous faecal protein

Endogenous faecal protein was estimated by Hogan and Weston (1968) to be equivalent to 1.8 g N (11.3 g CP)/kg OM passing from the stomach or one quarter of total metabolic faecal N. On this basis, with 13 forage diets the true digestibility of nitrogen passing from the abomasum was 78%, a value probably not significantly different from the 73% true digestibility reported in the small intestine (Lindsay et al. 1980). This is supported by observations that the amount of nitrogen that passes from the terminal ileum into the caecum is approximately equal to the amount excreted in the faeces. It appears that microbial protein synthesised in the caecum and any endogenous nitrogen added to the whole of the large intestine is balanced by loss of ammonia. The loss of nitrogen in the small plus large intestine therefore gives a reasonable indication of the quantities of amino acids absorbed from the small intestine.

Balance of Nutrients

The balance between the supplies of energy and protein is best expressed as absorbed amino acids (g)/MJ ME. However there are few if any data in the literature in which these measurements have been made on the same animal. Instead, the appropriate terms have been calculated on the basis of predicted values. As indicated earlier, with mature tropical forages for which there are few measured values, for either variable, this procedure requires substantial assumptions, some of which are insecurely based.

As an alternative Weston (1971) introduced the concept of expressing the amino acid to energy balance as DCP_i/DOM where DCP_i represents intestinally digested crude protein, while DOM, through its relationship to ME, provides an indication of energy supply. This concept has the advantage that most of the measurements required can be performed as part of experiments being conducted to measure aspects of animal production.

The measurements required for this calculation are the intakes and faecal outputs of organic matter and crude protein. The calculations, using information presented earlier, then are

DOM intake = *OM intake – Faecal OM output*

Assuming that 65% of organic matter loss occurs in the stomach

OM leaving stomach	=	*OM intake – 0.65 DOM*
Faecal endogenous CP	=	*11.3 g/kg OM leaving stomach.*
Crude protein leaving stomach	=	*0.36 CP intake + 0.16 DOM intake + 6*
CP digested in intestines	=	*CP leaving stomach – Faecal CP*
		+ Endogenous faecal CP

As an example of this calculation, in an experiment with sheep, OM and CP intakes were 690 and 78 g/day and faecal outputs of OM and CP 320 and 28 g/day. From these data:

DOM intake	= 690–320	= 370 g/day.
OM leaving stomach	= 690 – (0.65 × 370)	= 690 – 241 = 449 g/day.
Faecal endogenous CP	= 11.3 .449	= 5 g/day.
CP leaving stomach	= (0.36 × 78) + (0.16 × 370) + 6	= 28 + 59 + 6 = 94 g/day.
CP digested in intestines	= 94 – 28 + 5	= 71 g/day.
DCP$_i$/DOM	= 71/370 × 100	= 19.2

It must be remembered that small errors in either the numerator or denominator of a ratio can have major effects on the value obtained. However this calculation gives a first indication whether an animal would respond to supplements of protein of a type capable of increasing amino acid supply to the intestines.

In studies with growing lambs, Weston (1971) found no improvement in growth rate when DCP_i/DOM was greater than 180 g/kg, whereas growth was reduced at 140 g/kg. A similar nutrient balance was required in controlling feed intake. This type of animal has a relatively high requirement for amino acids to meet the needs both for extensive protein synthesis and to supply the large quantities of sulfur amino acids needed for wool growth. Calves at a corresponding stage of development have lower requirements for amino acids because the demand for sulfur amino acids is proportionally less. The female in late pregnancy needs a diet with a high DCP_i:DOM ratio; the foetus has a high demand for amino acids for the synthesis both of its body proteins and for conversion to glucose and with mature forages feed intake is likely to be restricted at that time. The lactating animal also requires amino acids for the synthesis of milk proteins but can increase feed intake by 40−50% and hence the DCP_i:DOM ratio can be lower.

The more slowly growing adult cow appears to have relatively lower requirements for amino acids than the wool-growing sheep. Calculations based on growth rates observed with cows slowly gaining weight on tropical grasses suggest that the DCP_i:DOM ratio need not exceed 120−130 g/kg; that appears to be met with grasses that can supply adequate energy.

There is an important corollary to the desirable DCP_i:DOM ratio for different aspects of production. As the protein content of a diet declines the supply of intestinally digested protein becomes increasingly dependent on microbial protein synthesised in the rumen. If as Hogan and Weston (1981) suggested, microbial protein synthesis is about 160 g/kg DOM and if that protein has a true digestibility of 73%, DCP_i derived from rumen microbial protein cannot exceed 117 g/kg DOM. A DCP_i:DOM ratio of this type might thus approach the needs of beef cattle at or about weight maintenance and this could be derived by synthesis from a survival supplement of urea and molasses. However higher levels of productivity would require additional amino acids and hence more dietary protein and this conforms to practical observations on survival feeding of cattle to be reported in a later section.

As indicated above, the balance between energy and protein in a diet is ideally expressed as absorbed amino acids (kg)/MJ ME, with due account being taken of inefficiencies of use of both amino acids and ME for maintenance and production. The information available appears to describe adequately the nutritional situation that applies with animals fed temperate pastures and

especially with dairy cattle virtually or totally hand-fed to maintain high levels of production. Inadequacies in data for protein and energy transactions in animals fed mature tropical grasses have led to criticism of the current approach to nutritional evaluation of feeds and to the capacity of nutritionists to predict nutritional imbalance (Leng 1990). These criticisms appear to have only limited validity.

In applying the ME system, it has been recognised for many years that the efficiency of use of ME varies with the nutritional value of the diet, and this is taken into account by use of a quality factor 'q' calculated as ME/gross energy. In the published British system (ARC 1980) the minimum 'q' value is 0.4 which describes a feed of 50% digestibility. With a forage of q value 0.4, the efficiency of use of ME for maintenance (k_m) is about 64%, and k_m increases to 68% with a forage of 74% digestibility having a q value of 0.6. The extent to which extrapolation downwards is valid with forages of less than 50% digestibility is not known; however k_m values for two tropical grasses with q values of 0.34 and 0.38 were 65% and 60% respectively (Graham 1967).

There is also another difficulty in comparing tropical and temperate grasses. The forages used in the British studies were probably nutritionally balanced, that is, the protein and minerals in the diet were adequate to ensure the complete utilisation of forage energy. Nutrient imbalance might be expected to depress the efficiency of use of ME for maintenance and production and this appears to be so. When Graham (1967) supplemented *Digitaria decumbens* (Pangola) with urea, k_m increased from 67 to 80%. The effect of correcting imbalances on k_f and k_l is not known but is likely to be equally beneficial.

The critical features of animal production in the tropics are that the animal is almost entirely dependent on feed obtained by grazing or browsing; relatively low levels of productivity are expected; and there is only very limited use of supplements.

Because of the general lack of information on the composition of the diet selected, only broad generalisations can be made about nutritional value and the need for supplementation. For instance in many situations the only feed available is dead grass, the digestibility of which will probably not exceed 40% and the crude protein content 4%. It is possible however to evaluate such feed in terms of adequacy of rumen degradable N, of protein supply to the intestines, of OM digestibility, and the possible extent of improvement in all these variables with supplementation. It is also possible to estimate ME supply and the adequacy of that supply without and with N supplementation. Despite limitations to the accuracy of these calculations, they present a valuable base from which to make decisions on the need for an value of supplementation.

The steps to be taken in evaluating and supplementing a forage are:
· Determine the adequacy of nitrogen to supply desirable amounts of

ammonia for the rumen by use of DOM:CP ratio; calculate supplementary N needed.

· Predict the amount of protein passing to the intestines from relationships involving DOM and CP intakes.

· Predict the balance between amino acids and energy from the calculated DCP_i:DOM ratio. Calculate any additional intestinally digested N needed.

· Calculate ME intake, assuming that 1 kg DOM is equivalent to 15.5 MJ ME, with fully supplemented diet.

· Calculate from standard tables of recommended nutrient allowances the expected performance of animals with that level of intake of ME.

· Decide whether supplementary feeding is warranted.

The validity of these types of calculation of ME transactions in cattle fed tropical forages was examined recently by McSweeney et al. (1993) from data on lactating Brahman–Shorthorn cows fed mature sorghum hay without and with energy and protein supplement. The levels of ME in dietary constituents was calculated from data on the digestibility of organic matter (OM), the gross energy of milk from its analysed contents of protein, lactose and fat by the formula of Clarke and Moate (1988), and the ME requirements and factors for the efficiency of conversion of ME from MAFF 1975). The observed and predicted weight changes (kg/day) were respectively: control −0.20, −0.03; control + energy + protein 0.50, 0.64; control + energy 0.48, 0.70 and control + protein 0.53, 0.26. Despite the chain of assumptions involved, these predicted values are close enough to the observed values to confirm the fact that the nutritional theory incorporated into the ME system is basically sound when applied to cattle and to feeds quite different from those on which it was established.

Examination of numerous supplementary feeding experiments (see Factors Affecting Feed Intake) indicate that, although supplementation with nitrogen is required to increase feed intake, the production responses observed are readily explicable in terms of ME intake. There is therefore no reason to doubt the principle that energy is the primary nutrient and the role of nitrogen supplementation is to ensure that the animal can maximise both feed intake and the efficiency of utilisation of absorbed nutrients.

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Principles of Supplementary Feeding

J. Hogan

The use of supplements of non-protein nitrogen or protein depends on need and economic return. Both factors must be taken into account in deciding whether to offer supplementary feed, when to offer it and in what amounts it should be offered.

There are four situations in which the supplementation of animals must be considered.

· To maintain or increase production.
· To raise the nutritional value of a diet from sub-maintenance to maintenance.
· To control the rate of weight loss.
· To raise the nutritional value of a diet to a level consistent with survival.

Each situation presents different problems but they all relate to the interaction of the animal and the forage that is its main source of nutrients. As indicated earlier, nutritional value declines as a forage matures. The level of intake falls and the amounts of nutrients derived per unit intake also decline. A forage that supplies enough nutrients for maintenance plus production when immature passes through a stage of declining nutritional value where it supports less and less production, then merely maintenance and finally sub-maintenance. A nutritional deficiency can be met for a time by use of reserve fat and protein from the tissues, but in doing so the animal loses weight. When weight loss occurs gradually over a long time the animal reaches a minimal weight for survival. This is a quite different physiological state from that of weight maintenance and presumably represents a low rate of metabolism marked by reduced rectal temperature, dejected appearance and reluctance to make unnecessary movements (Morris 1968). Alternatively weight loss can occur more rapidly or extensively and endanger the life of the animal especially that of the female in late pregnancy.

In seeking the best way to use the available forage, the nutritionist has sought to develop principles that can be applied in different situations to the solution of supplementary feeding problems.

Nutritional Principles

The principles required relate to:

· the amounts of nutrients, energy, protein and minerals, required for maintenance of a given physiological state;

· the additional nutrients required for particular aspects of production and the efficiency with which nutrients are converted into products;

· the balance and amounts of nutrients needed to regulate weight loss or to reduce it to zero.

Nutritional principles have been embodied within the various systems in use around the world. Australia (SCA 1990) has adopted the Metabolisable Energy System developed in Britain (ARC 1980). In this system (see Fig. 2 on page 9) the energy within a forage, as measured by heat of combustion is regarded as 'gross energy' (GE). When eaten by the animal, part of the energy appears in the faeces. The remainder is called 'digestible energy' (DE). Some DE appears as energy in urine or in the gases of fermentation and the remainder is referred to as metabolisable energy (ME). In the use of ME, heat is generated and when this has been subtracted from ME, the remainder is regarded as useful or Net Energy (NE).

ME is used with varying efficiency for different functions. With diets ranging in digestibility between 50 and 75% (ARC 1980) efficiency for maintenance expressed as k_m ranges from 0.64 to 0.71, that for growth or fattening (k_f) from 0.32 to 0.47, for pregnancy (k_p) about 0.13 and for lactation 0.56 to 0.63. These efficiency factors clearly decline with advancing maturity of the feed expressed as declining digestibility. This is partly taken into account in the ME system by inclusion of a term for feed quality, q, estimated as ME/GE. However the ME content of British forages on which the system is based does not fall to the low levels observed in mature tropical forages and there are few estimates available on the extent to which the published efficiency values can be extrapolated to feeds of lower digestibility. The picture is complicated because such forages are generally deficient in nitrogen. Graham (1967) observed that when pangola grass (*Digitaria decumbens*) with 54% digestibility and 4% crude protein was supplemented with urea, both intake and digestibility rose and k_m increased from 0.67 to 0.80. Similarly with Kedah Kelantin cattle Liang et al. (1991) showed that as the diet was changed from 100% grass to 30% grass 70% concentrates, km rose from 0.47 to 0.75. It is clear from these observations that nitrogen:energy imbalance affects not only feed intake but also the efficiency with which absorbed nutrients are used.

Criticism of the inadequacy of the ME system for mature tropical feeds is thus justified. However the question must be asked: 'Is the inadequacy of prediction an inherent fault of the ME system or a reflection of the lack of pertinent data to

describe the performance of these feeds?' If the former, there is little hope of obtaining a system of feeding standards applicable to these feeds. If the latter, a framework exists that can be built on in studies of energy balance with the mature feeds offered without and with supplements.

The evidence (see Energy and Protein Interactions) suggests that the answer to the question favours the retention of the framework on which the ME system was built, while recognising the dangers of extrapolating from a series of predictions based on nutritionally-balanced temperate forages more than 50% digestible to those of lower digestibility and protein content. If the more mature grasses of interest have similar digestive features there is every reason to believe that the ME system can be extended to predict their nutritional value when appropriate data have been accumulated. Such data will probably not be obtained by measurement of energy intake and output based on respiration chambers such as that of Graham (1967) but rather on studies of production responses to changed intakes of feed. This technique used by Liang et al. (1991) and their colleagues determines maintenance requirement as the point of zero weight change in animals fed increasing or decreasing amounts of feed. When maintenance, and the efficiency of use of ME for maintenance have been calculated, the efficiency of conversion of ME to various forms of production can readily be estimated. The ME value of the feed is itself calculated (see Methods for Studying Ruminant Nutrition) from estimates of OM digestibility assuming that 1 kg digestible OM is equivalent to 19.2 MJ digestible energy (DE) and as ME = 0.81 DE therefore provides 15.6 MJ ME.

The significance of the ME system in establishing the principles of under-nutrition can be seen by examining the results of studies of protein and energy interactions in supplementary feeding experiments.

The Role of Protein Compared with Energy

Difficulties in interpretation of responses to protein supplements were discussed by Hunter (1987). In describing the feed intake responses to a protein supplement above that obtained with urea and sulfur (Lindsay et al. 1982), Hunter indicated that the response may have been caused by the intestinal digestion of protein in the concentrate protected from microbial attack, minerals in the concentrate, the slow degradation of some of the protein in the rumen leading to elevated levels of ammonia, or some combination of these.

A strong argument can be advanced that with animals dependent for most of their nutrients on forages there is first a need to improve feed intake by correcting deficiencies of ammonia and of amino acids. When this has been achieved production responses can be explained on the basis of improved ME supply. This is illustrated by supplementary feeding experiments with steers and

with pregnant and lactating cows. Steers were used in supplementary feeding experiments of Hennessy et al. (1983) with a basal diet of low quality roughage containing 6.3 g N/kg DM (Table 1). With assumptions regarding the ash content and digestibility of this diet the ratio of DOM to CP was probably above 14 indicative of a severe deficiency of ammonia in the rumen. Supplementation with two levels of protein increased feed intake from 2% of live weight to 2.4 and then 2.6% whereas supplementation with two levels of sorghum meal depressed roughage intake to 1.45% and 1.54% of live weight. Weight gain improved with both protein and grain supplements but the efficiency of use of ME for growth was clearly much less with sorghum than with the protein mixture. This observation would be consistent with the concept that with the control and sorghum diets, feed intake and the efficiency of use of feed were limited by lack first of ammonia in the rumen and then of absorbed amino acids. Improved intake and efficiency of ME use followed the correction of a nitrogen deficiency by protein supplementation. A similar situation almost certainly prevailed in steers fed mature subtropical pasture supplemented with two sources of N, urea/molasses and protein meal and two sources of energy, cracked or whole maize (Lee et al. 1987). The data presented in Table 2 suggest a deficiency in protein relative to energy (DCP_i/DOM) with the diets receiving no nitrogen supplement but adequacy in this regard with those diets containing supplementary nitrogen. The correction of this deficiency appeared to improve the efficiency of use of ME for weight gain.

Table 1. Responses to supplements (Hennessy et al. 1983) in steers fed mature subtropical pasture.

Diet DM intake (kg/day)	Roughage DM intake (kg/day)	Total ME intake (MJ/day)	Calculated change (kg/day)	Live weight
Roughage	2.85	2.85	16.2	−0.035
Roughage + 564 g protein meal	3.69	4.25	28.3	+0.425
Roughage + 1128 g protein meal	4.09	5.22	38.0	+0.730
Roughage + 504 g sorghum meal	2.01	2.51	18.3	−0.125
Roughage + 1008 g sorghum meal	2.20	3.20	27.6	+0.020

Cows in late pregnancy fed mature *Heteropogon contortus* (Lindsay et al. 1982) had very low intakes, equivalent only to 1.05% of body weight (Table 3). This was primarily due to reduced microbial activity in the rumen because

supplementation with N and S substantially increased intake. However even with additional synthesis of microbial protein, the amino acid supply to the tissues apparently did not improve sufficiently because there was a further increase in feed intake when supplementary protein was given. This effect was greater than when lucerne was provided because the additional 2 kg roughage prevented any appreciable rise in the intake of the basal roughage. Live weight change reflected ME intake with the two nitrogenous supplements but the lucerne supplement was used less efficiently. In this experiment the birth weight of calves on the control diet, 22 kg was much lower than the normal 30–32 kg, observed with supplemented diets. Glucose deficiency can severely impair birth weight and it is possible that the control diet provided inadequate glucose in addition to energy.

Table 2. Responses to supplements of urea/molasses (U/M) or protein without or with crushed (c) or whole (w) maize in steers fed subtropical pasture hay (Lee et al. 1987)

N supplement	Nil			U/M			Protein		
Maize	0	c	w	0	c	w	0	c	w
Hay intake (kg OM/day)	1.98	2.45	2.85	4.32	3.97	4.28	4.40	3.91	3.96
ME intake (MJ/day)									
Roughage	10.3	12.7	14.8	22.4	20.6	22.2	22.8	20.3	20.5
Protein							6.8	6.8	6.8
Maize		6.8	6.2		6.8	6.2		6.8	6.2
Molasses				2.1	2.1				
Total	10.3	19.5	21.0	24.5	29.5	30.5	29.6	33.9	33.5
Calculated DCP/DOM (%)	12.7	12.9	12.9	15.9	16.6	16.4	15.4	16.1	16.1
Weight gain (g/day)	-676	-420	-480	-50	160	20	100	260	330

Low feed intakes, equivalent to about 1.2% of live weight, were observed in lactating Hereford cows fed mature subtropical pasture hay (Lee et al. 1985). Rumen ammonia levels were low (Table 4) and probably reduced feed intake. With stepwise additions of protein, feed intake and ME intake rose, milk yield improved, and weight loss in the cow was reduced. It appears that the additional nitrogen improved both the supply of rumen ammonia and amino acids to the tissues. When that had been achieved, production responses reflected ME intake.

Table 3. Response to supplementary feeding of cows in late pregnancy offered mature Heteropogon contortus (Lindsay et al. 1982).

Diet	Roughage DM intake (kg/day)	Total DM intake (kg/day)	Calculated ME intake (MJ/day)		Live weight change (kg/day)
			Roughage	Suppl.	
Roughage	4.21	4.21	24.0	–	–0.815
Roughage + urea/sulfur	6.21	6.33	35.4	–	–0.308
Roughage + urea/sulfur + protein meal	8.12	9.13	46.3	11.4	+0.750
Roughage + lucerne	6.68	8.47	38.1	11.4	+0.405

Table 4. Lactation responses to supplementary feeding in 380 kg Hereford Cows fed mature subtropical grasses (Lee et al. 1985)

Supplement (g/w$^{.75}$ day)	Hay intake (kg OM/day)	Supplement intake (kg/day)	ME intake (MJ/day)	Rumen NH$_3$ (mg N/L)	Milk yield (kg/day)	Weight change (kg/day)
0	4.47	–	23.0	31	3.6	–2.54
5.25	5.37	0.42	31.7	50	3.8	–2.54
10.50	6.64	0.89	42.6	50	4.9	–0.92
15.75	7.84	1.37	53.3	73	5.1	–0.38
21.00	7.44	1.81	55.4	81	5.1	+0.08

The observations with these and many other experiments in which supplements have been offered to cattle fed mature tropical roughages thus conform to the general principles of firstly ensuring adequate nutrients for the rumen microbes and then, especially in the young growing animal or the pregnant and lactating cow, ensuring that adequate amounts of amino acids are supplied to the tissues.

Hence although the size of response to a protein supplement cannot be predicted precisely, information in the protein and ME systems can be used to indicate when supplementation is necessary and the general direction that production variables will take following supplementary feeding. In brief it can be

said that improved intake and utilisation depend on increased nitrogen supply but the production responses are largely related to the improved supply of ME.

An important corollary of these observations is that the supplement supplies only a small part of the energy and that most comes from the basal roughage. This is in marked contrast to the use of such forages in rations for high-producing dairy cows such as those producing 28 L milk who receive, in addition to 8 kg rice straw/millet straw, 7.5 kg protein pellet (Leng 1990). With such animals the roughage component supplied no more than one third of the ME. In the present context supplementary feeding is in general intended to ensure that a roughage with particular potential ingestibility and digestibility characteristics is supplied with adequate nitrogen to permit the animal to express that potential. Having done so, the level of animal production will be constrained by those same characteristics–a roughage delivering 5 MJ ME/kg for example cannot fill the role of a concentrate delivering 12. Hence the animal production systems dependent for most of the nutrients on mature forages must be geared to relatively low rates of production.

Supplementary Feeding

A self sustaining herd comprises bulls, castrate bulls (steers or bullocks), young milk-fed male and female calves, young cows before puberty (heifers), and breeding cows who may be at varying stages of pregnancy or lactation or non-pregnant and not lactating (dry). Supplementary feeding must take into account the fact that the ingredients of the supplements represent an additional cost to what is generally a low profitability system of production. There is therefore need to exercise strict economy in the use of supplements and to maximise the use of all cheaper sources of feed. Aspects of herd management to select those animals with highest priority for supplementation will be discussed elsewhere, but the emphasis is generally placed on the cow in late pregnancy and, where milk is harvested for sale, on the lactating cow. A further consideration is the extent to which supplementation is part of normal management during the dry season or a strategy for survival feeding during drought. In normal management the aim of the producer is to have lactation, the period of the greatest nutrient demand, coincide with the peak of pasture production after the rainy season is well established. In other words late pregnancy and early lactation are timed to occur late in the dry season when pasture quality is at its lowest level. The cow may lose weight in late pregnancy (Lindsay et al. 1982) and certainly does so in early lactation (Lee et al. 1985, Table 4) but it is the intention of the producer that peak lactation should be supported by the flush of green pasture appearing a few weeks after the opening rains of the wet season. Weight loss associated with lactation should be reduced

or reversed if the cow is to conceive within three months of calving, a procedure needed to ensure the production of one calf per year. If maternal weight losses during the dry season have been too severe, the cow cannot regain sufficient weight even from satisfactory wet season pastures to recommence ovarian cycling. Hence the producer may have to consider supplementary feeding during the dry season to ensure not only the survival of the pregnant cow, production of a calf of reasonable birth weight and the development of mammary glands capable of producing reasonable quantities of milk but also the maintenance of sufficient maternal body weight to ensure the resumption of ovarian function within 3 months of calving.

It has been suggested that a cow in late pregnancy might require 40 MJ ME/day for maintenance and a further 32 MJ/day to meet the needs of the uterus (Lindsay and Hogan 1987). From the data of Lindsay et al. (1982) presented in Table 3 it may be seen that a calculated 24 MJ/day derived from the roughage was grossly deficient; the provision of 35 MJ from roughage + urea/sulfur brought live weight loss back towards zero, but with the weight gain occurring in the uterus, there was still maternal weight loss. However 50–58 MJ ME provided from roughage + lucerne or protein meal brought the animal to positive balance. As indicated earlier, calculations of nutrient needs are far from precise but they can be used as a guide to determine the amount and type of supplement required.

In tropical areas the normal growth pattern of the animal involves a period of weight gain during the wet season, a reduction in gain during the late wet–early dry season and then a period of zero gain. Following this is a time of weight loss, the extent of which depends on the quantity and quality of feed available and the physiological state of the animal. If weight loss is severe the life of the animal is threatened. The producer has various options do nothing and hope for rain, supplement to prevent further weight loss, supplement to control but not totally reduce weight loss.

The latter is generally the preferred option because compensatory weight gain can permit the animal to achieve the same live weight at the end of the next wet season as its better fed counterpart. Hence in this system of production there is no economic benefit in providing supplementary feeds to maintain body weight during the dry season. However there are two situations in which supplementation for weight gain may be considered. The first of these is with the 6–12-month-old heifer to assist her to reach puberty at a particular age. With this type of animal which needs about 21 MJ ME/day for maintenance and a further 28 MJ/kg gain (Lindsay and Hogan 1987), urea might not provide the basis for adequate amino acid synthesis and some form of protein supplementation such as that of Hennessy et al. (1983) (Table 1) could be required. The second situation is that of the bullock that at the end of a wet

season has failed to reach a desired slaughter weight. The experience of Hunter and Siebert (1986) with older cattle suggests only a relatively small increase in feed intake in response to urea, and if so a protein supplement would be needed for further weight gain.

The nutritional principle involved in control of weight loss is that energy equivalent to 28 MJ ME appears to be needed to prevent 1 kg weight loss in lactating dairy cows (MAFF 1975). Calculations from data of Morris (1968) suggest that similar values apply to non-lactating beef cattle (Teleni and Hogan 1989). Hence from knowledge of the nutritional value of the forage available, supplements can be formulated to reduce weight loss to acceptable levels. The data in Tables 1–4 for instance, indicated that from knowledge of ME intakes the extent of energy deficit and hence of weight loss were approximately predictable, that substantial reduction in weight loss could be achieved through increased roughage intake in response to urea supplementation but that a return to weight gain required the provision of additional protein.

Conclusion

The cattle producer has relatively few management options. These include the date of commencement and the duration of mating, the grazing pressure to be applied to pastures during the periods when soil moisture is adequate and as it becomes increasingly inadequate for plant growth and finally the extent to which nutrients available from pasture need to be increased by supplementation. The decisions to be taken revolve around the perception of need to maximise the use of the pasture resource in the cheapest way possible while maintaining a desired standard of animal productivity. This is an imprecise system because the length of time until the next effective fall of rain is uncertain and so the number of animal-days to be supported by a given area of pasture is also unknown. There is also need to maintain adequate vegetative cover on the soil surface as protection against soil erosion when rain falls. The producer has to judge carefully the amount of forage available, the probable daily rate of consumption by the cattle on that area of land and the consequences of commencing supplementary feeding early or late in the dry season–if early, the cattle will maintain body weight better but at the expense of eating more forage; if late the body weight of cattle will be reduced. There will be a greater reserve of mature feed of reduced quality and instead of urea, more expensive protein sources may be needed. The producer has to decide the value to place on the maintenance of a particular body weight or condition especially with a view to achieving a desired conception rate the following year. Finally the producer has to be prepared to use strategies for the survival feeding of livestock if the dry season extends into drought.

These are the operating conditions under which decisions on the need to feed urea or protein are made. The production goals are not precise and effects of supplements on cattle are matters of judgment rather than accurate measurement. There is little or no control exerted over individual cattle and supplements must be provided in a self-rationing form that ensures the provision of at least some nutrients to the smaller or weaker animals. Despite their limitations, the principles incorporated in the protein and ME systems are of great value in first deciding the form and level of supplement needed. When this has been done adjustments can be made based on the judgment of the producer on the effects of supplements on the animals.

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Part 2. Ruminant Production in the Tropics and Subtropics

Use of Non-protein Nitrogen and Protein in Farming Systems in Bangladesh

A.M.M. TAREQUE

The total land area of Bangladesh is 14.8 million ha. Of this about 3.3 million ha are not available for cultivation, 2 million ha are forested and 0.3 million ha are cultivated wastes leaving 9.2 million ha for cultivation (BBS 1990).

Agriculture is the dominant sector in the Bangladesh economy contributing about 37% of GDP (BBS 1990) and providing almost 60% of the total labour force in the year 1985–86. Of the agriculture sector's contribution to Bangladesh's GDP 78% is derived from crop production, 7% from fisheries, 7.7% from livestock and 7.3% from forestry.

Livestock in the Bangladesh Economy

Livestock have been considered as an essential component of farming systems in Bangladesh. In addition to the supply of meat, milk and eggs to meet the balanced nutrient requirement of the human population, this sector contributes about 98% of the draught power for crop production and a substantial amount of the power needed for transportation of goods, threshing of grains and oil extraction. In addition it contributes hides and skins, bones and horns for industry and export, manure for crop fields and fuel for domestic use, slaughter-house by-products, such as feather, meat offal, rumen ingesta and blood together with other wastes as raw materials for various industries.

Cattle are the most important component of farm animals. The numbers of bovine animals (cattle and buffalo) were 22 million constituting about 90% of animal units possessed by 7.3 million household or 52.5% of total households. About two thirds (66.2%) of the farm holdings and 16.3% of non-farm holdings were reported to have bovine animals (Agricultural Census 1983–84).

The Current Livestock Feed Situation

The heavy population pressure and land scarcity have left very little scope for the cultivation of fodder for livestock. As a result the majority of livestock subsists on low quality roughages like rice straw, rough grazing on road sides and embankments and on by-products of some agro-industrial milling processes. Production potential has thus suffered to a great extent and disease susceptibility of the animal has increased significantly. Out of the total dry

matter available (29.05 million t), 69% constitutes dry roughage which is of very low quality, 27% green roughage and 5% concentrates derived as agro-industrial by-products (Table 2).

Table 1. Livestock population and annual nutrient requirements (BBS 1984–85).

Species	Number	Average liveweight	Total	Dry matter	Crude protein	Metabolisable energy
	(million)	(kg)	(million/kg)	('000 t)	('000 t)	(million MJ)
Cattle	21.50	145	3117.0	34127	3413	341270
Buffalo	0.57	183	105.0	1150	115	11498
Sheep	0.67	10	6.7	99	7	986
Goat	1.36	12	162.7	2373	178	23725
Poultry	73.71	1	73.7	2690	489	314739

Source: Bangladesh Bureau of Statistics 1984–85.

It is evident from Table 2 that rice straw alone constitutes 87% of the total dry roughage. After deducting wastages or losses the net availability is 6.8 million t, accounting for 23.4% of the total dry matter available for livestock feeding contributing 258 000 t crude protein and 56 million MJ metabolisable energy. It is also evident from Table 3 that 300 000 t of crude protein and 60 400 million MJ of metabolisable energy are available from dry roughage for animal feeding.

The contribution of green roughage to total dry matter available is about 27%, comprising sweet potato leaves, natural grasses (roadsides, embankments, fallow lands, cultivation waste-lands, homesteads, etc.), weeds available from cultivable area, water-hyacinth, cultivated fodder, and sugarcane tops. This green roughage contributes a significant quantity of dry matter (7.8 Mt) with crude protein approximately 0.5 Mt and more than 52 000 million MJ metabolisable energy.

Concentrates consist of rice polish, wheat bran, oil cakes, pulses, bran, molasses, cotton seed cake, fish meal and broken rice and contribute 243 000 t protein and 18 200 million MJ of metabolisable energy.

From the balance sheet of supply and demand for nutrients in livestock feed (Table 4) it is evident that only 37, 26 and 19% of the amounts ideally required for dry matter, crude protein and metabolisable energy respectively are available for animal feeding.

Chemical composition and nutritive values

The chemical composition of feedstuffs available in Bangladesh varies widely; for example, the crude protein content ranges from 39 g/kg in rice straw to 309 g/kg in sunhemp fodder.

The crude fibre content ranges from 137 g/kg in Dhaincha leaves to 389 g/kg in wheat straw (Table 5). Significant (P ‹ 0.01) differences were observed among the varieties and different parts of rice straw in respect of chemical components ADF, NDF, CF cellulose, hemicellulose (Table 6a). The moisture

Table 2. Source and availability of feeds and fodder in Bangladesh (1987–88).

Crops	Quantity ('000 units)	By-product	Extraction rate	Dry yield ('000 t)	Available DM ('000 t)
Cereals/others					
Rice (88–89) (t)	15 400	Straw	100–150	18 950	17 000
Wheat (t)	1 020	Straw	100	1 020	920
Other grains (t) [maize, sorghum]	48	Stem/Haulm	250	120	110
Pulses (t)	520	Straw	100	520	470
Sugarcane (t)	7 200	Bagasse	30	2 160	1 080
Greens					
Sweet potato (t)	540	Leaves	150	810	160
Weeds (ha)	6 800	–	2.5 t/ha	17 000	2 550
Roadside/bunds (ha)	1 700	–	12 t/ha	21 500	4 300
Culturable waste current fallow					
Fodder (ha)	12	–	17 t/ha	204	40
Waterhyacinth (ha)	0.08	–	6 t/ha	–	480
Sugarcane (t)	7 200	Tops	15	1 080	300
Fruits					
Mango	160	Wastes	20	32	8
Banana	684	Leaves	85	581	116
Pineapple	145	Wastes	25	36	5
Jackfruit	254	Wastes	50	427	25
Concentrates					
Rice	14 000	Rice polish	6	840	672
Wheat	160	Bran	20	32	29
Oil seeds	430	Oilcakes	70	300	272
Pulses	470	Bran	30	140	126
Molasses	0	–	–	–	62
Cotton seed cake (bales)	60	–	25–37	5	4.7
Fish meal	–	–	–	–	30.0
Cereal grains (broken)	–	–	–	1	140
Wheat grain					33.0

content and other nutrients vary greatly depending on season, stage of maturity and fertility of the soil. In Bangladesh there are four well defined seasons as follows:

· Mid-November to mid-February–cool season with little rainfall, growth of fodder plants is very limited
· Mid-February to mid-May–hot season, rainfall begins in May start of grass growth
· Mid-May to mid-July–sufficient rainfall with heavy growth of grasses
· Mid-July to mid-October–heavy rainfall slowing the growth of grasses.

Table 3. Estimated nutrient available for livestock feeding.

Feed type	Dry matter '000 t	Crude protein '000 t	ME million MJ
Dry roughage	7 400	300	60 400
Green roughage	5 898	496	52 550
Fruit wastes	164	10	1 150
Concentrates	1 369	243	18 250
Total	14 931	1048	132 350

Table 4. Livestock feed nutrient supply and demand balance in Bangladesh.

Nutrient character	Dry matter '000 t	Crude protein '000 t	ME million MJ
Supply	15.0	1.1	132000
Demand	40.4	4.2	690000
Balance	−25.6	−3.1	−560000
% available	37%	26%	19%

Non-protein nitrogenous components such as amino acids, amides and nitrates vary with both the physiological state of the plant and the rate of growth as influenced by season and rainfall. After a long drought stage a sudden and heavy rainfall stimulates the plant to grow very rapidly increasing the nitrate content of the grasses to a level that sometimes becomes toxic to animals.

The digestibility and nutritive values of grasses are low compared with grasses in temperate climates. The crude protein and crude fibre content also vary significantly between the rainy and dry seasons suggesting that special attention is needed to develop feeding systems in the two seasons.

Table 5. Chemical composition and nutritive value of commonly used feed stuffs in Bangladesh.

Name	Basis	DM	CP	CF	EE	NFE	Ash	Ca	P	DCP	TND	Chicken Kcal/kg
		Average chemical composition (g/kg)								Nutritive value cattle		
DRY ROUGHAGE												
Rice straw (*Oryza sativa*)	As fed	895	35	322	12	393	133	3.0	1.2	2.0	380	–
	Dry	1000	39	359	14	440	149	3.4	1.3	3.0	430	–
Wheat straw (*Triticum aestivum*)	As fed	920	34	351	14	439	78	2.0	1.0	3.0	400	–
	Dry	1000	37	389	16	488	88	2.2	1.1	3.0	440	–
GREEN ROUGHAGE												
Banana leaves (*Musa sapientum*)	As fed	190	19	40	11	98	23	2.4	0.5	–	–	–
	Dry	1000	100	210	55	513	122	12.6	2.7	–	–	–
Banyan Tree leaves (*Ficus bangalensis*)	As fed	272	29	61	8	136	38	4.1	0.4	6.0	120	–
	Dry	1000	106	225	30	501	138	15.1	1.2	2.1	430	–
Bajra Napier (*Pennisetum purpurium*)	As fed	186	16	58	6	84	22	0.6	0.8	8.0	100	–
	Dry	1000	86	312	32	452	118	3.1	4.2	45	540	–
Black gram (*Phaseolus mungo*)	As fed	220	29	46	8	112	25	2.1	0.7	–	–	–
	Dry	1000	130	210	37	509	114	9.5	3.2	–	–	–
Cowpea plant (*Vigna unguiculata*)	As fed	150	27	39	4.0	59	21	2.0	0.3	20	90	–
	Dry	1000	180	261	25	394	140	13.0	2.0	134	600	–
Dal grass (*Hymenachne pseudointerrupta*)	As fed	20	13	50	5	100	32	1.4	0.7	6.0	100	–
	Dry	100	65	250	25	500	160	7.0	3.5	30	500	–
Dhaincha leaves (*Sesbania aculeata*)	As fed	256	66	35	12	124	20	2	0.9	–	–	–
	Dry	1000	259	137	45	482	77	7.0	3.5	–	–	–

Table 5. Chemical composition and nutritive value of commonly used feed stuffs in Bangladesh—cont'd.

Name	Basis	DM	CP	CF	EE	NFE	Ash	Ca	P	DCP	TND	Chicken Kcal/kg
Durba grass (*Cynodon dactylon*)	As fed	230	20	55	5	120	29	1	0.7	–	–	–
	Dry	1000	88	238	23	523	128	5	3.0	–	–	–
Khesari plant (*Lathyrus sativus*)	As fed	182	35	47	3.0	67	30	2.0	0.9	–	–	–
	Dry	1000	192	259	16	368	165	11	4.9	–	–	–
Maize plant (*Zea mays*)	As fed	221	15	60	3.0	126	17	1.2	0.6	10	150	–
	Dry	1000	72	270	14	570	74	5.4	2.7	44	660	–
Mandar Tree leaves (*Erythrina* spp.)	As fed	161	32	22	13	75	19	2.7	0.5	–	–	–
	Dry	1000	199	137	81	465	118	16.7	3.1	–	–	–
Napier grass (*Pennisetum purpureum*)	As fed	197	20	65	5	85	22	0.9	0.6	12	110	–
	Dry	1000	102	330	24	433	111	4.6	3.0	63	550	–
Para grass (*Brachiaria mutica*)	As fed	222	24	65	5	104	24	0.7	0.8	13	120	–
	Dry	1000	108	293	23	469	107	3.2	3.6	61	560	–
Roadside grass (Mixed)	As fed	208	10	76	4	90	28	1.0	0.1	6	120	–
	Dry	1000	48	365	19	432	164	4.8	0.6	27	560	–
Sugarcane tops (*Saccharum officinarum*)	As fed	271	15	90	5	145	14	1.4	0.6	7	150	–
	Dry	1000	56	333	17	535	55	5.2	2.2	27	560	–
Sunhemp leaves (*Crotolaria gensea*)	As fed	185	56	27	11	69	22	2.0	0.6	–	–	–
	Dry	1000	309	150	60	361	120	10.0	3.2	–	–	–
Sweet potato leaves (*Ipomoea batata*)	As fed	200	29	43	7	92	29	2.6	1.1	–	–	–
	Dry	1000	145	215	35	460	145	13.0	5.5	–	–	–

Table 5. Chemical composition and nutritive value of commonly used feed stuffs in Bangladesh—cont'd.

Name	Basis	DM	CP	CF	EE	NFE	Ash	Ca	P	DCP	TND	Chicken Kcal/kg
Water-hyacinth (*Eichhornia*	As fed	95	13	18	3	42	19	-	-	-	-	-
crassipes)	Dry	1000	148	185	31	436	200	-	-	-	-	-
CONCENTRATES												
Bone meal	As fed	925	162	33	48	74	608	-	-	-	-	-
	Dry	1000	175	35	52	81	657	-	-	-	-	-
Coconut oilcake (*Cocos nucifera*)	As fed	908	200	123	90	434	61	2.4	6.9	176	750	1723
	Dry	1000	220	136	99	477	68	2.6	7.3	194	830	1897
Fish meal A1 grade	As fed	864	518	20	97	32	197	-	-	-	-	-
	Dry	1000	597	24	113	38	228	-	-	-	-	-
Fish meal A2 grade	As fed	824	419	1.3	63	115	213	-	-	-	-	-
	Dry	1000	509	16	77	142	256	-	-	-	-	-
Fish meal A3 grade	As fed	814	364	14	64	139	235	-	-	-	-	-
	Dry	1000	447	17	79	168	289	-	-	-	-	-
Ground cake (*Arachis hypogaea*)	As fed	914	401	119	76	259	59	-	-	-	-	-
	Dry	1000	439	130	84	283	64	-	-	-	-	-
Kheshari bran (*Lathyrus sativus*)	As fed	871	108	332	10	362	69	-	-	-	-	-
	Dry	1000	120	378	12	412	78	-	-	-	-	-
Meat meal	As fed	920	623	7	182	78	30	0.1	1.7	580	-	2287
	Dry	1000	677	8	198	84	33	0.1	1.8	630	-	2485

Table header (spanning): Average chemical composition (g/kg) covers DM, CP, CF, EE, NFE, Ash, Ca, P; Nutritive value cattle covers DCP, TND; Chicken Kcal/kg.

Table 5. Chemical composition and nutritive value of commonly used feed stuffs in Bangladesh—cont'd.

Name	Basis	| Average chemical composition (g/kg) |								Nutritive value cattle		Chicken Kcal/kg
		DM	CP	CF	EE	NFE	Ash	Ca	P	DCP	TND	
Molasses (Conc.)	As fed	748	31	–	–	640	77	9.1	0.9	10	630	1952
	Dry	1000	42	–	–	855	103	12.2	1.2	14	840	2610
Mustard oilcake milk	As fed	855	259	104	115	294	83	–	–	–	–	–
	Dry	1000	303	121	135	344	92	–	–	–	–	–
Mustard oilcake Ghani	As fed	861	217	82	109	386	67	–	–	–	–	–
	Dry	1000	252	95	127	448	78	–	–	–	–	–
Rice polish	As fed	895	121	31	131	517	95	0.5	14	92	810	2864
	Dry	1000	135	35	146	577	106	0.6	16	103	910	3201
Sesame oilcake (*Sesame indicum*)	As fed	913	315	74	80	319	125	21	11	283	690	1937
	Dry	1000	345	81	87	349	138	23	12	310	750	2122
Silkworm pupae (dehydrated)	As fed	908	646	51	140	14	57	1.9	6.9	–	880	–
	Dry	1000	711	56	154	16	63	2.1	7.6	–	970	–
Soybean feed (*Glycine max*)	As fed	875	375	58	145	262	35	2.8	6.7	334	840	3131
	Dry	1000	428	66	166	300	40	3.1	7.5	374	940	3510
Wheat bran Fine	As fed	893	130	86	40	593	44	–	–	–	–	–
	Dry	1000	146	97	44	664	49	–	–	–	–	–
Wheat bran Coarse	As fed	873	113	93	39	583	45	–	–	–	–	–
	Dry	1000	129	106	45	668	52	–	–	–	–	–

Feeding Systems

Under the existing availability of cultivable land, feed resources, animal genetic resources and differences between seasons, feeding systems may be classified as follows:

·   Intensive system—cut-and-carry system developed with high producing, upgraded or cross bred animals small numbers.
·   Mixed system—tethering, cut-and-carry).
·   Rice straw-based system—this is the most prevalent system in the country mainly with local non-descript animals. Generally rice straw (soaked or unsoaked/treated or untreated/cut into pieces or whole) is fed throughout the day, with occasional grazing along the roadsides, embankments and fallow lands.

Rice straw-based system

Rice straw constitutes about 85% of the total feed dry matter available in Bangladesh. This sole item of feedstuffs forms about 70–100% of daily ration of the animals. The low quality of rice straw has been attributed to factors such as the high content of ligno-cellulose and silica and the low of content of fermentable and total nitrogen, energy, and micronutrients. This is indicated in Tables 6a and b which shows that, between varieties and locations, the cell contents fraction which includes some minerals, may range between 21 and 36 percent. For this reason it has become pertinent to improve the nutritive value of rice straw by treating/supplementing with urea, supplementing with high quality grasses/tree leaves and concentrates. Roughages used were mainly rice straw treated or untreated green grass - napier, cowpea. Supplements used were mainly concentrates: oilcakes, wheat bran, soybean meal, babla seed, fish meal.

Table 7 summarises some performance results of cattle fed urea as treated straw or as a supplement. Rice straw has lower content of lignin than that of other straw. Significant improvements in terms of voluntary intake, digestibility and weight gain in calves, as well as milk yield in cows were observed with the feeding of urea-treated rice straw (Saadullah 1980a,b; Khan and Davis, 1981; Perdock et al. 1982). Supplementation of rabous based on urea-treated or untreated straw with high quality forage or concentrates such as water hyacinth, Dhainca, cowpea grass, oil cakes, soybean meal, wheat bran, rice polish showed significant improvements in terms of growth and digestibility (Preston 1981; Neilson 1982; Haque et al. 1982; Saadullah et al. 1989; Dolberg et al. 1981; Akbar et al. 1986; Tareque 1987).

Urea, a cheaper and available source of fermentable nitrogen, is considered as a supplement to low quality roughage, mainly rice straw-based rations of cattle in Bangladesh.

Table 6a. Mean chemical composition of different varieties of rice straw (per cent dry matter basis).

Type of straw	NDF**	ADF	CF**	Crude cellulose*	Hemicellulose	Lignin with silica	Cell content	Ash	Crude protein
Balam	$73.40^a \pm 1.64$	$47.36^a \pm 2.32$	$37.19^a \pm 2.80$	$23.79^a \pm 1.48$	$26.04^a \pm 3.24$	$23.61^a \pm 1.05$	$26.60^b \pm 1.64$	$11.14^a \pm 1.52$	$6.52^a \pm 1.11$
Mala	$64.12^b \pm 2.01$	$40.24^a \pm 1.91$	$31.21^b \pm 1.39$	$31.37^{ab} \pm 1.30$	$23.88^a \pm 2.34$	$8.86^a \pm 1.35$	$35.88^a \pm 2.01$	$13.96^a \pm 0.59$	$3.27^b \pm 0.78$
Payjam	$73.69^a \pm 0.61$	$47.55^a \pm 1.28$	$36.16^b \pm 1.39$	$36.98^a \pm 0.51$	$26.59^a \pm 0.79$	$10.57^b \pm 1.17$	$26.31^b \pm 0.62$	10.64 ± 0.98	$3.11^b \pm 0.34$

Source: A.M.M. Tareque and S.A. Choudhury, 1988, unpublished data.

Data having same letters in a column differ significantly (P < 0.05 and < 0.01).

Table 6b. Chemical composition of five types of Payjam rice straw collected from five different locations (per cent dry matter basis).

Attribute	Type I	Type II	Type III	Type IV	Type V
NDF**	$74.39^{ab} \pm 1.08$	$75.04^{ab} \pm 1.76$	$69.04^b \pm 0.85$	$78.69^a \pm 1.39$	$71.39^b \pm 1.82$
ADF**	$45.12^b \pm 2.44$	$55.24^a \pm 0.39$	$44.82^b \pm 1.77$	$49.23^{ab} \pm 2.23$	$43.35^b \pm 1.05$
F	$33.50^{NS} \pm 1.84$	$37.04^{NS} \pm 1.51$	$33.27^{NS} \pm 0.50$	$39.75^{NS} \pm 1.40$	$37.23^{NS} \pm 2.75$
Crude cellulose*	$36.43^b \pm 1.55$	$41.99^a \pm 1.51$	$34.21^b \pm 1.05$	37.01^b	$35.25^b \pm 1.48$
Hemicellulose*	$29.27^a \pm 1.44$	$19.81^b \pm 2.13$	$24.22^{ab} \pm 2.60$	$29.46^a \pm 0.94$	$28.05^a \pm 2.71$
Lignin + silica	$8.68^{NS} \pm 0.95$	$13.25^{NS} \pm 1.43$	$10.61^{NS} \pm 1.63$	$12.22^{NS} \pm 0.94$	$8.11^{NS} \pm 0.86$
Cell content*	$25.61^{ab} \pm 1.08$	$24.95^{ab} \pm 1.76$	$30.94^a \pm 0.84$	$21.31^b \pm 1.39$	$28.62^a \pm 1.82$
Ash**	$14.59^a \pm 1.56$	$4.84^b \pm 0.42$	$10.86^a \pm 1.03$	$12.55^a \pm 1.25$	$10.33^a \pm 0.96$
CP	$3.99^{NS} \pm 0.52$	$2.34^{NS} \pm 0.19$	$2.79^{NS} \pm 0.43$	$3.39^{NS} \pm 0.28$	$3.01^{NS} \pm 0.44$

Source: A.M.M.Tareque and S.A. Choudhury, 1988, unpublished data.

Data having same letters in a row differ significantly (P < 0.05 and < 0.01). NS = not significant. NDF = neutral detergent fibre. ADF = acid detergent fibre. CF = crude fibre.

CP = crude protein. Note: Each type indicates a payjam rice straw collected from a different locality.

In a study in Bangladesh Agricultural University, urea, at the rate of 30% total ration protein, replacing the total quantity of oil cake and khesari used in the conventional fattening ration could fatten equally well as compared to the control ration (Qumrul and Nesar 1965). Urea can successfully be fed to mature ruminants for growth, fattening and milk production directly mixed with concentrate feeds in addition to molasses (1:10) and at S.N. (1:10) (Quddoos and Tareque 1967), soaked in water (Akbar and Tareque 1987).

Table 7. Performance of cattle fed on diets containing treated or untreated rice straw (RS).

Treatments	Urea treated RS + suppl.	Untreated RS + suppl.	Urea suppl. RS	Urine treated RS
No. of experiments	12	8	6	2
Roughage in diets (%)	80	75	85	85
Intake kg/100 kg bodyweight/day	2.5	2.9	2.8	3.0
Digestibility (DM)	66	57	46	51
Liveweight gain g/day	344	315	282	127

Source: Tareque 1987.

Green forage

A supplement of a small quantity of highly digestible green forage to a low quality roughage-based ration significantly improves animal performances indicating that such supplement a corrects the deficiencies of fermentable nitrogen and micronutrients which help to improve the rumen ecosystem. A supplement of water hyacinth, cowpea, or azolla to a rice straw-based ration improved the growth of animals (Table 8).

Table 8. Performance of growing local calves on rations based on rice straw and supplemented with water hyacinth, azolla or cowpea.

	Water hyacinth	Azolla		Cowpea
		0%	15%	
Liveweight gain (g/day)	344	220	260	323
Daily DM intake (kg/100 kg body wt)	3.00	2.75	3.01	2.80
%DM of straw in ration	60	69	66.5	67
%DM of green supplement in the ration	25	0	15	18
Feed conversion (kg DM/gain)	8.5:1	11:1	10:1	9:1

Methods of urea feeding

Urea can be provided by different methods:

1. Urea is fed directly by mixing thoroughly with molasses and other concentrate ingredients of the ration, in divided doses.
2. Soaking rice straw in an aqueous solution of urea or an aqueous solution of urea sprayed on the straw fed to animals in divided doses.
3. Liquid supplements combining molasses for energy and urea as a protein source.
4. Urea added to dry roughage.
5. Urea in salt/molasses blocks.

There is a risk of toxicity associated with all these methods due to over feeding. Judicious use of urea in rations based on low quality roughage will improve the performance of the animals but an adjustment period is very essential in feeding urea directly.

Urea utilisation may be improved by ensuring a constant level of rumen ammonia (150 mg/L rumen liquor) through increased frequency of feeding or by feeding slow releasing nitrogenous substances. Urea can also be fed indirectly by ensiling straw with 5% urea solution. This method is good especially in respect of increased availability of total nutrients from low quality roughage but farmers' acceptability is poor due to cumbersome technology so far available. An easy technology needs to be developed for its better utilisation.

The supplementation of high quality legume and tree leaves increases the utilisation of urea and low quality roughages. It is important to identify the leaves correctly to avoid toxicity from secondary chemicals such as tannin, oxalates, nitrates and cyanides. The most beneficial level of supplementation of these legume feeds should also be determined.

The high concentrations of oxalates and silicates in rice straw may cause considerable losses of calcium and magnesium in urine and faeces suggesting the need for special supplementation of these macro-minerals in production rations of ruminants.

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Use of Nitrogenous Supplements for Improving Animal Productivity in India

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India possesses about 15% of the world's livestock population with only 2% of the world's geographical area. Livestock constitutes an important component of the economy of villages. In accordance with the 1982 livestock census, the total cattle and buffalo population in India was 190.89 and 68.78 million, respectively. Out of the total cattle population 66.60 million are males over 3 years, 50.71 million are females over 3 years and young stock are 49.53 million. The total buffalo female population was 28.32 million (Table 1). The bovine population trend in India over the last 2–3 decades has not shown any appreciable change and it is expected that in 2000 AD the population of productive females will rise (data scope) and a decline will occur in draught animals, particularly in the northern states of Punjab, Haryana and Western Uttar Pradesh.

The country has about 4% of the cultivated area under forages and about 25% of the country's land area offers a varied degree of grazing resources to the animals. These constitute mainly natural grasslands including barren and uncultivated lands, permanent pastures, grazing land and cultivable wastes and degraded forests. The opportunities for increasing this area for cultivation of forages are remote because of the preferential need for human food. Therefore, availability of feeds for animals in the near future will remain similar and concerted efforts are required to improve productivity and achieve targets of milk production in 2000 AD (Table 2).

Farmers in India adopt varied types of farming systems which are governed not only by ecosystems in a particular agroclimatic zone but also by socioeconomic factors and land type either favourable for production of grains or rearing of livestock or both. Among many combinations, the crop and dairy enterprise is best suited for most of the farmers in different parts of India. Cattle holding is positively related to land holdings particularly in the northern states of Punjab, Haryana and Uttar Pradesh. Farmers aware of livestock management systems and recent developments in animal improvement programs have shifted their attention towards crossbreds for higher economic benefits through sale of milk. A study in Operational Research Project villages of NDRI has indicated that 43% of milch buffalo, 58% of local cows and 41% of crossbred cows are owned by small, marginal and landless labourers, respectively (NDRI 1983). On the contrary high intensity agriculture has also been adopted and land devoted to

Table 1. Bovine population trends in India, 1961–1982 (million head).

Categories	1961	1966	1972	1977	1982
Cattle					
Females over 3 years breeding					
In milk	20.72	20.97	22.03	23.19	23.23
Dry and not calved even once	30.29	30.80	31.38	31.43	27.48
Total	51.01	51.77	53.41	54.62	50.71
Cows used for work only and not in use for work or breeding	3.31	2.91	2.99	2.98	1.34
Males over 3 years					
Used for breeding only	0.38	0.43	0.39	0.41	
Working bullocks	68.60	69.18	70.57	71.24	66.60
Used both for breeding and work	1.98	2.26	1.99	1.99	
Not in use for breeding or work	1.52	1.47	1.51	1.27	
Young stock					
Males and females	48.87	48.08	47.48	47.63	49.53
Total	175.67	176.19	178.34	180.14	190.89[a]
Buffaloes					
Females over 3 years breeding					
In milk	12.58	12.92	15.07	16.96	15.79
Dry and not calved even once	11.66	12.59	13.54	14.31	12.53
Total	24.24	25.51	28.61	31.27	28.32
Buffalo used for work only and not in use for work or breeding	0.79	0.63	0.63	0.60	0.24
Males over 3 years					
Used for breeding only	0.29	0.33	0.22	0.22	0.55
Working buffalo bullocks	6.61	6.97	7.01	7.32	
Used both for breeding and work	0.51	0.62	0.60	0.61	5.35
Not in use for breeding or work	0.26	0.27	0.23	0.22	
Young stock					
Males and females	18.45	18.59	20.12	21.79	21.23
Total	51.15	52.92	57.42	62.03	68.78[a]

[a] Includes census data for Gujarat, Jammu and Kashmir, Rajasthan and Tamil Nadu, for which break-up is not available.
Source: Livestock Census, Government of India.

forage production in earlier years is reduced and there has been a shift in the cropping pattern towards relatively more profitable crops on the farms. The area under cereal crops increased from about 74% in 1983–84 to 77% in 1986–87 while fodder crops decreased from about 23% in 1983–84 to 20% in 1986–87 (Patel et al. 1987). These reports highlight the fact that farmers in an attempt to derive greater benefits change farming systems and adopt a mixed agriculture–dairying enterprise.

Table 2. Data scope 2000 A.D.

Human population (million)	996
Milk production (million tonnes)	78
Cow	37.25
Buffalo	38.00
Goat etc.	2.75
Total bovines (million)	282
Cattle	204
Buffalo	78
Milch herd (million)	103
Cows	59
Crossbreds	4.5
Buffalo	39.5

Source: Dairy India 1992. IVth Annual Edition.

Animal Management Systems and Feeding Practices

Neither specific management systems nor standard recommended practices for feeding livestock are followed generally by rural farmers in India. The practices adopted by individual farmers are traditional and vary to a great extent in a particular zone, often depending on manpower available for the management of animals, farm size, income and socioeconomic status. Progressive farmers with large land holdings have adequate knowledge of developments in agriculture and dairying, in general, take adequate care of their animals and optimally feed greens, concentrates and minerals. Productive animals are given production allowances and lactating animals are given a good amount of cereals, concentrate mixture, and/or pelleted feeds. Pregnant animals are looked after better than even those lactating and the practice of feeding oils and high carbohydrate diets, particularly in the last third of pregnancy, is not uncommon in rural areas. Small and marginal farmers, who adopt a mixed

farming system to derive greater benefits, take care of their animals to maximise production from limited resources and women generally devote most of their time in arranging feeds and fodders for the animals. Landless farmers often maintain only productive animals or those which may be adequately maintained on scrub grazing. Both lactating animals and draught animals are reared. Draught animals are maintained on concentrate feeding as they often do not get enough time for roughage feeding. Lactating animals are looked after by female(s) of the family staying at home.

The management and feeding practices of livestock in hot dry regions, particularly in the states of Rajasthan, Gujarat and other adjoining areas, differs a lot from other northern or southern states in India. In these areas animals remain in the open most of the time. Stall feeding is not practised and animals subsist almost entirely on natural grazing available in the scrub grazing areas. Leaves and stems of permanent bushes and shrubs and also loppings of trees like acacia are utilised for feeding cattle, goat and camel. Wherever possible some of the farmers become involved in agricultural practices and grow crops like cotton, millets, wheat, pulses and cluster beans. Fibrous residues of these crops are utilised for feeding during dry periods. The animals are allowed to graze on the residues of harvested fields; some farmers who own a large number of animals purchase grazing rights after crops are harvested. The crop residues are stored in huts or houses and during dry weather animals are fed straws, stovers and other by-products of crops. Milch cattle are given a small quantity of concentrates consisting of oilcakes, broken grains and crushed cluster beans.

The majority of animal breeders and rearers are nomadic and take their animals for distant grazing. In drought conditions these nomadics move in search of food and water and may be seen in most of the northern and central states with Zebu cattle herds, camels and sheep flocks of several hundreds to thousands animals per batch. These animals are exposed to weather, do not get a maintenance ration throughout the year and subsist on natural grasses and shrubs. Such animals may be supplied with additional feeds and often require feed supplementation for optimising production. In and around cities like Bikaner, Jaipur and Jodhpur, some cattle keepers have settled and depend on earnings from sale of milk. These dairy farmers largely depend on concentrates, feeding chiefly oil cakes, crushed grain, pulses, chunnies, wheat bran etc. These concentrates are soaked in water for several hours and given heat treatment either by keeping in open sun or boiling in earthen pots or canisters before feeding to animals.

The hot dry tract of Rajasthan and Gujarat is famous for milch cattle-Rathi, Tharparkar and for some well known draught breeds like Nagori, Kankrej, etc. A general practice in these areas is that male Zebu calves are not weaned and receive particular attention. Most of the male calves who are potential bullocks,

are left loose with mothers and unrestricted suckling of mothers is allowed, but females are given only two teat milk and the remaining milk is used for making curd, butter oil or other milk products.

The majority of farmers in Punjab, Haryana and Western Uttar Pradesh own less than eight hectares of cultivated land and they generally keep 6-9 head of cattle and buffalo. During the past two decades growth in mechanisation and animal husbandry development programs have changed the animal scenario in rural areas. Buffaloes and crossbreds are maintained for milk production and the buffalo male for draught purposes. The bullock population has declined to only 10-15% of the total animal population due to mechanisation. In these states, grazing lands are limited and most of the agricultural land is under intensive cultivation. Animals are fed sorghum, maize, beans, grasses etc. which are available for about 8-10 months of the year. In the dry season animals are fed mainly wheat straw and some quantity of concentrates and pelleted feeds. Milch animals are fed 1-2 kg of concentrates either before or after milking. Paddy straw, which is produced in large quantities, is not fed to the productive animals because farmers use large quantities of fertilizers and pesticides and feel that they are harmful to animal and man. Often paddy straw is either left in the fields or burnt. Only limited feeding of paddy straw is practiced and that generally by landless farmers in these areas and particularly during scarcity periods.

In the parts of Maharashtra, North and South Karnataka, animals are generally sustained on good quality sorghum stovers. The other important base bulk roughage is finger millet straw, pearl millet straw and stovers of maize. In parts of southern India, pearlmillet is fed as the bulk roughage and a variety of straws of millet are fed in different localities. Combinations of crop residues are also fed to obtain maximum utilisation of dry matter and nutrients (Sampath 1984, 1988). In the areas of Kerala paddy straw is the only dry fodder and supplementary feeding of milch animals is done. Cottonseed, tamarind seed, rice bran, coconut cakes and black gram husk are fed to lactating and working animals.

Feed Availability and Nitrogenous Supplements

Authentic statistical data on production and utilisation of crop residues in India is not available. Few estimates based on grain to straw ratio have been made and these estimates point out that green fodder and feeds are in short supply. An estimate of Mudgal and Pradhan (1988) point out that the annual requirement of feeds and fodders is 25.4 million tonnes concentrates. 353.0 million tonnes dry fodder and 308.0 million tonnes of green fodder (Mudgal and Pradhan 1988). In contrast the feed available comprises about 16.5 million tonnes concentrate; 300.5 million tonnes dry fodder and 261.0 million tonnes

green fodder highlighting a short fall of 44% concentrate and 38% green fodder. This whole picture represented in terms of digestible crude protein and total digestible nutrients indicates a shortfall of 34 and 37%, respectively.

Feeding of coarse fibrous crop residues and other straws alone has an adverse effect on rumen fermentation. Various drawbacks associated with straws exaggerate impassive effect on rumen microbial digestion. The rate at which the straws rich in lignocellulosic compounds can continue to be eaten by a ruminant are determined by the rates at which previous inputs are removed (Hogan and Leche 1981). With most of these fibrous residues, the major factor controlling intake is the feed particle size, which, in turn, is decided by the amount of microbial fermentation in the rumen. Low microbial activity in the rumen due to limited availability of energy from cell walls of fibrous feed stuffs, often leads to accumulation of undigested straws in the rumen and a slow fibre degradation process (Hogan 1981). Therefore animals maintained exclusively on coarse fibre require supplementation of protein and energy for optimising production.

Long association of farmers with animals has resulted in understanding of the animal requirements for feeds and nutrients. Farmers try to improve intake of poor quality fibrous crop residues or straws by chaffing, soaking straws in water or by washing chaffed straws. in an attempt to augment feed intake leguminous greens and chaffed maize and sorghum are also mixed. Soaked crushed grains, cakes and concentrates are spread over wheat straw and other fibrous crop residues to increase feed intake of animals. About 0.4 million tonnes of agro-industrial by-products and by-product based pelleted feeds are also offered to productive animals (Punj 1988).

For increasing the productivity and to exploit the full genetic potential of existing livestock population, nutritional aspects assume great importance. supplementation of protein, energy, minerals and vitamins is often required in most livestock populations, particularly those maintained on straws. Supplementation of nutrients for lactation and pregnancy is essential. The supplementation of feed to a group of livestock or an animal needs to be considered in relation to the physiological state of the animal and seasonal availability of a supplement. Problems of feed deficits in south Asia and inadequate) and efforts to reduce the magnitude were highlighted in a publication emanating from consultations held in India (Devendra 1988). Fibrous crop residues as animal feed have also been discussed with a view to biologically improving nutrient availability and enhancing digestibility (Singh and Schiere 1988). In the past, discussions have also been made for improving fibrous crop residues by biological, chemical and physical treatment (Singh et al. 1988; Preston and Leng 1987) and an All India symposium was devoted exclusively to protein and non-protein nitrogen (NPN) utilisation in ruminants (Gupta and Arora 1980). Factors limiting crop residue utilisation with special

reference to antiquality factors and their amelioration has also been a subject of discussion (Gupta et al. 1986) in the last decade.

Greens and succulent feed supplements

Jowar (*Sorghum vulgare*, maize (*Zea mais*), bajra (*Pennisetum typhoides*) and sudan grass (*Sorghum sudanense*) are the most common non-leguminous fodder crops of the kharif season (July to October). Most of these have 0.5–1.0% digestible crude protein (DCP) and 10–17% total digestible nutrients (TDN). Oats (*Avena sativa*) and barley (*Hordeum vulgare*) are two important crops of the rabi season (November to April) and have about 2% DCP and 17% TDN on fresh basis. Non-leguminous perennial fodder crops consist of Napier grass (*Pennisetum purpureum*), Hybrid Napier (a cross of Napier and Bajra), Guinea grass (*Panicum purpureum*) and para grass (*Brachiaria mutica*). Main leguminous fodders of kharif are cowpea (*Vigna catjang*) and cluster bean or guar (*Cyamopsis psoraloides*) and contain 2–3% DCP and 8–10% TDN on fresh basis. Two other important fodder crops of rabi season are Berseem (*Trifolium alexandrinum*) and lucerne (*Medicago sativa*) and contain 2.5–3.0% DCP and 10–12% TDN on fresh basis.

Straws of both rabi and kharif non-leguminous crops are preserved for animal feeding during the lean period in India. The preservation is either in the form of stacks, or in roofed houses or in the form of specially made enclosures of strong fibrous residue, for storing wheat straw. The straws, in general, do not contain digestible crude protein, and TDN content is about 30–40%. The straws of leguminous fodders like cowpea, groundnut, gram, mung and pea have 2–3% DCP and 30–40% TDN. Chemical composition and nutritive value of Indian feedstuffs have been presented in Table 3.

Energy-rich concentrates consisting of grains and seeds, mill by-products, molasses, etc. and protein-rich concentrates consisting of oil seed meals, cakes, and industrial by-products are fed to milch and working animals (Tables 4, 5). These concentrates are given to productive animals only and as a supplement along with fibrous crop residues. Greens whenever or wherever available are preferred over dry hays or straws for feeding productive animals.

Plant protein and non-protein nitrogenous supplements

Protein is one of the critical nutrients for young, growing, high producing and working animals. Most Indian feeds and fodders do not meet even maintenance needs of protein and therefore at least a moderate quantity of protein needs to be fed to these animals for optimising production. The protein feeds which are used as supplements in ruminant and poultry diets are plant proteins, animal proteins, non-protein nitrogen and single cell proteins.

Table 3. Chemical composition and nutritive value of India feedstuffs.

Feedstuffs	Chemical composition on DM basis							Nutritive value on kg/100 kg dry matter basis[a] Mcal/kg dry matter (DM)	
	CP	CF	NFE	EE	TA	DCP	TDN	DE	ME
Roughages									
Pearl millett (*Pennisetum tyhoides*)									
Milk stage	10.6	28.0	50.2	2.1	9.2	–	–	–	–
All analysis	6.9	31.8	48.9	1.5	10.9	4.3	59.2	2.6	2.1
Berseem (*Trifolium alexandrinum*)									
Average (all analysis)	17.4	25.9	40.7	1.9	14.2	12.5	59.2	2.6	2.1
Cowpea (*Vigna unguiculata*), average	18.2	15.3	39.6	2.6	14.2	–	–	–	–
Grasses									
Bermuda grass (*Cynodon dactylon*), av.	10.5	28.2	47.8	1.8	11.8	–	–	–	–
Bore Love (*Eragrostis chloromelas*)	6.8	37.0	47.8	1.4	6.4	–	–	–	–
Canary young grass, flowering	13.9	9.9	31.3	5.2	19.7	–	–	–	–
Napier hybrid	10.2	30.5	41.0	2.1	16.2	–	–	–	–
Para grass (*Brachiaria mutica*)	12.0	28.2	45.7	2.9	11.2	67.9	59.5	–	–
In running water	6.9	35.4	46.1	0.8	10.8	–	–	–	–
Waterlogged	15.4	32.3	38.0	1.2	13.1	–	–	–	–
Rye (*Lolium perenne*)	12.2	13.3	63.2	3.6	7.8	–	–	–	–
Spear grass (*Heteropogon contortus*), av.	5.2	33.8	50.1	1.8	9.1	–	–	–	–
Sudan grass (*Sorghum sudanese*)	5.7	27.0	51.0	1.9	14.4	1.6	44.4	2.0	1.6
Guar (*Cyamopsis tetragonoloba*), 2-month old	8.6	30.0	47.6	1.7	12.7	6.1	48.4	2.2	1.8
Sorghum (*Sorghum bicolor*)	8.9	35.1	44.4	2.1	9.4	4.2	56.3	2.5	2.0
Young	4.6	38.7	47.5	1.2	8.1	1.1	53.9	2.4	2.0
Ripe	20.2	30.1	36.6	2.3	10.7	13.5	58.8	2.6	2.1
Lucerne (*Medicgo sativa*), average	7.2	30.8	51.6	1.8	8.6	4.2	67.8	3.0	2.5
Maize (*Zea mays*) average									
Oat (*Avena sativa*)	6.4	28.7	53.2	2.3	9.3	–	–	–	–
Milk stage	9.2	34.8	44.8	1.8	9.4	–	–	–	2.1
Ripe	11.8	29.8	41.7	1.0	8.7	7.8[b]	72.9[b]	3.2	2.6
Pea (*Pisum sativum*)	10.1	38.4		1.2	8.6	–	–	–	–
Podding (*Stylosanthes bojeri*)									
Sugarcane tops (leaves)	5.5	36.3	48.5	1.5	8.2	2.7	45.7	2.0	1.6

Table 3. Chemical composition and nutritive value of India feedstuffs—cont'd.

Feedstuffs	Chemical composition on DM basis							Nutritive value on kg/100 kg dry matter basis[a] Mcal/kg dry matter (DM)	
	CP	CF	NFE	EE	TA	DCP	TDN	DE	ME
Silages									
Teosinte	5.6	31.5	48.3	4.6	10.2	–	–	–	–
Hays									
Alfalfa hay	14.1	31.7	41.6	1.8	10.8	–	12.0a	2.5	2.0
Marvel grass hay in flower	4.1	39.9	44.4	1.0	10.6	–	–	–	–
Oat (*Avena sativa*)	5.6	35.9	48.4	1.7	8.3	2.6	60.1	2.8	2.3
Para grass hay	5.3	34.6	45.7	2.0	12.4	2.1[b]	46.2[b]	2.0	1.7
Rhodes grass hay (*Chloris gayana*)	12.3	27.3	45.8	2.4	12.1	7.4	55.1	2.4	2.0
Ripe	6.4	39.3	44.1	1.3	9.1	3.1	53.0	2.3	1.9
Spear grass (*Heteropogon contortus*) ripe	5.3	44.1	46.9	1.2	9.7	0.0	50.7	2.2	1.8
Sugarcane (*Saccharum officinarum*) leaves	2.6	36.9	52.7	1.4	6.1	0.0	46.3	2.0	1.7
Legume hays									
Berseem (*Trifolium alexandrinum*)	14.7	30.6	41.0	1.6	12.1	10.3	65.8	2.9	2.4
Cowpea (*Vigna unguiculata*) hay	15.3	34.8	35.4	1.1	13.3	10.3	50.5	2.2	1.8
Large variety without pods	11.4	32.8	45.9	1.4	8.6	7.5	55.6	2.4	2.0
Gram hay, average	12.2	33.0	41.8	2.3	10.2	–	–	–	–
Groundnut hay	21.5	24.5	38.2	1.0	14.8	14.9	48.9	2.2	1.8
Lucerne hay	21.3	29.4	35.2	1.4	12.7	16.4	55.9	2.5	2.0
Pea (*Pisum sativum*)	10.9	29.2	50.3	1.9	7.7	–	–	–	–
Straws									
Barley straw	2.2	47.4	41.4	0.9	8.1	0.8[b]	46.9[b]	2.0	1.7
Sorghum (*Sorghum bicolor*) straw, average	3.8	35.6	51.0	1.3	8.3	1.2	56.4	2.5	2.0
Maize kadbu (straw)	3.6	33.2	51.9	0.8	10.5	–	–	–	–
Wheat bhoosa, average	3.6	34.0		1.5	13.7	–	–	–	1.6
Wheat straw, average	3.2	34.9	43.8	1.5	11.6	0.0	48.4	2.1	1.7
Concentrates, grains and seeds									
Cotton seed, average	18.1	21.6	37.6	18.2	4.6	12.5	88.8	3.9	3.2
Gram (Chuni), average	17.4	11.4	61.7	4.3	5.3	–	–	–	–

Table 3. Chemical composition and nutritive value of India feedstuffs—cont'd.

Feedstuffs	Chemical composition on DM basis							Nutritive value on kg/100 kg dry matter basis[a] Mcal/kg dry matter (DM)	
	CP	CF	NFE	EE	TA	DCP	TDN	DE	ME
Concentrates—cont'd									
Sorghum (*Sorghum bicolor*)	15.2	–	79.5	2.5	2.8	7.3	85.7	3.8	3.1
Maize	11.1	1.9	80.7	4.4	1.9	8.2	94.3	3.5	2.98
Oat, average	9.3	15.5	69.4	5.8	5.1	–	–	3.5	2.8
Soybean seeds	41.6	6.0	28.8	17.4	6.1	37.5	87.5	3.9	3.2
Wheat, average	10.4	2.0	82.6	2.6	2.5	6.3	92.3	4.1	3.3
Cakes and meals									
Coconut cake, Expeller pressed, average	23.5	10.2	49.9	9.6	6.8	22.8	83.9	3.7	3.0
Cottonseed cake, average	27.5	18.4	38.4	9.4	6.4	19.4	79.6	3.5	2.9
Groundnut cake, average	47.0	6.1	33.1	6.6	7.5	46.4	78.9	4.6	2.9
Maize cake, average	21.4	8.7	45.2	18.7	2.9	15.3	82.3	–	–
Rape cake (*Brassica compestris*), average	35.0	7.9	38.0	10.0	9.0	39.0	86.8	3.8	3.1
Sesame cake (*Sesamum indicum*), average	42.7	5.1	33.1	6.5	12.6	42.6	86.9	3.8	3.1
Sunflower seed cake	26.2	22.9	23.6	20.5	6.8	22.7	71.0	3.1	2.6
By-products									
Arhar (*Cajanus cajan*) husk, average	6.3	41.5	45.3	2.0	5.0	–	–	–	–
Bagasse	3.1	45.1	44.7	4.2	3.0	0.00[b]	22.3[b]	1.0	0.8
Brewery grain	19.2	13.5	59.3	3.8	4.2	–	–	–	–
Cowpea husk	7.4	24.6	51.3	4.7	12.2	–	–	–	–
Groundnut husk	17.8	12.1	46.3	16.7	7.1	–	–	–	–
Guar powder	42.9	12.3	35.1	3.7	5.9	–	–	–	–
Maize, bran	11.9	10.5	75.2	1.7	0.8	6.2[b]	76.7[b]	3.4	2.8
Gluten	24.9	1.8	65.1	1.8	6.4	21.4	68.5	3.0	2.5
Mango-seed-kernel	6.5	4.0	77.1	11.0	2.2	4.7	70.0	3.1	2.5
Molasses (Khandsari)	0.9	–	93.1	10.2	2.3	–	–	–	–
Rice bran, average	10.4	22.6	38.1	7.5	21.5	7.9	70.3	3.4	2.8
Rice bran, polish, average	6.1	27.4	42.0	4.5	19.9	–	–	–	–
Tapioca (*Manihot esculenta*)	1.9	2.3	94.4	0.2	1.2	1.5	83.3	3.7	3.0
Flour	2.9	10.9	76.2	0.4	9.5	–	–	–	–
Wheat bran, average	12.8	11.1	64.3	3.2	8.4	10.3	72.7	3.3	2.7

Notes on Table 3 at foot of next page.

India produces large quantities of oil seeds (Table 4). In processing these seeds not only vegetable oils are produced for human consumption but also protein-rich products are obtained which have great value as livestock feeds. Groundnut, mustard, cottonseed and other cakes are the most widely used high protein animal feed supplements in India. These oil cakes have about 95% of the nitrogen as true protein with a digestibility ranging from 75 to 95%. The oil cakes have a high content of phosphorus and B-vitamins. Most oil cakes are poor in glutamic acid, cystine, methionine and lysine.

A good quality of protein supplements for feeding poultry is obtained from inedible animal tissues and these animal proteins are fed in small quantities, generally to supply essential amino acids. Meat, bone and blood meal are used for feeding swine and poultry in India. Fish and feather meals are also used as livestock feeds (Gupta 1988; Shukla 1988).

In northern India, wheat straw is produced in April–May and paddy straw in September–October. These bulk fibrous roughages are fed to ruminants in the lean period. Non-availability of adequate nitrogen-rich feeds, particularly from April to mid-July for pregnant and draught animals often results in poor performance by these animals. Both milk production and work output of animals are affected. Repeated attempts have been made by various groups in India to improve digestibility and nutritive value of poor quality fibrous roughages using chemical, mechanical and biological treatments and by supplementation with NPN substances. The results of some selected studies carried out on various fibrous crop residues and conclusions have been reviewed.

Many systems are followed for feeding urea and other NPN chemicals to ruminants. Urea is mainly fed to animals as a feed supplement to concentrates in place of proteins or to supply some easily soluble NPN, as a supplement to

Notes on Table 3:

[a] For converting the values expressed on dry matter to those on raw matter basis, the following ad hoc figures for dry-matter content of different category of feed stuffs may be employed: all air-dry materials such as dry roughages, cake, grain, etc 90%; succulent silage 30%; green pasture, green forages 25%; jowar (prime) 30%; sorghum (ripe) 40%; green legume 20%.

[b] As no digestibility figures have been reported by Indian workers, foreign digestibility coefficients have been used to calculate the nutritive values of these feeds. These figures are, therefore, approximate. When not available, the values oof DE and ME are calculated from the TDN values as follows: 1 kg TDN = 4.4 Mcal of DE; 1 kg TDN = 3.6 Mcal of ME.

Source: Nutritive values of Indian cattle feeds and the feeding of animals by K.C. Sen. Revised by S.N. Ray and S.K. Ranjhan 1978, ICAR, New Delhi, 27–55.

protein-deficient forages and as a chemical to increase the nutritive value of poor quality roughages. The addition of urea increases rumen microbial activity particularly when animals are fed high roughage diets. Urea spraying over crop residue with and without molasses has been used to enhance nutritive value of feeds. Studies on enrichment of crop residues such as maize and Jowar stover, paddy and ragi straw with 2% urea and 10% molasses has also been tried in India. Feeding of enriched straws to bullocks revealed an improvement in intake over untreated straws (Bhaskar et al. 1980). The DCP of enriched crop residues ranged from 4.8 to 7.0/100 kg dry matter revealing the utility of feeding urea-enriched crop residues to ruminants.

Table 4.   Forests, agriculture and industrial by-product in India

Feed source	Total available	Total by-product available	Extraction rate	By-product
	(million tonnes)	(million tonnes)	(%)	
Tapioca	4.47	2.55	57.0	Starch waste
Guar seed	0.71	0.40	57.0	Toasted
Salseed meal	5.50	4.78	87.0	Meal
Mahua seed	2.17	1.41	65.0	Cake
Neem seed	0.42	0.34	80.0	Cake
Rubber seed	0.34	0.12	35.0	Cake
Karanj	0.13	0.10	73.0	Cake
Kosum	0.10		67.0	Cake
Khankan, Undi, Nahar	0.10	0.10	40.75	Cake
Mango seed	1.00	0.50	50–55	Kernel
			Hulls	Red bulls
Tamarind seed Babul pods	1.0	0.2	–	Chunni as pods
Banana	4.2	0.8	Reject	Banana reject
Citrus	16.0	3.4	10	Dried pulp

Source: Fertilizer Statistics 1990–91.

Treatment of fibrous crop residues and straws of paddy and wheat with urea solution releases gaseous ammonia which reacts with straw. The treatment of straws with 4% urea, as a source of ammonia, and stacked under polythene sheets for a period of 4–5 weeks has been quite effective in improving the crude protein content (Rai and Gupta 1990). The ammoniation process solubilises hemicellulose and as a result acid detergent fibre and crude fibre contents increased in ammoniated straw. The excessive release of ammonia appears to react similarly to that of anhydrous ammonia or solutions of ammonia in water

(Sundstol et al. 1978; Saadullah et al. 1981; Shariff and Gupta 1987; Rai and Mudgal 1987; Rai and Gupta 1990).

Feeding of maize straw impregnated with 1% urea and 5% molasses to Surti heifers has increased dry matter intake and digestibility but the nutrient requirements for growth were not fully met from such a treatment (Balasubramanya et al. 1980). However, studies of Bhaskar et al. (1980) proved that feeding of enriched roughages exerted a favourable effect on the body weights of cattle and dry matter intake ranged from 1.53 to 1.93 kg/100 kg body weight.

Table 5. Major by-products feeds from cereals

Feed source	Total available	Grain by-product available	Grain to fibrous residues available	Estimated fibrous residue available	Fibrous residue available for animal feeding
	(million tonnes)	(million tonnes)		(million tonnes)	(million tonnes)
Rice	74.6	14.9	1.5	111.8	80.0
Wheat	54.5	16.4	1.5	81.7	50.0
Jawar	11.9	–	4.0	47.6	38.0
Bajra	6.9	–	4.0	27.6	20.0
Maize	9.1	2.7	3.0	27.3	20.0
Ragi (rye)	2.3	–	2.0	4.6	2.5
Small millets	1.2	–	4.0	4.8	3.0
Barley	1.6	–	2.0	3.2	2.5

Although use of urea and molasses in different forms have been useful, distribution of molasses, storage and mixing of ingredients with straw often proves to be a barrier in popularisation of a valuable technology. Urea molasses solidified blocks have been recommended for ruminant feeding. The concept of urea molasses block lick (UMBL) was originally conceived in Australia (Beames 1961) which spread later to India and Philippines in different forms (Leng 1990; Kunju 1986, 1988). Leng (1984), while discussing the main principles for formulating diets for ruminants in developing countries, highlighted the importance of supplementation of non-protein-nitrogen compounds to cattle and buffaloes. He concluded that provision of a continuous supply of urea in the form of solidified feed blocks, to increase the intake and digestibility of roughage-based diet, could be appropriately used by small farmers in developing countries.

Urea molasses blocks, consisting of 15% urea with 45% molasses, 4% calcite powder, 10% cottonseed meal, 8% sale, 15% minerals and 3% bentonite, have been used for ruminant feeding (Leng and Preston 1984; Kunju and Mangat

Ram 1989). These blocks have been used for growing, lactating and dry pregnant ruminants under farm and field trials. Beames (1961) supplemented urea molasses mineral block licks to cattle along with low quality native pasture hay. hay intake improved 29 and 45% in younger and older animals respectively on supplementation than the controls. Feed intake and live weight of lambs given a diet of wheat straw supplemented with urea molasses block and cottonseed meal increased (Sudana and Leng 1986). The study indicated that combination of the block with bypass protein increased feed intake and production by more than the combination of urea and protein. The studies carried out in lactating buffaloes in India (Leng 1984) have also indicated that urea molasses block may be used as a supplement to a fibrous diet particularly to reduce the amount of concentrate needed to maintain milk yield (Kunju 1986). Other studies conducted on growing buffalo calves (Madhu Mohini 1991), crossbred calves (Mangat Ram Garg 1989) and lactating crossbred cows (Bandla Srinivas 1991) support the recommendation regarding supplementation of UMBL (Leng 1990). The improvement in the productivity in cattle and buffaloes have been attributed to the adequate nitrogen and energy availability to the animals after provision of UMBL. Keeping in view the encouraging results, three commercial plants of 10 million tonnes capacity have been installed for making available urea–molasses blocks to farmers under cooperative sector. One brick of 3 kg is sufficient for an animal for 6–7 days.

Compounded feed manufacture in India also makes use of urea for supplementing feed. Compounded livestock feed was produced to the extent of 2.16 million tonnes in India during the year 1990 (Fertilizer Statistics 1990–91), out of which 1.33 million tonnes was used by cattle and other ruminants while 0.83 million tonnes was poultry feeds. There are many other feed industries which produce both cattle and poultry feeds. Urea constitutes on an average 1% of the cattle feed, thus numerical calculations indicate that urea used by compounded feed manufacturers is approximately 0.15 million tonnes annually.

In India, feeding of NPN and urea to animals has yielded limited interest and the response of an average farmer maintaining 3–4 animals for milk and farm purposes is poor. Many attempts at the door steps of farmers have resulted in confusion as farmers accustomed to feeding readily available fibrous crop residues do not like any treatment with urea due to ammoniacal smell. Further, dung produced from such treatments is not worthy of making dung cakes which are used for burning due to change in consistency. Thus, practices of NPN and urea feeding at the individual farmer level has not found applicability due to varied reasons but certainly urea feeding offers a great promise for supplementing protein to inadequately fed animals. Such supplementary feeding will be of great importance to large dairy farmers, particularly in lean periods when adequate greens are not available.

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Feeding Management of Ruminant Livestock in Indonesia

B. Bakrie

Ruminant animals are mostly reared by farmers in Indonesia on a small scale with the average ownership of two per head. There are few large scale animal enterprises in Indonesia; this could be related to the function of these animals because large ruminants are kept mainly to help farmers in their agricultural operations while both large and small ruminants serve as a form of money, savings or security. Due to these reasons most of these animals are found on Java Island which is inhabited by more than 60% of the total Indonesian population, although it represents only 7% of the Indonesian landmass. Numbers of cattle and buffalo on this island are 5.69 million which represents 41.7% of total cattle and buffalo population whereas the 11.87 million sheep and goats form 70.2% of the total sheep and goat population.

The number of these animals is still below that needed to meet the demand for consumption (Table 1). From the 1989 figures demand for meat increased by 7.6% annually. This requires importation of 2,000 p/year and imports are expected to increase at 1.55% p/year (Anon. 1991). Furthermore an increased number of cattle and buffalo is also required for power, as more than 500,000 ha of land are opened every year through the transmigration program.

Besides increases in the quantity of animals, quality still needs to be improved. Mature body weight of both cattle and buffalo is still low with a mean value of 350 kg due to a low daily weight gain (Anon. 1978). It has been reported that by increasing the nutritive value of the diet, e.g. by supplementary feeding with concentrates, the daily weight gain can be improved (Moran 1978). To increase the quantity and quality of animal products requires sufficient amounts of feed of adequate quality. The quantity of forages is not a problem in Indonesia it is the quality of the feed which appears to be very poor and supplementation is considered necessary. The feeding management of ruminant animals will be discussed in this paper together with some thoughts on improving the quality of animal feeds by using available feed supplements.

Animal Ownership

Cattle and buffalo are usually reared separately from sheep and goats and are seldom kept together by one rearer. The ownership of the animal varies between one rearer to the others. The animals are either owned by farmers or kept under

a share-in basis. For example, 80% of cattle and buffalo in Subang, west Java, are reared by the owner (Santoso et al. 1987) while only 44% of sheep and goats in Pandansare, west Java, were owned by the rearers (Basuno 1983). Those who own animals possibly have obtained them through self purchase, received them as a gift, or inherited them from parents. In the share-in basis the animals are usually owned by rich farmers and the rearers will get payment mostly from the young animals produced. The rearers get one calf or lamb/kid from every two produced.

Table 1.   Meat production and consumption in Indonesia in 1989.

	Ruminants	Non-ruminants	Total
Population ('000 head)	30 532 (3.74)[a]	286 570 (6.16)	317 102
Meat production (t)	391 000 (2.07)	580 100 (−2.08)	971 100
Meat consumption			
Demand	–	–	973 100 (6)
Import	–	–	2 000 (1)

[a] Figure in brackets is the trend of increase (%/year) calculated from data of year 1988–89.
Source: Anonymous (1991).

In a village in Sunang, west Java, middlemen distribute 12–18 month-old buffalo to farmers to be kept for one year or so. The rearers will be responsible for feeding and looking after the animals and could use them to work for ploughing in their rice field. After that the middlemen will come back to replace one animal with two calves and so on.

In the transmigration area, the government supplies 18-month-old female cattle or buffalo under a credit scheme known as the in-kind system to help farmers in cultivating their 2 ha allocated lands (Soejoto 1988). The rearers will have to pay back two calves in a five-year period. For every ten females distributed one rearer receives a bull as well as one female; this farmer has to pay one extra calf in the same period of time. Calf production is thus an important feature of farming systems in this region.

The government has also recently launched a new system of rearing animals, the so called nucleus estate smallholder scheme. It is a joint venture between large animal enterprises and farmers, mainly for fattening cattle. In this system, farmers will provide the animals plus all the feed required; the rearer has to feed and care for the animals and will get a proportion of the profit when the animals are sold after 4 to 6 months.

Feeding Management

The extent of feeding management largely depends on the farmer's activity and is greatly affected by crop seasons. Farmers will have more time to look after the animal outside the crop season, except for those who can pay herding boys with responsibility for taking animals to grazing areas during the day or to cut grass to be fed to the penned animals at night.

Animals are usually kept in the vicinity of the house, either in pens all the time or taken out of the pen in the morning. Draught animals will usually be taken directly to the working areas during working season to work until noon and then taken to grazing areas in the afternoon. Animals will be taken back to the pen at 166–1800 hours in the afternoon. Outside the working season, animals are usually tethered outside the house and will also be taken to grazing areas in the afternoon.

The animals therefore are fed either from grass obtained during grazing or provided in the pen by means of a cut-and-carry system. There is great variation amongst rearers in the grazing and hand feeding systems adopted and it has been reported that there are 12 different combinations of feeding for large ruminants over the yearly cycle in west Java (Sumanto et al. 1987). The combination of hand feeding and/or grazing seems to depend on the relative availability of grazing area and forage for cutting as well as labour for herding versus hand feeding. Handfeeding increases when farmers' labour becomes limiting for herding, for example during the rice planting season. However if forage is difficult to collect, herding becomes more attractive.

Type of Feed

Almost all the feed consumed by ruminants is in the form of roughage, comprised of grasses collected from waste or fallow land, crop residues and tree leaves (Nell and Rollinson 1974; Thahar and Petheram 1982). Apart from that, other types of forages are also consumed/offered to animals including shrubs, weeds and herbs, as well as banana stems, banana leaves and bamboo leaves. These types of roughages are more or less consumed accidentally by animals if presented in the bunch of forages cut by the owner but they may be included deliberately when not enough grass is available.

The mixture of roughages given to the animals depends on the proportion of grazing to hand feeding, season within the year (wet, dry, ploughing or planting), rainfall, cropping pattern, types/proportion of land accessible to cut or graze, and the availability of labour (Santoso et al. 1987). It has been estimated that the amount of grass consumed by animals is between 42 and 93% of the total roughage, while crop residues form 2 to 30% and tree leaves 1 to 14% (Van Eye et al. 1983; Mathius 1989; Bakrie 1991).

The types of roughages consumed by animals in several villages in Indonesia have been identified and presented in Table 2. Data were collected from villages in Southern Sumatra (Bakrie 1991), West Java (Van Eys et al. 1983; Santoso et al. 1987, Sumanto et al. 1987; Little et al. 1988; Mathius 1989; Pulungan 1989; Zulbardi 1989; Lowry et al. 1992) and East Java (Little et al. 1988; Yusran et al. 1989). Most samples were collected from the bunch of forages cut by farmers for feeding to the animals. Identification of the types of roughages grown in the are have also been made in some villages studied.

The types of grass grown vary from one region to another. The quality of the grass is generally low with the crude protein content 5.6–15.7% and NDF content 45.2–85.4% (Table 3). According to Little et al. (1988), one of the limitations of feed consumed by animals in the villages is a shortage of digestible energy. Therefore supplementation is needed to be able to fulfil the requirement of animals for energy.

The use of good quality grass, such as King grass and Elephant grass, is limited to the area where the grass has been introduced by government, scientist or extension workers. However, there are few farmers interested in producing and maintaining introduced grasses, partly due to lack of land and shortage of time available to look after the grass. Another cause is lack of knowledge as many farmers are unwilling to adopt new technology. There is also lack of motivation to grow grass as an enormous amount of free grass is still available.

Feeding of crop by-products follows the cropping pattern. These roughages are mainly given to animals under the cut-and-carry system. Quantity and kind of crop by-products generally reflect the cropping system and other characteristics of the agricultural enterprises (Van Eys et al. 1983). However, at most only 50% of all crop by-products are used as animal feed (Djuned and Budiastuti 1991). Crop by-products are used as they become available after harvesting time, a time at which farmers are fully occupied in handling their harvested crops. Most of them are wasted through lack of suitable storage technology. Storing roughages is not common and most are given in the green state immediately after harvest. In drier regions such as est Java farmers store rice straw, but in the more humid west Java, storage of roughage is never practiced by farmers because treatment is required to protect stored forages from deterioration.

The types of crop by-products utilised by animal rearers are not the same in the different villages, as not all types of crops listed in Table 2 are grown in all regions. Therefore the crop by-products used depend on what is grown by the farmers. Rice straw is grown in most regions as rice is the Indonesian staple food. In some areas it is grown three times a year, so that it is available almost all year round. However, most of the straw is burned, only 10% being used as animal feed (Djuned and Badiastuti 1991). The availability of other crop by-products is less as these crops are gown more or less sporadically or less intensively than rice.

Table 2. Types of roughages comsumed by animals in several villages in Indonesia.

| Grasses | Crop residues | Tree leaves | | Herb/weeds/shrubs |
		Legumes	Non-legumes	
Andropogon caricosus	*Arachis hypogea* (tops)	*Acacia auriculiforme*	*Artocarpus heterophyllus*	*Ageratum houstonianum*
Apluda mutica	*Cajan cajan* (leaf)	*Acacia mangium*	*Artocarpus integra*	*Amaranthus hybridus*
Axonopus compressus	*Canavalia ensiformis* (leaf)	*Albizia falcataria*	*Azadirachta indica*	*Banbusa* spp.
Brachiaria decumbens	*Citrullus vulgaris* (leaf)	*Calliandra callothyrsus*	*Carica papaya*	*Boehmeria pilosiuscula*
Cynodon dactylon	*Glycine max* (straw)	*Gliricidia maculata*	*Ceiba pentandra*	*Borreria alata*
Cyperus polystachius	*Grenvillea robusta* (leaf)	*Gliricidia sepium*	*Cordia obliqua*	*Bridellia tomentosa*
Cyperus rotundus	*Ipomea batatas* (tops)	*Leucaena leucocephala*	*Erythrina lithosperma*	*Centrosema pubescens*
Cytococeum acerescens	*Lablab purpureus* (tops)	*Samanea saman*	*Hibiscus tilliacius*	*Clerodendron* spp.
Desmodium triflora	*Manihot utilissima* (peeler)	*Sesbania grandidflora*	*Lannea grandis*	*Clibadium surinamense*
Dicanthium	*Manilot utilissima* (tops)	*Tamarindus indica*	*Haesopsis emini*	*Commelina diffusa*
Digitaria fuscescens	*Mucuna pruriens* (tops)		*Mangifera* spp.	*Commelina nudiflora*
Digitaria microbachne	*Musa paradisiaca* (leaf)		*Persea gratissima*	*Croton hirtus*
Digitaria setigera	*Dryza sativa* (straw)			*Croton triglium*
Echinochloa	*Pachyrrhizus erosus* (tops)			*Diplazium proliferum*
Eleusine indica	*Phaseolus lunatus* (tops)			*Elaeocarpus obtusa*
Equisetum debile	*Saccgarum officinarum* (tops)			**Euphorbiaceae**
Eragrostis	*Solanum tuberosum* (leaf)			*Euphorbia heterophylla*
Eupatorium riparium	*Zea mays* (stover)			*Euphorbia hirta*
Heteropogon contortus				*Euphorbia prostrata*
Imperata cylindrica				*Fimbristylis miliacae*

Table 2. Types of roughages comsumed by animals in several villages in Indonesia—cont'd.

Grasses	Crop residues	Tree leaves		Herb/weeds/shrubs
		Legumes	Non-legumes	
Ischaemum timorense				Galinsoga parviflora
Oxalis latifalia				Gluta renghas
Panicum barbatum				Leea aequata
Panicum maximum				Ludwigia hyssopifolia
Panicum montanum				Micania cordata
Panicum repens				Micania scandens
Paspalum conjugatum				Mimosa invisa
Paspalum javanicum				Mimosa pudica
Paspalum scrobiculatum				Poinsettia spp.
Pennisetum purpuroides				Portulaca oleracea
Pennisetum purpureum				Rynchospora orymbosa
Polytrias amaura				Stachytarpheta spp.
Pueraria javaanica				Synedrelia rodiflora
Sacciolepsis insulica				Viola odorata
Sporobolus cryptandrus				Zingiber spp.
Themeda gigentea				Triumfetta rhombaidea

Table 3. Chemical composition of some roughages consumed by animals (components expressed on DM basis).

Forage species	Dry matter (%)	Ash (%)	Crude protein (%)	NDF (%)	Gross energy (MJ/ kg DM)	Ca (%)	P (%)	IVDHD (%)
Grasses								
Andropogon caricosus	23.73	10.51	9.21	68.73	12.72	0.99	0.32	–
Axonopus compressus	27.10	10.79	10.07	74.58	15.95	1.21	0.31	–
Cynodon dactylon	25.68	12.72	11.16	67.00	14.20	–	–	–
Cyperus polystachius	–	7.40	10.00	79.50	17.30	0.31	0.17	–
Cyperus rotudus	29.00	13.51	15.72	78.56	–	–	–	–
Desmodium triflora	20.94	15.28	9.71	69.49	16.57	0.64	0.40	46.80
Digitaria setigera	–	8.70	16.60	77.40	18.20	0.24	0.19	–
Eleusine indica	25.70	10.84	13.42	73.19	15.50	0.71	0.30	–
Equisetum debile	26.23	11.75	7.23	50.98	16.90	1.35	0.35	–
Eupatorium riparium	26.79	7.10	10.67	45.15	18.01	0.42	0.29	–
Imperata clyindrica	32.10	7.87	8.57	85.35	–	–	–	–
Ischaenun timorense	23.15	9.83	9.69	63.10	15.48	0.51	0.34	41.21
Panicum barbatum	16.70	10.44	11.86	74.91	–	–	–	–
Panicum montanum	18.91	12.38	8.79	64.19	17.32	1.37	0.40	64.13
Panicum repens	18.90	5.66	5.64	82.96	–	–	–	–
Paspalum conjugatum	19.80	12.72	10.94	77.80	16.40	0.40	0.09	–
Paspalum scrobiculatum	18.40	12.03	11.20	80.71	–	–	–	–
Pennisetum purpuroides	–	18.60	13.50	59.70	–	0.37	0.35	–
Pennisetum purpureum	19.80	10.59	11.51	69.36	12.80	0.44	0.28	–
Themeda gigentea	27.46	14.42	8.21	46.32	16.56	0.07	0.31	55.63
Triumfetta rhombaidea	30.32	16.55	8.76	66.46	16.34	0.61	0.45	–
Crop residues								
Arachis hypogaea (tops)	19.93	9.29	16.67	32.56	16.21	1.51	0.52	64.30
Citrullus vilgari (leaf)	36.80	11.90	7.12	39.02	14.37	2.43	0.11	–
Glycine max (straw)	–	–	5.35	72.48	–	–	–	–
Grevillea robusta (leaf)	33.60	6.69	12.38	55.38	–	1.14	0.28	–
Ipomea batatas (tops)	25.49	11.14	13.21	65.13	15.86	0.87	0.34	59.57
Manihot utilissima (peeler)	36.10	13.14	6.13	54.08	15.56	1.56	0.10	–
Manihot utilissima (tops)	22.68	9.03	21.09	55.44	14.56	0.76	0.28	54.13
Musa paradisiaca (leaf)	25.34	12.39	6.98	68.79	14.19	0.88	0.17	–
Oryza sativa (straw)	20.72	20.60	5.39	75.70	14.30	0.10	0.10	31.30

Table 3. Chemical composition of some roughages consumed by animals (components expressed on DM basis)—cont'd.

Forage species	Dry matter (%)	Ash (%)	Crude protein (%)	NDF (%)	Gross energy (MJ/ kg DM)	Ca (%)	P (%)	IVDHD (%)
Saccharum officinarum (tops)	18.17	10.45	7.38	73.90	15.56	0.45	0.19	–
Solanum tuberosum (leaf)	28.43	8.84	9.18	53.01	16.76	0.81	0.31	–
Zea mays (stover)	22.05	10.75	10.59	68.69	14.05	0.54	0.37	–
Legume tree leaves								
Calliandra callothyrus	–	5.76	24.00	24.32	–	–	–	37.80
Gliricidia sepium	23.00	17.50	24.22	43.50	15.20	2.57	0.30	69.00
Leucaena leucocephala	23.00	12.06	24.72	54.45	–	2.70	0.23	–
Sesbania grandiflora	–	10.10	27.25	43.30	–	1.41	0.42	–
Non-legume tree leaves								
Artocarpus integra	27.36	12.48	8.12	70.96	13.01	0.27	0.16	–
Ceiba pentandra	19.21	8.57	5.64	67.13	16.57	0.75	0.19	47.23
Cordia obliqua	31.53	11.41	12.90	47.47	16.29	2.21	0.39	39.27
Erythrina lithosperma	28.18	10.80	13.96	58.68	13.51	2.07	0.30	–
Hibiscus tilliacius	35.97	10.26	11.32	55.81	17.07	1.02	0.39	–
Persea gratissima	26.79	7.10	12.67	45.15	17.15	1.12	0.29	–
Herbs/weeds/shrubs								
Boehmeria pilosiuscula	37.38	14.09	6.61	67.99	14.15	0.34	0.11	37.81
Borreria alata	–	16.50	23.30	33.10	14.30	1.82	0.28	–
Clibadium surinamense	–	23.70	22.20	65.00	14.60	1.30	0.52	–
Croton triglium	21.57	18.71	6.35	55.76	13.54	0.57	0.40	50.42
Diplazium proliferum	26.25	9.05	12.01	41.84	16.56	–	–	–
Elaeocarpus obtusa	18.73	8.48	10.61	67.64	18.52	0.49	0.27	45.24
Euphorbia prostrata	23.54	12.07	8.78	56.18	15.54	1.31	0.39	50.11
Galinsoga parviflora	19.69	9.27	8.71	53.13	15.95	0.43	0.31	42.41
Gluta renghas	30.95	10.77	8.85	52.53	13.59	0.47	0.27	39.28
Leea aequata	31.68	9.40	9.88	50.82	16.51	1.61	0.20	41.50
Micania cordata	–	14.90	19.40	43.50	17.00	0.84	0.56	–
Portulaca oleracea	20.50	14.70	9.27	69.34	16.74	0.54	0.35	46.80
Synedrella rodiflola	29.14	18.52	8.81	45.37	16.37	1.13	0.35	–

The quality of some of the by-products has been by several workers (Table 3), although most of them have low quality they can be used as substitutes/ supplement when other types of roughages are not available. Some techniques to improve the quality of these by-products have also been introduced.

Many different types of tree leaves have also been fed to animals in a cut-and-carry system (Table 2), particularly when grass or by-products are not sufficiently available. The types of leaves offered mainly depend on the availability of different trees at the time of harvest. There are legume and non-legume tree leaves, the legume tree leaves have a high protein content of great value to supplement low protein grasses (Table 3). Some legumes are native to the region and others have been introduced. Again there is lack of knowledge by farmers of the nutritional benefits of feeding high quality legume tree leaves to animals.

There is very little if any concentrate feeding, mainly because of cost. Farmers are relatively poor so they cannot afford to spend much money to buy supplements for their animals. The main concentrates are rice bran and ground corn, as they are readily available in the village and may be cheaper to buy. Rice bran may be obtained from the rice mill, while corn is the second staple food consumed by farmers in the village. However, with dairy cattle and in beef cattle fattening enterprises concentrate feeding is very common with concentrates comprising 40–60% of the diet. In these enterprises concentrates may be mixed on-farm from different ingredients or they may use readily available commercial premises.

Type of Feed Supplement

Improvements in the quality of forage given to animals may be made either through teaching farmers to fully utilise the available sources around them, introducing good quality roughage to be grown by them, or teaching them to use the accessible/available feed supplements. Farmers have first to be taught and educated on what is available to be fed to animals. After that, good quality grass as well as legume trees may be introduced by farmers. Another possibility is to use cheap sources of supplement for farmers who have access to them. Most of these types of supplements are at present being wasted. Examples of supplements may be grouped in this category are presented in Table 4.

The supplements listed in Table 4 have been used by many workers in experiments in laboratories but economic studies of their use in animal production systems are often lacking. This type of information should be sought as the feeds should represent a low cost way to improve animal productivity in regions where they are produced.

Table 4. The types and chemical composition of possible supplements for animals in the village.

Forage species	Dry matter (%)	Ash (%)	Crude protein (%)	NDF (%)	Gross energy (MJ/ kg DM)	Ca (%)	P (%)	IVDHD (%)
Cassava (dried)	82.40	–	2.20	17.30	15.62	–	–	–
Cocoa bean shell	68.40	6.64	16.60	–	19.33	0.29	0.52	–
Cocoa pod husk	17.00	12.20	7.16	66.26	14.97	0.36	0.23	26.21
Corn (ground)	86.00	4.47	11.93	–	150	0.20	2.30	85.45
Cotton seed	92.00	7.84	23.00	44.00	–	1.30	4.10	68.60
Molasses	77.00	–	1.90	–	14.30	8.40	0.90	–
Pineapple (peeler)	27.00	5.50	5.20	48.87	20.10	0.18	0.15	–
Rice bran	86.40	11.20	20.00	52.90	19.18	2.00	1.00	–
Sago waste	80.36	4.53	1.18	–	–	0.34	0.11	–
Soybean (young plant)	14.40	18.10	18.90	56.28	14.10	1.50	0.47	67.20
Soyben curd (tofu) waste	15.80	–	18.60	46.80	19.45	0.83	0.24	–
Soybean fermented (tempeh) waste	19.50	2.90	17.20	–	18.00	0.40	0.20	81.60
Soysauce waster	36.50	34.00	29.20	25.30	13.61	0.58	0.25	–
Tapioca waste	88.70	–	1.20	39.20	16.56	0.32	0.03	–

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Supplementary Feeding of Ruminant Animals in Malaysia

J.B. Liang

Ruminant production plays a minor role in Malaysia, contributing 6.3% of the total value of livestock products (DVS 1989). It has been a backyard industry based on a low-input low-output system, where almost all sheep, cattle and buffalo are kept as secondary farming activities, providing extra income when necessary to the owners. Some draught animals were kept in the past to plough rice fields, but this function has been replaced by machines. Animals kept for milk are limited in number and are generally confined to small family farms near to towns where markets for their products are easily accessible. Although some changes have occurred in the last two decades in the ruminant production scenario in this country due mainly to governmental policy encouraging local meat and milk production in an attempt to reduce importation, these changes have been very slow. The bulk of the ruminants are still in the hands of small farmers who manage their animals under the traditional methods of production. Medium and large-scale farms run as commercial enterprises are few in number and their economic viability is yet to be proven.

The objective of this paper is to discuss feed resources and feeding systems, with special emphasis on supplementary feeding for ruminant animals under Malaysian conditions.

Management Systems

Traditional system

The traditional low-input low-output system of rearing cattle and buffalo is based on the principle that ruminants are efficient converters of roughage to meat and milk. The animals are allowed to feed on whatever comes their way. Stray grazing on native grasses and shrubs near the village, along road verges, and around rice fields after harvesting are the most typical way by which these animals are fed. No supplementary feeding is practiced, except on rare occasions when some cut-grass and common salts are offered to the animals. Cattle, buffalo and sheep kept under this system grow very slowly and reach market weights after about five to six years.

Draught animal system

In the past, cattle and buffalo were kept to plough rice fields. These draught animals had been phased out and are now completely replaced by machines, which are suggested to be more efficient in the modern systems of multiple rice crop production. However, some cattle and buffalo are now being used to pull carts to transport fruit bunches in the oil palm plantations. These draught animals which feed solely on the undergrowth of the palms (consisting of a wide variety of native grasses and shrubs) were shown to be productive and efficient (Liang and Rahman 1985).

Integration with plantation crops

Due to the abundant supply of green forages under the oil palm and rubber plantations, increasing numbers of ruminants especially cattle and sheep are now being integrated with plantation crops in Malaysia. The carrying capacity under plantations depends on the availability of the forages which in turn is determined by the amount of soil moisture, age of the crop, and light penetration to the ground. This system of ruminant production based on integration with plantation crops offers an excellent alternative to the traditional low-input low-output system in Malaysia. The feed resources and potential of this system have been well described (Chen et al. 1991).

Feedlot system

Encouraged by the success of local research, fattening cattle and buffalo using agro-industrial by-products, especially palm kernel cake, under the feedlot system has gained some popularity in the last decade in this country. The scale of operation ranges from a few animals owned by individual farmers to several thousand head owned by some commercial companies. However, this system of ruminant production as a business enterprise has yet to be proven, primarily due to the high costs of feeds and lack of suitable and cheap feeder cattle.

Dairy production

The Local Indian Dairy (LID) cattle and the Murrah buffalo which form the base population of dairy animals in this country are believed to have been brought in by the early immigrants from India and Pakistan. Thus, dairy production has been limited to the Indian community operating as family farms near large towns where their products are easily disposable. Stray grazing on native grasses around the farms supplemented with self-formulated concentrates has been the standard feeding system in these farms. Recent governmental policy to increase local milk production has created a new group

of dairy farmers in this country. New breeds of dairy cattle, particularly Sahiwal × Freisian crossbreds, were imported from New Zealand and Australia to supplement the traditional local dairy cattle production. In addition, more organised marketing systems based on government-supported milk collection centres have been formed to help in the marketing of the milk production.

Feed Supply

Basal feed supply

The basal feeds for ruminant production in Malaysia are the native grasses and shrubs. These tropical forages, which are also the sole feed in most ruminant production systems in Malaysia become fibrous earlier and have lower digestibility values as compared with their temperate counterparts. Nitrogen content of these grasses is just marginally above 1% (Devendra 1979) and their potential for animal production is low. The net result is poor quality feed and in some situations (e.g. during dry seasons) insufficient supply as well for the animals. This, together with other available information, such as low intake capacities of local cattle and buffalo (Liang and Samiyah 1988; Liang et al. 1988) and/or nutrient imbalance (Preston and Leng 1987) suggests that native forages are able to supply only a low level of ruminant production in this country. Experimental results report that local Kedah–Kelantan cattle and their crossbreds grazing on native grasses under farmers' conditions gained only 170–200 g/day (Dablan and Ariff 1987).

However, local grasses and legumes sampled under oil palms were shown to be of better quality, probably benefiting from the large amount of fertilizers regularly applied to the palms. The average nitrogen and energy contents of these native forages are reported to be comparable to those recorded for the introduced tropical grasses and legumes (Table 1). It has been reported that draught buffalo which grazed on these native grasses consumed up to 1.6 times the amount of metabolisable energy required for maintenance (Liang et al. 1989) and gained 0.3–0.5 kg/day depending on their age (Liang and Rahman 1985). Supplementary feeding of palm kernel cake has not improved body weight gain of these animals, probably because of the abundant supply of good quality forages available to the animals under such situations (Liang and Rahman 1985).

Supplementary feeding for meat and draught animals

In almost all cases, no supplementary feeds are offered to ruminant animals kept for meat or draught, even during the dry seasons because of cost factors. Small quantities of cut forages may in exceptional cases be offered to some

animals in certain parts of the country where the farmers are known to be more caring of their animals. The cut forages mainly consist of native grasses and shrubs of various species and qualities.

Table 1. Nitrogen (N) content, DM digestibility (DMD) and metabolisable energy (ME) of some common forages under different production systems in Malaysia.

Forage production system	N (%)	DMD (%)	ME (MJ/kg DM)
(a) Under plantation			
Grasses	1.58	47.61	7.13
Legumes	3.07	47.80	7.17
Ferns	1.96	35.60	5.34
Edible dicotyledons	2.81	55.60	8.34
(b) Legume–Guinea pasture			
Guinea	1.60	52.62	7.80
Legumes	3.55	40.33	6.01
Weeds	1.97	48.04	7.13
(c) N-fertilised pasture			
MARDI Digit grass	2.61	59.40	8.78
Guinea grass	2.54	52.62	7.80
Signal grass	2.39	56.09	8.31

Source: Liang et al. 1989.

Asystasia intrusa, a herbaceous dicotyledon plant widely found under shade, deserves special mention here. This plant, commonly referred to as a weed in the plantations, has been shown to be excellent feed for ruminant animals; highly digestible (DM digestibility = 62%) and containing up to 20% crude protein (Mokhtar and Wong 1988). Asystasia thus serves as a good source of protein supplement to improve the poor nutritional status of ruminant animals feeding solely on native pastures. Although the amount of Asystasia used as cut forage and its effect on animal production under farmers' conditions is not known, field observations have shown that grazing cattle and buffaloes consume *Asystasia* readily. However, excessive consumption of Asystasia results in watery faeces and may occasionally cause digestive disorders such as bloat.

Leucaena, which contains up to 26.5% crude protein (Wong et al. 1989), is a leguminous plant that is used as a supplementary feed for ruminants in some parts of the country. Good live weight gains were reported for cattle

supplemented with *Leucaena* under research conditions. These animals, however, had enlarged thyroids (Izham and Wan Hassan 1986). It has been suggested that urinary DHP (the active goitrogen, 3-hydroxy-4 (1H)-pyridone, a metabolic product of mimosine) of local cattle and goats consuming more than 50% *Leucaena* in the total diet may exceed the 0.1% toxic threshold, resulting in ill effects (Wong et al.1989). The results thus suggest that *Leucaena* is more suitable as a supplementary rather than as a sole feed for ruminants, at least until the technology for transferring DHP-degrading bacteria to ruminants to overcome *Leucaena* toxicity is successfully implemented under farm conditions.

Supplementary feeding for dairy animals

Supplementary feeding is more commonly practised by dairy farmers in this country than by other producers. This is because most dairy farms are situated near urban centres where forages are lacking. In addition, farmers can see an immediate increase in their milk yields and income when supplementary feeds are given to their milking cows.

Types of supplementary feeds given to dairy cattle and buffaloes differ from farm to farm depending on the background of the farmers and the availability of feeds in their respective vicinities. The traditional Indian farmers generally formulate their own concentrates using various ingredients, including wheat bran, wheat husk, soybean waste, copra cake and sesame cake, the choice depending on price and availability. Commercial dairy cattle pellets are widely used by the new dairy farmers because of convenience. Crude protein and gross energy content and degradation rates of some commonly used concentrates for local dairy cattle and buffaloes are presented in Table 2. The farmer's self-formulated concentrates as presented in Table 2 consist of wheat bran, wheat husk and sesame cake. The extremely high level of crude protein (34.9%) recorded in this feed sample is difficult to explain, and could be due to the high proportion of sesame cake. The high protein and energy (14.8 MJ/kg) concentrations as compared with the commercial feeds reflect the farmer's understanding in formulating a balanced feed to support the desired milk production of his lactating cows. The average daily milk yield, body weight changes and some milk parameters of the lactating cows of this particular traditional buffalo farmer are presented in Table 3.

Milk yield for various breeds of cattle (Local Indian Dairy, Friesian × Local Indian Dairy and Friesian) kept in Malaysia was reported to be 1520–2200 kg/cow/lactation with 2–8 kg supplementation/cow/day (Sivarajasingam et al. 1983). The report of Wong et al. (1986) was very informative in providing data to show that milk yield/cow/lactation of grazing Sahiwal × Friesian cows increased

by 1.6 and 1.9 times, respectively, when supplemented with 4–6 kg/head/day of concentrates. However, the reported feed conversion efficiencies of utilisation for the 4 and 6 kg supplementation (1.21 and 1.08, respectively), are higher than values theoretically possible. Profits based on per cow basis also increased significantly for cows supplemented with concentrates as compared with cows grazing on forages alone.

Table 2. Crude protein and gross energy contents and degradation rate of some commonly used concentrates by dairy cattle farmers in Malaysia.

	CCP-1[a]	CCP-2[a]	Farmer[b]
Crude protein (%)	17.76	17.67	34.85
Gross energy (MJ/kg)	11.46	15.07	14.80
DM degradation %			
6 hours	46.15	60.41	70.55
12 hours	56.92	67.05	84.41
24 hours	60.79	67.81	89.14
48 hours	71.11	72.88	89.30

[a] CCP-1, CCP-2 = Commercial cattle pellet from 2 different sources.
[b] Farmer   = Farmer's self formulation for Murrah buffaloes.
Source: Liang et al. 1992, and unpublished data.

Table 3. Average bodyweight changes and some milk parameters of Murrah buffalo cows from second to fifth months under farmers' conditions in Malaysia.

Parameters	Average of 12 cows
Initial weight (kg)	580 (26)[a]
Final weight (kg)	561 (26)
Wt. change (kg/day)	−0.22 (.17)
Milk yield (kg/day)	9.38 (1.6)
Milk decline (kg/week)	−0.13 (.10)
% milk fat	5.89 (0.9)
% protein	5.25 (0.5)
% lactose	3.71 (0.3)

[a] Figures in brackets represent standard error
Source: Liang et al. 1992

Use of agro-industrial by-products

Fattening of cattle and buffalo using agro-industrial by-products especially from the oil palm industry, has gained some popularity in the last decade. The most widely used oil palm by-product is palm kernel cake and its chemical composition and energy contents are presented in Table 4. Most medium and large feedlot operations usually depend solely on palm kernel cake although sometimes substituted by other feed ingredients because of price. In some smaller operations, animals are kept under a semi-intensive system whereby the animals are allowed to graze during part of the day and supplemented with palm kernel cake at night in the shed. Weight gains of local Kedah–Kelantan cattle fed on palm kernel cake and related agro-industrial wastes under farmers' conditions were reported to be 0.4–0.6 kg/day (Samsuddin et al. 1987). However, better weight gain of up to 1 kg/day can be expected from crossbred cattle fed palm kernel cake under intensive feedlot conditions.

Due to its high copper content, high levels of palm kernel cake in feed can result in copper toxicity, in severe cases resulting in death in sheep. However, copper toxicity in sheep fed a high proportion of palm kernel cake can be prevented by supplementation of zinc and/or molybdate to the diet of the sheep (Wan Mohamad et al. 1989; Hair-Bejo and Ubmon 1992). No such detrimental effect was reported for cattle, although there is unreported evidence to show that the rumen walls of cattle fed solely on palm kernel cake were less developed than those fed with roughage diets.

Table 4. Chemical composition (% DM basis) and energy contents (MJ/kg) of palm kernel cake.

Crude protein	16.6
Crude fibre	25.9
Ether extract	3.5
Nitrogen free extract	49.4
Ash	4.5
Gross energy	18.1
Metabolisable energy	12.9

Sources: Wong et al. 1987a; Miyashige et al. 1987.

Recent experimental results from MARDI (J.B.Liang, unpublished data) indicate that some buffalo fed solely on palm kernel cake often went off-feed for several days without showing any clinical symptoms of disease. Cattle in the same feeding trial were not affected. The affected buffalo were suspected of suffering from gastrointestinal disorders. More research, however, is needed to confirm the above occurrence.

Conclusion

Because of the poor quality natural feed supply, supplementary feeding provides a sound method to improve ruminant production in tropical countries such as Malaysia. The effect could be due to provision of extra nutrient and/or correction of nutrient imbalance of the animals concerned. However, unless the farmers are convinced that supplementary feeding is simple and cost effective, bringing in substantial increases in their products (meat, draught or milk), this practice will not be readily accepted. Livestock scientists should, therefore, not only measure the product's output in isolation when carrying out their research, but should work together with extension personnel and farmers to formulate acceptable feeding systems under their respective production environments.

Acknowledgment

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Supplementary Feeding of Australian Ruminants

J. HOGAN

The Australian ruminant population comprises about 150 million sheep, 24 million beef cattle, 2 million dairy cattle and small numbers of goats, deer and largely feral camels and buffalo. Most of the sheep are Merino or Merino Cross animals and 75% of the wool sold is of 24 micrometre diameter or less (Turner et al. 1986). Many of the remainder produce fat lambs and a small but increasing part of the national flock produces carpet wools.

About half the beef cattle are *Bos taurus* derived from British and European breeds and their crosses. The other half, located in northern Australia are *B. indicus* or crosses with European breeds. The *B. indicus* cattle were introduced to Australia from USA. but originated as Brahman cattle in India.

The dairy herd is largely Friesian but there are significant numbers of Jersey, Guernsey and Ayrshire cattle.

Climate and Pasture Regions

Australia is the flattest and driest of continents and on most days of the year in most of Australia evaporation exceeds precipitation. The climate can be subdivided into summer rainfall, November–March in the north; winter rainfall, March–September in the south; and areas of general rainfall between the two. The east coast, which abuts a mountain range of an average 500–700 m height, receives the most rain whereas the centre of the continent with low reliability of rain and generally low total rainfall varies from arid where little vegetation grows to semi-arid where sufficient pasture and browse species can grow to provide feed for a sparse ruminant population.

The factors affecting pasture growth, including solar radiation and the temperature and moisture content of soil, have been incorporated into models based on rainfall, light and air temperature (e.g. Fitzpatrick and Nix 1970, Jones et al. 1990). These models indicate that in most areas of Australia soil moisture is the main determinant of pasture growth. Because of this most ruminants in Australia subsist for part of the year on dead plant material. In the Mediterranean climate of southern Australia this occurs in the November–February summer period whereas in the subtropical and tropical northern areas the dry season occurs in the winter months of July–October.

In animal production terms the major differences between the two regions during the dry season are the productivity of the animals following adaptation to the region; and the nutritional value of the dead feed.

Cattle in southern Australia, almost entirely of British and European origin, are well adapted to the environment and to the pasture species developed in similar temperate and Mediterranean environments in the northern hemisphere. By contrast, the need for heat tolerance and tick resistance in cattle in the northern Australian environment has required the development of cattle with Brahman blood, but the price of adaptation is reduced potential productivity compared with European breeds. In addition the more vascular nature of the tropical grasses, the generally low soil fertility that reduces uptake of minerals by plants, and the dilution of those minerals in the very large masses of organic matter synthesised by the plant all combine to present dead grass of low nutritional value in the dry season. The extent of deficiency of nutrients, and the need for supplementary feeding, thus tend to be greater for tropical than temperate grasses.

Animal production enterprises

The nature of an animal production enterprise is determined by climate, soil type and fertility, and proximity to markets.

The first two factors determine whether the area is suitable for crops or livestock or both, the intensity of animal production, and the value of land. Hence the livestock industry represents three types of activity, intensive production seeking high value per unit product, extensive or pastoral production with lower value placed on the product, and mixed production with income partly derived from cropping and with crop by-products fed to livestock. Per unit area of land, crop production is generally more profitable than livestock raising and is the preferred system of land use where possible. Intensive animal production is largely confined to the more favoured southern regions not suited topographically for cropping whereas the pastoral system occupies those areas towards the centre and the north of the country that are climatically unsuitable for crops.

Australian animal production aims to satisfy the needs of a relatively small domestic market but in many ways is orientated towards export. The sheep industry exports annually about 150 000 t of mutton and lamb (Thomas 1986). In recent years the annual export of several million live sheep has had a major impact on the sheep industry and has led to the need for extensive research into diet composition, heat stress and environmental stresses in sheep travelling at high population density for 20–30 days aboard ship. Beef exports amount to about 350 000 t year.

The principal markets for meat are USA, Japan, Korea and Taiwan. Much of the meat sent to USA is of processing grade and is obtained from older animals with low levels of fat. Exports to Japan contain processing meats but also meat from younger animals and increasingly beef from animals fattened in feedlots. As a broad generalisation the higher quality products are grown in the region of intensive animal production and to some extent in the crop-producing areas whereas the pastoral zone produces older animals of much lower annual weight gain. The nature of the enterprise determines the policy adopted for supplementary feeding.

The use of non-protein nitrogen and protein in different regions of Australia is intended generally for either survival of the animal or for increased production and differs in application between sheep, dairy cattle, and beef cattle.

Supplementation for Survival

Survival of an animal is threatened during any extended period of nutritional deficiency; in Australia these periods occur annually for several months each year during the dry season and are considered part of the normal animal production system. However during the past century the country has experienced at least eight major and many minor extensions of the dry season into droughts and various management strategies have been developed for these situations (Briggs 1968) including early weaning and supplementary feeding of the lamb and survival feeding of adult sheep.

Sheep

The survival of fine wool lambs in the Mediterranean zone depends on attainment of a live weight between 25 and 30 kg by the time of year that the pastures die through lack of soil moisture. There is need to supplement lambs that have not attained survival weight and increasingly this is being achieved by grazing mature crops of grain legumes such as lupins (*Lupinus angustifolius*), field beans (*Vicia faba*) or field peas (*Pisum sativum*) (Hynd and Allden 1986) or even by grazing the postharvest stubble of such crops provided a reasonable quantity of grain has fallen from the ear before or during harvest. Alternatively, proprietary supplements containing a high proportion of grain plus oil seed meals and minerals may be fed. The inclusion of urea at 10–20 g/kg is commonly practised with diets containing high proportions of grain.

The strategies developed for feeding sheep during a dry season that extends into drought are based on a knowledge of ME requirements for different classes of sheep (Briggs 1968, Table 1). In a total drought with little or no forage available sheep confined to yards to reduce the energy costs of movement can be sustained for long periods on a grain diet, generally offered twice weekly to

ensure a more equal distribution to all sheep in a group. The grain is usually supplemented with calcium carbonate at 15 g/kg and sometimes with 10 g/kg urea. However the adhesion of urea to grain may be unsatisfactory and fatalities associated with excessive intakes of urea have occurred. The principles of survival feeding and the practical application of those principles are now firmly established (e.g. Lloyd Davies et al. 1988).

Table 1. Weekly feed requirements (kg) for drought maintenance of sheep.

Class of sheep	Oats	Wheat	Prime hay
Weaners	2.3	1.9	3.4
Adult dry	3.0	2.5	4.5
Ewes (6 wks before lambing)	3.8	3.1	5.7
Ewes (lactating)	5.3	4.4	7.9

Source: Briggs 1968

Where reasonable amounts of plant material are available, supplementary feeding with lower amounts of grain or of legume seed is frequently practiced. The aim in this strategy is to maximise the amount of nutrient obtained from the plant material. In other regions with forests of edible browse plants such as *Acacia* spp., available herbs and forbs are augmented with the leaves of these trees even though such leaves may possess substantial levels of tannins.

Dairy cattle

Dairy production occurs in regions less subjected to drought. If survival of such cattle is at risk, lactation is interrupted and cattle are fed in a similar manner to beef cattle.

Beef cattle

Survival of beef cattle during a drought appears to be determined by the variables, class and age of the animal, body condition, level of feed intake, length of time on the 'drought' ration, and environmental factors (Morris 1968). The classes of cattle most at risk in a drought are pregnant and lactating cows, especially young cows, and calves. The segregation and preferential supply of supplements to these animals forms a critical part of the management of cattle in a drought (Fordyce et al. 1990).

From the observations of Morris (1968) it has been calculated that the loss of 1 kg weight is equivalent to an energy deficit of approximately 28–32 MJ ME (Teleni and Hogan 1989). The rate of weight loss in drought affected cattle can

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thus be used to estimate energy deficit and provide the basis for calculating the amounts of energy needed as a supplement to reduce the rate of weight loss to within desired limits. It is assumed that the composition of weight loss is similar to that of weight gain (SCA 1990). If so, the Brahman × Shorthorn cow of 300 kg might be expected to lose 170 g protein/kg weight loss (Siebert and Field 1975). In attempting to prevent 1 kg weight loss the ration would need to supply 205 g absorbed amino acids (Lindsay and Hogan 1987).

The major use of non-protein nitrogen in Australia occurs in the north within about 200 km of the sugar producing areas on the coast. This region supplies the cattle producer with molasses, an energy supplement that is of relatively low cost and readily transported. Molasses provides about 0.5 kg sucrose/kg, (Wythes et al. 1978), a small amount of N equivalent to about 3% crude protein, and useful quantities of minerals (Stewart 1976). However additional N is required for the rumen microbes fermenting this quantity of sucrose and this is provided as 30 g urea/kg molasses. In practice a further 50 g urea/kg molasses is often added to suppress appetite. The molasses + 8% urea (M8U) mix supplies about 7.5 MJ ME/kg. Thorough mixing of urea and molasses is required to prevent metabolic disorders arising from fermentation in the rumen of sugar to lactic acid or of urea to ammonia and roughage is desirable to stimulate propulsive movements of the rumen. Intake of this mixture alone appears to be adequate for the survival of those cattle with the lowest nutritional requirements, steers and non-pregnant, non-lactating cows and, for a time, for the other classes of cattle with higher nutritional requirements (Wythes and Ernst 1984). However pregnant cows are forced to store energy and protein in the developing foetus and a cow in late pregnancy merely maintaining live weight must be reducing maternal body weight. Gulbransen (1984) concluded that molasses/urea alone cannot provide the protein needed to produce satisfactory performance by pregnant or lactating females or by calves and emphasised the need in ensuring the survival of the pregnant cow, and the post natal survival of the developing foetus, to supplement molasses with sources of intestinally-released amino acids such as cottonseed or meat meals.

Supplementation for Production

Sheep

Production of wool is achieved almost entirely by the grazing of sheep on pasture. Apart from stud rams and some survival feeding, there is little stall feeding of fine wool sheep. The major use of supplements arises from the need to maintain the strength of the wool fibre thought to be reduced by nutritional and environmental stresses late in the summer in Mediterranean regions. Wool

growth is largely controlled, apart from genetic factors, by the supply of amino acids, and grain legumes are the preferred supplementary feed.

Extensive studies of the stimulation of ovulation in Merino ewes by supplementation with lupins for as little as 6 days (Lindsay 1976) have led to the wider use of grain legumes to increase nutritional status of the ewe and hence reproduction rate.

Sheep exported by ship overseas were at first fed high-grain pelleted diets at levels intended to maintain weight. However over-eating by some sheep caused deaths associated with excessive production of lactic acid in the rumen or with toxicity arising from the excessive growth of *Salmonella typhimurium* in the small intestine. Modifications to the diet now include the replacement of cereal grain with legume grain and increased content of roughage.

Dairy cattle

Supplementary feeding of dairy cows including the use of protein concentrates depends on the level of production desired, an attribute affected by the cost of land and the value of milk, and the nature and cost of dietary components. The nutrients used by Australian dairy cows are derived as far as possible from pasture or forage crops and supplements are supplied to augment but not substantially replace those from pasture. For this reason, production per beast, though exceeding on average 3000 L/lactation with the temperate pastures of southern Australia is low in comparison with production targets set in more intensive production systems elsewhere. Average production is about 2000 L/lactation in the northern regions of the milk producing areas where the cattle experience greater environmental stress but also where the pasture is based on tropical grasses of lower nutritional value.

Estimates made in Australia of efficiency of conversion of ME to milk conform to those made elsewhere (SCA 1990). The formulation of dairy rations commences with the assessment of the quality and probable supply of energy from the available pasture, determines the energy needed to supply a given quantity of milk and the balance of protein and minerals required. The energy supply is derived largely from legume hays, silage from cereal or summer forage crops, and cereal grains. The main sources of protein are mill offal and oil seed concentrates. Increasing interest is being shown in the use of protein treated with formaldehyde to prevent breakdown in the rumen (Hamilton et al. 1992). Commercially treated sunflower meal with about 60–70% of the protein protected against fermentation increases the yield of milk by perhaps 1 kg/day. A small proportion of the 'crude protein' is generally supplied as urea and this augments the ammonia released in the rumen from the more readily fermentable protein components of the ration. Dairy production is unlikely to be

limited through deficiency of ammonia in the rumen because the producer generally attempts to supply high levels of dietary protein either as supplements or in the form of irrigated, nitrogen-fertilised forage crops and pastures. In fact the converse may occur because generally inconclusive investigations have been made of possible relationships between high levels of soluble nitrogen in such feeds and various disorders in dairy cows including low milk production and reproductive problems ranging from failure to conceive to increased incidence of abortion (Norton et al. 1987).

Beef cattle

Beef cattle receive relatively little supplementary feeding during their lifetime. As indicated earlier most supplementation occurs in the regions of more intensive production and ultimately in feedlots. However there is increasing interest in all areas of the industry in changed management practices leading to improved efficiency of cattle production and strategic supplementary feeding is seen as one management option towards this goal. The classes of animals involved include the cow in late pregnancy, the early-weaned calf and its dam, the underweight bullock, and cattle of all classes in feed lots and the supplementation of these animals is regarded as part of whole property management. The most important biological factor in maintaining a viable cattle production system is the nine-month gestation period which permits only three months for conception, post-calving, if the production of one calf per year is to be maintained. Maiden heifers generally first conceive on attaining a weight of 250–300 kg which occurs in the first year in temperate regions but in the second or third year in the north. In much of Australia which experiences a pronounced dry season with zero pasture growth, the cow subsists on mature dead forage during late pregnancy and early lactation. The generally negative nutrient balance during this period is reflected in weight loss and an extended period of post-partum anoestrus. The severity of this problem and its duration are affected by the live weight/body condition of the cow and the quantity and composition of milk produced in relation to nutrient intake. It is a truism that the secretion of increased amounts of nutrients in milk accelerates weight loss in the dam and weight gain in the calf, and that the severity of weight loss in the cow regulates the length of the post-partum interval. Recent research indicating reduced development of ovarian follicles in undernourished cows in late pregnancy has led to the development of 'spike' feeding, the provision of 1 kg protein meal daily for six weeks in late pregnancy which improves ovarian development and conception rates at mating 4 months later (G. Fordyce pers. comm.). Supplementary feeding pre- and post-partum has become accepted practice to maintain reproductive performance in European breeds of beef cattle. It is less

effective in the Brahman strain imported into Australia, possibly because these cattle appear to behave metabolically more as a dairy breed than a beef breed (Hunter and Magner 1988).

Supplementation of Brahman × Shorthorn crossbred cows pre-partum and pre- and post-partum improved the birth weight and growth rate of the calf but made no improvement to anoestrus (McSweeney et al. 1993a,b). Weaning of the calf at two months of age, or 50–60 kg in weight, brought a prompt return to oestrus in this type of cow weighing more than 370 kg (Schlink et al. 1988). The effect of weaning on anoestrus diminished with the weight/body condition of the cow between 370 and 290 kg, but the rate of return to oestrus was improved by the provision of 1 kg/day energy or protein concentrates for six weeks (Schlink et al. 1992).

Calf nutrition. The nutrition of the young calf changed from milk to forage diets has been extensively studied in the temperate zone, and this information is applied by Australian producers in that zone. Until recently little direct information was available for tropically adapted cattle. However the requirements for nutrients of the Brahman–Shorthorn calf from birth to 150 kg appear to follow the same principles as those pertaining to calves of the European breeds (A.C. Schlink, pers. comm.). Supplementation of these calves is now based on knowledge of their capacity to eat roughage, on any nutritional deficits that may occur in consequence and on the amounts of locally available supplements needed to meet these deficits. In general terms, with forages of relatively low ME and protein content and with young growing animals showing high requirements for both, supplements are designed to supply energy after ensuring adequacy of protein. Pasture, especially during the wet season, appears capable of supporting adequate growth of weaned calves provided their needs for protein are met (Schlink et al. 1994). If rations are to be provided for complete hand feeding, molasses represents the cheapest source of energy concentrate, but on a dry matter basis provides only about half the energy of maize grain and supports significantly lower weight gain. Least cost rations can be prepared from maize, molasses and protein meal to permit desired growth rates between about 0.2 and 0.6 kg/day (A.C. Schlink, pers. comm.). Supplementary feeding usually continues until calf weight approaches 140 kg when it is believed that the calf can subsist on available pasture. There is some evidence though that failure of bulls and heifers to continue growing between 6 and 12 months of age incurs penalties in the extent of reproductive development the following year and there may be need for more extensive supplementation of these animals (K.W. Entwistle, pers. comm.).

The extent to which supplementary feeding is adopted depends on the perception by the producer of the economic advantages of the practice. Where

cattle are segregated and the animals in most need of supplements can be preferentially fed, producers may more readily accept the technology. However in pastoral regions with little control over the cattle, and hence where the whole group must be supplemented to provide benefits to only some members economic benefits are less easy to demonstrate and acceptance by producers is much slower.

Nutrition of adult cattle. Cattle in the areas of more intensive production tend to be marketed at all times of year and are often prepared or 'finished' for market by the provision of supplements. These generally contain a high proportion of cereal grain with little need for protein concentrates if the pasture is of high quality but cereal grain is replaced with legume grain or whole cottonseed if favoured by price.

Cattle in the pastoral areas tend to be sold when they attain a desired weight during or at the end of the pasture growing season. Those animals that do not reach the target weight may be sold as lightweight bullocks, held on the property to grow for another year, or supplemented to bring them quickly to target weight. The extent and success of the latter practice depends on the quality of the available pasture, the cost of supplements and the perception by the producer of the economic benefits accruing from earlier sale.

This process extends into feedlotting in which cattle are supplemented with grain and protein concentrates for 100–300 days to prepare them for a particular market. Young animals are preferred to assist in the production of tender meat. Tenderness is equated with marbling, that is the distribution of intra-muscular fat, and the lotfeeding process is designed to achieve a desired level of marbling, without the deposition of excessive amounts of extra-muscular fat. Lighter weight cattle are fattened for the shorter periods for the domestic market whereas heavier weight carcasses are produced for export, principally to Japan. However to keep feedlotting in perspective, of 200 000 t of beef shipped to Japan in 1990, only about 16% was grain fed.

Conclusion

The use of supplements in the Australian animal production system is aimed at ensuring survival of the animal or improving the quality and quantity of product. The ruminant industries which receive virtually no financial subsidies, and which must compete in markets remote from Australia, have had to become highly cost effective. To do so they have had to set production goals realistic in relation to the pasture resource available and to devise low cost strategies for supplementary feeding when the nutrients derived from pasture prove inadequate to meet the production goal or even to sustain the life of the animal.

Much has been achieved in ration formulation by the application of research findings into the energy and protein systems. However much remains to be learned as population pressures increase the demand for animal products worldwide and as competition for land pushes the ruminant industry into areas of lowered productivity. The continuing challenge to scientists involved in animal production is to sustain outputs while minimising inputs.

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