PASTURE UTILISATION:

APPLYING PRINCIPLES OF RUMINANT NUTRITION TO PASTURE UTILISATION

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Abstract: Increased efficiency of livestock production from grazed pastures is a common goal for Australian researchers and producers. Achieving this goal can be made easier if we have sound knowledge of the nutrient requirements of grazing animals at each stage of their production. Such knowledge includes an appreciation of the role played by micro-organisms in the reticulo-rumen in determining the flow of nutrients to the animal itself. It also involves an understanding of the major factors which influence intake of forage by grazing ruminants and the subsequent digestion of the plant material in various sections of the digestive tract. Combining information on the nutrient requirements of various classes of stock with the nutrients they are likely to derive from pastures, allows us to predict the level of production that will be attained. It should also allow feeding management strategies to be developed to overcome deficiencies in the intake or utilisation of the base pasture. Ultimately we can work towards minimizing the proportion of feed nutrients required for maintenance, and increase the nutrients going into saleable products.

INTRODUCTION

Domesticated ruminants such as sheep, cattle, goats and deer are kept for their production of milk, meat, fibre, hides, antler or a combination (Table 1). In addition buffaloes and cattle provide traction power in some countries (Table 1). In most cases the product is formed from nutrients consumed in excess of daily maintenance requirements. Thus to increase efficiency of production we need to know how maintenance requirements are determined, and how they vary throughout the year in relation to changes in the physiology of the animal and the processes involved in converting excess nutrients to commercial products. This is a particularly difficult assignment in countries like Australia, where nutrients are mainly derived from pastures which vary seasonally in quantity and quality, and where pasture quality largely determines nutrient intake and productivity grazing animals .

Table 1: Products (or outputs) of a range of grazing livestock (after Spedding 1975).

Species	Milk	Fibre	Meat	Fert.	Hide	Wool	Work	Transport
Cattle: *B.taurus*	+	+	+	+	+	-	-	-
- *B.indicus*	+	+	+	+	+	-	+	+
Sheep	+	+	+	+	+	+	-	-
Goat	+	+	+	+	+	-	-	-
Horse	+	+	+	-	+	-	+	+
Buffalo	+	-	+	-	+	-	+	+
Alpaca	-	+	+	-	-	-	-	-
Yak	+	+	+	-	+	-	-	+
Camel	+	+	+	+	+	-	+	+

Ruminant livestock are generally grazed on pastures to produce saleable products and so ensure an adequate income over a prolonged period. The challenge is always present to utilise the pasture as efficiently as possible to maximise income while maintaining basic environmental resources. To do this the owner/manager needs to understand the nutrient requirements of ruminant livestock for maintenance and various production processes, particularly where the level or type of nutrient intake may affect product quality. At the same time there is a need to understand the nutrients pasture can provide to livestock and how these may vary with species, season, grazing conditions and pasture management.

While the basic management strategy for all productive livestock is to match requirements with the nutrients provided in the ration, this is most difficult to achieve in practice because of the limitation feed quality can place on voluntary feed intake of grazing animals. Species composition, community structure and distribution of forage throughout the year will affect the quality of a pasture consumed by livestock. An appreciation of the factors influencing intake allows a manager to determine the preferable nutritional management strategy: either one based on grazing management of pastures or one involving supplementary feeding in conjunction with pasture grazing.

The purpose of this paper is to consider some aspects of the application of knowledge on ruminant nutrition to increasing the efficiency of pasture utilisation. This subject can be approached by considering some of the main factors involved in answering a series of questions :

1. *What nutrients does a ruminant need ?*
   - for maintenance
   - for production

2. *How does a ruminant derive nutrients from its feed, particularly forage it consumes while grazing ?*
   - factors which affect intake
   - factors associated with digestion
   - factors related to absorption and metabolism

3. *How can the nutrients provided by forage be modified ? How can utilisation be modified ?*
   - grazing management
   - supplementary feeding

REQUIREMENTS FOR NUTRIENTS

There are two ways of considering the requirements of ruminant animals. The first is to consider the need for specific classes of nutrients: protein, energy, minerals and vitamins. The second way is to consider overall needs in relationship to the fundamental requirement for maintenance. For ruminants both approaches must take account of the fact that we are supplying nutrients for two distinct systems: the *rumen microbial population* and the *ruminant animal* itself.

Maintenance nutrient requirements

In the context of nutritional management of livestock the term maintenance refers to that state when animals do not change their liveweight from one day to the next. Taken to a greater degree of precision, it means that they keep a constant weight and body condition, neither gaining nor losing the total amount of protein, energy or minerals in their body tissues.

In general, a forage of sufficient quality to provide the daily energy needs to maintain a constant liveweight will also provide sufficient protein and minerals for daily maintenance of body functions. For this reason, emphasis is generally placed on the animal's need for maintenance energy. Such energy is used to maintain constant body temperature, whether by movement or shivering in cold weather, or panting or sweating in hot weather. It also includes the energy expended in breathing, food digestion, blood transport of absorbed nutrients, basic metabolic transformations, and the replacement of protein or minerals used up in any of these processes. The daily requirement for energy, protein and individual minerals is dependent on liveweight, ambient temperature, distance walked (in obtaining nutrients, water or shade), and the nutritive value and potential digestibility of the forage available.

Protein is required for maintenance because even at constant liveweight, amino acids from the blood are used for protein turnover in the body and for continuing growth of wool, hair, horn and antler. For most livestock, maintenance requirements are modest, but this changes markedly when meat or milk are being produced. Milk from dairy cattle generally has a protein content of 3-4%, and that from sheep 5%. When protein is low in the diet, protein percentage in the milk may decline and total milk volume will be reduced.

Lean meat, or muscle, requires large quantities of dietary protein and correspondingly a high proportion of protein (or more correctly amino acids : the building blocks of proteins) in the nutrients absorbed by animals after digestion of ingested forage. In young growing sheep and cattle, an optimum protein percentage in the ration is often difficult to achieve from pasture and may only be approached if the animals are offered a high protein supplement in conjunction with the pasture. Alternatively, they may be placed in a feedlot where the control of ration ensures uniformity of product, optimum efficiency of feed conversion

Species	Fat %	Lean %
Fat beef	35.0	50.0
Lean beef	25.0	55.0
Pig	38.0	50.0
Venison	2.0	76.0
Buffalo	3.0	75.0

quality carcass production, and the deposition of fat is a metabolically inefficient process.

Acetic acid is generally in the highest proportion (60-70%), particularly in low quality/high fibre rations. Although acetic acid is less efficiently converted to energy than propionic acid, it still contributes the most energy to ruminants and has the added attribute of being a direct precursor of milk fat. The well-known low-fat syndrome of lactating dairy cows can most easily be overcome by the provision of roughage in the ration because more acetic acid than propionic acid will be produced once the roughage is ingested.

Most of the minerals and vitamins important to grazing ruminants are provided in adequate amounts by forages. The essential major elements (calcium, magnesium, phosphorus, potassium, sodium, sulphur) and trace (or minor) elements (cobalt. copper, fluorine, iodine, iron, manganese, molybdenum, selenium, zinc) are nearly always adequate in forage. Elements such as cobalt, copper, iodine, molybdenum and selenium can be deficient , particularly if they are naturally low in concentration or chemically unavailable in the soil. Some elements interact markedly with others, such as copper, molybdenum and sulphur. Some plants have high concentrations of copper, fluorine or sodium and these can have deleterious effects on ruminant health. In most cases mineral deficiencies or imbalances can be corrected by dosing with appropriate drenches or mineral-impregnated 'bullets', offering blocks or licks containing the required mineral, or by applying suitable fertilizers to the pastures.

Vitamins are generally not restrictive in ruminant rations.

Vitamin D is always adequate for ruminants grazing under the sunlight conditions which prevail in Australia. There is little risk of impairment to calcium or phosphorus absorption from the digestive tract due

... potential growth rates are the norm for finishing weaners, particularly under Australian grazing conditions.

The other highly important nutrient is energy. To a non-ruminant animal the major energy source to be metabolised is glucose and this is provided by the breakdown of sugars and starches. As mammals do not produce cellulase enzyme, monogastrics cannot themselves break down cellulose-like compounds and therefore highly fibrous feeds are not digested, except for some hind-gut fermentation which only becomes a significant contributor to overall nutrition in herbivorous species such as horses.

Ruminants also require glucose, but only a relatively small amount is absorbed from the small intestine as a result of the acid/enzymatic digestion (breakdown) in the stomach/small intestine of dietary sugars and starches which pass through the reticulo-rumen unchanged, or from polysaccharides derived from the microbial biomass.

A major source of energy for ruminants is provided as a by-product of the microbial-induced fermentation of carbohydrates in the reticulo-rumen. In breaking down cellulose and hemicellulose, the enzymes produced by the micro-organisms form volatile fatty acids (acetic, propionic and butyric), carbon dioxide and methane. These volatile fatty acids are absorbed through the rumen wall, although butyric acid is mostly metabolised in the wall to give the energy necessary for the active transport of other nutrients. The other volatile fatty acids continue through to the blood stream and are carried to the liver where they may be metabolised.

Propionic acid is important because it is more efficiently converted to other forms of energy than acetic acid, and is in fact an immediate precursor of glucose. The proportion of propionic acid absorbed from the rumen increases with rations which contain a higher proportion of readily soluble carbohydrates, such as sugars and starches from grain rations. Hence a high proportion of grain in a production ration can lead to a higher efficiency of growth and fattening. Not that fattening is desirable in domestic livestock such as beef cattle (Table 2) as their potential to lay down fat after maturity is above that desirable for to vitamin D deficiency.

Vitamin A only becomes deficient in animals when access to green feed is restricted for long periods (say six months). Vitamin A deficiency mainly affects the growth of young stock and the fertility of rams and bulls.

Vitamin B is synthesized by rumen micro-organisms and only becomes deficient when cobalt is deficient in the diet. Cobalt can readily be supplied as a cobalt 'bullet' administered to the animal, a cobalt-drench, or the application of cobalt-fortified fertiliser to the pasture.

Nutrients required for production of meat, milk, fibre, and antler

Protein is the basis of muscle (or in production terms - lean meat), as well as being the basis of most essential body organs. The requirement for protein increases as the metabolisable energy content (closely related to digestibility) of the ration increases. Also, at any given sheep or cattle liveweight, the protein requirement increases as growth rate, stage of pregnancy, or level of lactation yield increases (Egan and Walker, 1975). Protein is the major ingredient in fibres such as wool and an important component of milk. Thus, ingestion and absorption of amino acids from which body proteins will be formed is an important aspect of the nutritional management of livestock.

However, supplementary proteins are expensive, particularly feed proteins of animal origin such as fishmeal and meatmeal, and to a lesser extent plant proteins such as soybean meal, cottonseed meal and rapeseed meal. To reduce costs, urea is often used to provide up to 30% of the supplementary nitrogen, but it must be carefully managed to minimize the chance of urea poisoning.

Production processes must be considered as consisting of two parts. Each day maintenance requirements must be met, then nutrients in excess of maintenance will be converted to a product or stored as fat. The efficiency of conversion increases as intake rises above the maintenance level and is probably best at three or more multiples of maintenance (McDowell, 1975). However, for ruminants, an intake of three times maintenance would only occur when dry matter digestibility exceeds 70% which will only be achieved for relatively short periods on high quality pasture.

A specific aspect of optimising efficiency of nutrient conversion to product is well illustrated by an example for lactating ewes (McDowell, 1975). If a flock has a lambing rate of 100% and the lambs grow at a moderate rate, the ewe will require 67% of the total energy intake for her maintenance. However, if the same ewes produce 150% of lambs, and the lambs grow rapidly, the ewe's requirements for maintenance will only represent 45% of the total energy intake. Similarly, Hunter *et al.* (1993) have indicated that steers growing to 550 kg at rates of 100, 150 or 200 kg/ year will use 80, 62 and 49%, respectively, of their total intake for maintenance. Clearly the faster growing steers will be much more efficient in converting ingested energy to saleable product.

If intake of nutrients is below optimum requirements, the output of product may be reduced, but not cease altogether provided the animal has body reserves to make up the deficit. That is, maintenance plus production requirements may not be met by the daily intake of a high production animal. For example, a dairy cow with a high production potential may lose weight by continuing to produce high volumes of milk even when absorbed nutrients are limiting, either through poor quality forage or often because she cannot consume enough regardless of quality.

In summary, green feed generally contains adequate levels of protein, readily digestible carbohydrates, minerals and vitamins. Some species such as lucerne and chicory may have elevated levels of important minerals such as phosphorus and sulphur. As plants mature their protein and soluble carbohydrate proportions decline and the proportions of lignin and slowly digested carbohydrates increase. The decline in digestibility associated with an increase in lignin, results in an inverse relationship with intake. Mature fibrous roughage has to stay in the rumen longer for adequate breakdown of particle size, and hence rate of intake must decline. Thus, not only does the proportion of material digested decrease, but the overall intake declines at the same time, and the total digestible nutrients can decline quite dramatically. This concept is well illustrated in the example given by Weston and Hogan (1986) as shown in Table 3. Their data clearly indicates the cumulative effects of low

Table 3: Nutritive value attributes of clover (low fibre) and grasses with low, medium and high fibre content (adapted form Weston and Hogan, 1986).

	Grass			Clover
	Low fibre	Medium fibre	High fibre	Low fibre
Cell wall fibre[1]	43	56	67	36
Lignin[1]	3	4	6	5
Crude protein[1]	23	15	7	23
Feed intake[2]	75	65	51	85
Acetic acid[3]	230	220	180	240
Propionic acid[3]	90	75	65	80
Fibre digestion[3]	370	394	314	286
Protein digestion[4]	167	120	84	151
Net energy for:				
- maintenance	8.20	7.32	5.60	7.90
- production	5.73	4.77	3.14	5.44

Notes: [1](%); [2](g/kg $LW^{0.75}$/D); [3](g/kg forage); [4](g/kg forage digested in intestines)

digestibility which result in a substantially lower net energy values for poor quality roughages.

FORAGE NUTRIENTS TO MEET ANIMAL REQUIREMENTS

Intake

The intake of pasture by a grazing animal is very difficult to determine and yet is fundamental in determining how productive the animal will be. The nutritive value of a pasture depends upon the amount ingested and the degree to which the ingested material is digested. As animals are often confronted with low quality roughage their intake of digestible nutrients can be severely restricted because there is a close association between overall digestibility and rate of digestibility in the rumen. A roughage which has a low digestibility will also be slowly digested in the rumen, thus long pieces of the material will take a relatively long time to be broken down to particles small enough (1-2 mm in sheep) to be washed out of the reticulo-rumen in digesta proceeding down the gastrointestinal tract.

The slow breakdown means that space is not available in the rumen and hence more roughage can only be consumed at a slow rate. That is, with a low quality roughage not only does the animal extract only a relatively small proportion as nutrients, but it does this from a smaller intake. Alternatively, with high quality (low fibre) roughage such as green pasture, the digestibility will be much higher and therefore the rate of digestion in the rumen will be greater, the emptying of the rumen faster, and hence the intake rate higher (Table 4).

As an indication of the nature of mature herbage (which certainly may not be as low in quality as crop stubbles) we can consider mature ryegrass. Pearce *et al.* (1987) reported an analysis of 23 ryegrass varieties. They found an average nitrogen value of 0.6% (*ie.* a crude protein content of only 3.75%), and an *in vitro* dry matter digestibility of only 44% (range: 30 to 57%). The low digestibility was associated with a high neutral detergent fibre (*ie.* cell wall) of 82%, of which 43% was hemicellulose, 48% cellulose and 7% lignin.

With fresh, young forage, in addition to higher intake level, more nutrients will be extracted from each unit of roughage ingested. Willoughby (1959) was one of the first Australian workers to emphasise the value of a small increment in digestibility to the overall nutritive value of a forage. There are several ways in which this concept may be important in plant breeding or in selecting species to be sown in a sward. Firstly, a species which produces green material several units higher in digestibility may be more valuable for livestock production than one of lower digestibility of green material, even if the second species produces a greater amount of dry matter per unit area. Secondly, a species which has a longer growing period, or at least a longer period during which it maintains a higher level of digestibility, may be more useful in grazing animal production than one which produces more in total but declines in digestibility rapidly at the end of its growing period. Finally, a plant species which retains a higher level of digestibility as mature roughage, even though that level is well below its earlier digestibility as green pasture,

Table 4: Voluntary feed intake (g DM/day) of pastures of varying fibre content by sheep of different ages, weights and reproductive status (after Weston and Hogan, 1986).

	Grass			Clover
	Low fibre	Medium fibre	High fibre	Low fibre
Adult sheep				
- Dry	1190	1030	800	1350
- Lactating	1750	1510	1110	1980
Young sheep				
- 20 kg	1040	900	660	1180
- 35 kg	1586	1370	1010	1790

could be more valuable than one which declines to a lower level of digestibility once it reaches maturity. Clearly the level of intake of a pasture will greatly influence the nutrients available to the grazing animal and its subsequent productivity.

Factors affecting intake

The level of feed intake by animals is directly related to their size. A single estimate can be made by multiplying liveweight by 2.5% for cattle or 3% for sheep (Fig. 6.2: SCA, 1990). More complex calculations abound with the standard method being to raise liveweight to a power of three-quarters and multiply by various factors. For beef cattle on good quality rations a daily intake of 90-100 g/kg $LW^{0.75}$ is used (McDonald *et al*, 1988). It is also related to their need for specific nutrients and it is likely that meeting some limit of energy utilisation sets an upper limit on how much an animal will eat. However such a metabolic limit is a largely theoretical concept in ruminants as their limit to intake is usually determined by the physical capacity of the reticulo-rumen and the rate at which digestion proceeds there. That rate is set by the nutritive value of the feedstuff consumed: the forage digestibility, crude protein content, proportion of soluble carbohydrates and content of important minerals (*eg.* P, K, S, Na).

Plant tissues consist largely of cell walls and the contents contained within those walls. The cell contents (from about 25 to 45% of dry matter) are generally in solution and readily digested (*ie.* broken down to their components) by the enzymes secreted by the micro-organisms within the rumen. However the cell walls are much less digestible and whatever degree of digestion is going to take place in the rumen occurs at a slower rate. The cell walls mainly consist of cellulose, hemicellulose and lignin. It is the lignin component which largely determines the extent and rate of digestion of the fibrous cell wall portion of plant material.

As a plant matures the proportion of soluble cell contents declines and the proportion of lignin in the cell walls increases (Table 5). This leads to a marked decline in the rate and extent of digestion of the material in the rumen (Table 5). Plant material has to be substantially reduced in size between when it is first ingested and when it passes out of the rumen on its way through the rest of the digestive tract. If the rate of such breakdown is decreased by a high level of lignin then the animal is restricted in the rate at which it can eat and hence its total intake in a day is lower than when it is eating more digestible feed.

Table 5: Changes with maturity in structural celluslose (%), lignin (%) and dry matter digestibility (DMD - %) of perennial ryegrass and cocksfoot (adapted from Jones and Wilson, 1987).

	Cellulose	Lignin	DMD
Perennial ryegrass			
Vegetative	15.6	3.9	83
Stem elongation	17.1	4.1	79
Ear emergence	19.6	4.3	71
Flowering	24.9	5.9	64
Cocksfoot			
Vegetative	13.8	5.7	77
Stem elongation	17.1	6.8	71
Ear emergence	21.9	7.6	63
Flowering	21.8	8.7	55

The ruminal digestion process can be further impaired if the micro-organisms are experiencing any other problems, for example a deficiency in nitrogen or some other element, or low rumen pH (*ie.* contents too acid). Alternatively, the vigour of their growth and multiplication may be impaired by the presence in ingested forage of anti-nutritional factors such as alkaloids, nitrates or other chemical entities which occur in some plants all the time, or in other plants at some stages of their growth. Such anti-nutritional factors may be exacerbated by soil nutrient levels, the presence of fungi or the prevailing weather conditions.

There are other animal factors which can influence intake. Palatability, although difficult to quantify, incorporates the concepts of taste arising from plant chemicals, or growth of moulds or fungi, and the physical disincentives such as thorns, spines, coarse hairs or hard seed coats associated with many plants. Also, livestock increase their intake in late pregnancy, during lactation, immediately after shearing and in response to cold weather. On the other hand, intake may be reduced by the deleterious effects of internal and external parasites, foot or mouth soreness, irritation from grass seeds or blow-fly larvae, or various metabolic diseases.

Accessibility of plant material can also markedly influence grazing intake. Even with plant material of high nutritive value an availability of less than 500 kg/ha will limit intake. Above 1500 kg/ha any ability of the animal to select higher quality forage does not result in a higher total dry matter intake or higher average digestibility of intake, unless the material is widely distributed as bushes or tall growing tussocks.

Digestion

Digestion is the breakdown of feed material as it passes through the gastro-intestinal tract from the mouth to the rectum of an animal. Digesta is therefore the mixture of partially digested feed, water, and secretions such as saliva, acid and enzymes, which passes through the tract. This digesta undergoes several major changes in water content, acidity and nature of the digestion process as it passes along.

Once digesta reaches the abomasum of a ruminant, or the stomach of a monogastric (such as pigs or humans), large quantities of strong acid are added and contribute to the digestion process. Similarly, in both ruminants and monogastrics considerable quantities of enzyme mixtures are added in the early section (duodenum) of the small intestine. Subsequently, the chemical products of digestion are absorbed through the wall of the small intestine into the bloodstream, and transported to the liver and other organs and tissues for maintenance, growth or product formation.

The function of the earlier sections of the 'stomach' of ruminants (rumen, reticulum and omasum - Table 6) enables these animals to utilise pastures, particularly low quality pastures (*ie*. roughage or the vegetative portion of pasture which is fibrous, highly lignified and of low digestible). The large rumen and smaller reticulum (Table 6) serve as a vat in which the temperature, acidity and supply of nutrients is suitable for the maintenance of an enormous population of up to 60 species of microscopic organisms (bacteria [10^{10}], protozoa [10^{6}] and fungi). In the reticulo-rumen, 82% of the cellulose is digested (compared with only 2% in the small intestine), and 52% of total organic matter (27% in the small intestine) is digested.

Table 6: Relative capacity (%) of various sections of the digestive tract of cows and ewes (after Jimez and Parra, 1975).

Compartment	Cow	Ewe
Rumen	53	53
Reticulum	2	5
Omasum	5	2
Abomasum	6	8
Sub total	66	68
Small intestine	20	20
Caecum	2	2
Large intestine	12	10
Total	100	100

A standard means of determining *in vivo* digestibility is to house a few sheep in individual metabolism crates for seven days and collect the daily feed refusals and total faecal output from weighed amounts of test rations fed each day. Assessing average percentage dry matter, and often organic matter, of feed, refusals and faeces, allows calculation of dry matter and/or organic matter digestibility. Even when the measure of digestibility is made at a maintenance level of feeding for the animals, the quantity of feed, labour and time is quite costly. Thus, there has been extensive research on *in vitro*, chemical and physico-chemical (particularly - near-infrared reflectance spectrometry - NIR) methods for estimating digestibility in the laboratory.

Using small samples of a forage in a two-stage *in vitro* process (2 x 48 hours), its digestibility can be estimated in a test tube within a week. As this can be carried out simultaneously with a large number of forage samples there is considerable saving in cost and effort. Similarly, laboratory methods exist for estimating the degradability of plant protein, the content of digestible energy in a forage sample and the metabolisability of the energy.

The digestibility of dry matter or even gross energy of a ration only provides part of the information needed to accurately predict the animal response to ingestion of the material. To make a more accurate prediction the metabolisability of the energy needs to be known, but such a measure requires collection of urine as well as faeces, and more importantly requires collection of gases expelled by eructation. These measures are not easy, and certainly not cheap, and so considerable effort has been placed on devising equations which relate readily conducted laboratory methods with reliable estimates of the metabolisable energy content of a forage or ration sample.

From all the equations available, Minson (1987) nominated a series of equations of particular relevance to Australian temperate and tropical forage species, which use laboratory values as crude protein, dry matter digestibility (*in vitro* estimate), lignin, crude fibre or acid detergent fibre.

Micro-organisms

The rumen, or more correctly reticulo-rumen, and the micro-organisms they contain, are fundamental to the productivity of grazing ruminants and so we need to consider their contribution to the digestion process. The bacteria, and fungi when present, are particularly important because they secrete cellulases and hemicellulases; enzymes which the host animal does not produce in its range of gastric enzymes. It is cellulase/hemicellulase which causes the breakdown (digestion) of cellulose and hemicellulose (*ie.* fibre) in forage material. The importance of this process increases as forage matures, because as a plant approaches flowering and beyond, the proportion of fibre increases.

When fibrous material is digested in the rumen, energy (ATP) is released and the micro-organisms utilise some of this energy for their own growth and multiplication. The extent of growth of the microbial mass in the rumen is important to the 'host' because some of the micro-organisms are included in the digesta continually leaving the reticulo-rumen and being washed through to the abomasum. When this digesta is subjected to the strong acid secreted into the abomasum, the micro-organisms are killed and subsequently digested by the enzymes secreted into the duodenum. That is, they become part of the nutrient supply to the host itself. In fact for an animal consuming low quality roughage or pasture, the nutrients of microbial origin can be a major proportion of the nutrients absorbed from the small intestine.

The ability of ruminants to derive considerable quantities of energy from roughage material that other classes of animals can barely digest is important. Equally important is the specific contribution micro-organisms make to the protein economy of the host animal. Essential attributes of proteins are that they are a chain of amino acids, and that each amino acid contains nitrogen. During digestion, feed proteins are broken down (degraded - Table 7) to peptides (short chains of amino acids), to individual amino acids, and eventually to simple nitrogen-containing compounds; the simplest of which is ammonia.

Many of the micro-organisms then preferentially use ammonia as a nutrient, reconstituting it through amino acids and peptides to protein: microbial protein. The presence of micro-organisms in the rumen means that the quantity of protein (that is, amino acids) ingested by the animal may not be the same as the quantity reaching the abomasum/small intestine.

Table 7: Degradability of protein (dg) in the rumen for a range of fedstuffs.

Feedstuff	dg	Feedstuff	dg
Fresh pastures			
Phalaris	0.89	Forage oats	0.87
Cocksfoot	0.88	Lucerne	0.91
Perennial ryegrass	0.82	Sub clover	0.75
Hay and silage			
Maize silage	0.69	Lucerne	0.43-0.60
Wheaten	0.43-0.76	Subclover	0.33-0.51
Dried lucerne	0.62-0.70	Dried sainfoin	0.30
Grains			
Barley	0.75	Brewer's grains	0.70
Meals			
Soybean	0.39-0.74	Sunflower	0.66-0.70
Peanut	0.63	Cotton seed	0.63
Lupin	0.65	Linseed	0.46
Fish	0.27-0.52	Meat-bone	0.41

The make up of amino acid in microbial protein is relatively consistent and quite adequate for most production purposes, but may be quite different to the array of amino acids in the feed or plant protein consumed by the animal (Table 8).

There are two very important aspects of the use of ammonia by rumen micro-organisms which contribute to the efficiency by which ruminant animals in converting various feedstuffs to products. Firstly, micro-organisms do not discriminate between ammonia from plant protein and other sources. Thus, if feed protein is in short supply and the micro-organisms are in need of extra nitrogen, they can utilise ammonia recirculated to the rumen in saliva or they can source it from a simple chemical such as urea. It is the ready ability of urea to provide a cheap source of ammonia to rumen micro-organisms that has made it such a useful ingredient in supplementary rations, blocks and licks.

The second aspect of ammonia utilisation by rumen micro-organisms is not nearly so positive. This is because the micro-organisms need energy to grow, and if energy is in short supply they may not utilise all the ammonia available to them. An average of 32 g of microbial nitrogen or 200 g of microbial protein

Table 8: Amino acid composition (%) of microbial protein (MCP), a variety of livestock products and a selection of protein feeds.

	MCP	Livestock products					Meals		
Amino acids		Wool A	Wool B	Milk B	Lamb B	Beef B	Fish	Soy	Sun-flower
Alanine	6.8	5.2	4.1	3.8	5.8	6.4	5.7	3.8	3.6
Arginine	5.3	6.2	10.1	4.0	6.1	6.7	5.7	6.4	6.8
Aspartic acid	11.9	5.9	7.1	8.5	9.1	9.6	7.9	10.2	8.1
Cysteine	1.4	13.1	10.9	1.0	1.3	1.3	0.7	1.4	1.6
Glutamic acid	12.4	11.1	15.3	23.0	16.8	17.3	11.7	16.3	16.8
Glycine	5.4	8.6	6.0	2.2	5.0	5.6	8.6	3.8	4.7
Histidine	2.1	0.8	0.8	3.0	3.2	3.7	1.7	2.4	2.1
Isoleucine	5.8	3.0	3.4	5.6	4.6	5.1	2.5	4.0	3.5
Leucine	8.0	7.2	9.4	10.2	7.2	8.0	4.7	6.6	5.6
Lysine	9.2	2.7	3.0	8.2	9.8	9.1	5.9	5.6	2.6
Methionine	2.5	0.5	0.7	2.9	2.6	2.7	2.3	1.4	1.8
Phenylalanine	5.3	2.5	4.0	5.4	3.8	4.5	3.1	4.8	4.4
Proline	3.6	6.6	7.1	9.4	4.6	5.1	4.9	4.8	4.3
Serine	4.7	10.8	9.8	5.9	4.3	4.5	4.3	4.7	3.9
Threonine	5.7	6.5	6.5	5.0	4.6	4.6	3.4	3.6	3.2
Tyrosine	4.9	3.8	6.1	4.5	3.5	3.8	1.8	4.0	3.1
Valine	5.8	5.7	5.1	7.4	4.8	5.3	3.5	4.4	4.5

Notes: (1) Sources: A - Reis, 1979; B - Orskov, 1982; (2) MCP = microbial protein.

(184 g in cattle, 224 g in sheep: SCA, 1990) is formed for each kilogram of organic matter digested in the reticulo-rumen. The proportion of organic matter digested in the rumen is generally 60 to 70% of the total digested by the animal (63% in sheep, 60% in cattle: SCA, 1990), but as this is difficult to measure, the yield of microbial protein (MCP) is often considered in relation to total organic matter digested. The SCA (1990) gives an average value of 146 g MCP/kg digestible organic matter intake (DOMI) for sheep 121 g MCP/kg DOMI for cattle. More ammonia may be produced than can be incorporated into microbial protein by the micro-organisms when ruminants are fed rations containing a high proportion of protein. The excess ammonia will increase in concentration in the rumen and subsequently be absorbed through the rumen wall into the blood stream. Once in the blood it is transported to the liver where most of it will be converted to urea. Urea in the blood is of virtually no use to the animal and is concentrated in the kidneys and eventually removed from the animal in urine.

The full significance of feed protein degradation in the rumen can be gained by considering the situation in wool growing sheep with respect to digestion and metabolism of the sulphur-containing amino acids, cysteine and methionine. Wool consists mainly of the protein keratin: a protein which is unusually high (12-14%) in sulphur-containing amino acids. Microbial protein is of only average sulphur amino acid consistency (about 4%). This means that no matter how high the level of sulphur amino acids of forages or supplements ingested by sheep, if the feed protein is degraded in the rumen, the sheep will absorb an amino acid profile with only 4% cysteine and methionine (Table 8).

To increase the proportion of sulphur-containing amino acids towards that desirable for maximum rate of wool growth it is necessary to have a reasonable proportion of feed protein with high sulphur amino acids protected from degradation as it passes through the rumen. Options such as breeding plants with high sulphur amino acids in their leaf protein is not sufficient if the protein is unprotected and therefore going to be degraded to ammonia in the rumen. Only artificial protection with chemicals such as formaldehyde, or natural protection by linking with entities such as tannins, can provide the protection which will increase the level of sulphur amino acids absorbed from the small intestine. When such protection is operating, livestock response such as increased wool growth can occur (Table 9).

The possible wastage of feed protein by ruminants has generated considerable research in recent years. Most interest lies in understanding the proportion of feed protein which will be resistant to breakdown in the rumen: that is, the undegradable (UDP) or by-pass

Table 9: The response in clean wool production (kg/100 kg feed) to protection (with formaldehyde) of dietary protein against degradation in the rumen (after Ferguson, 1975).

Foodstuff	Untreated	Protected
Wheaten hay	0.89	0.89
Oats	1.23	1.23
Lucerne hay	1.31	1.39
Wheat	1.56	1.56
Lupin seed	1.47	1.84
Sunflower seed	1.29	2.31
Peanut meal	1.69	2.58
Linseed meal	1.91	2.67
Rapeseed meal	1.77	2.71
Cottonseed meal	2.44	2.88

protein in the ration. Such resistance to degradation (or digestion) may be a natural attribute due to chemical linking of proteins with compounds such as tannins, or artificially induced during processing by treating them with formaldehyde, or by heat and pressure. For example, condensed tannins which occur naturally in plants such as *Lotus* and sainfoin, are stable at pH 3.5 to 7.0 (*ie.* the range of pH occurring in the rumen), but unstable at pH 1 to 2 (*ie.* in the abomasum).

Alternatively, resistance to rumen degradation may be due to physical shielding of the protein from the proteolytic enzymes secreted by micro-organisms. Physical shielding may be of natural origin, such as the presence of lignin in the wall of plant cells, or may be caused by artificial encapsulation of the protein (or amino acids). Encapsulation involves a substance which is resistant to the conditions in the rumen, but which is dissolved by the highly acidic conditions of the abomasum, releasing its contents for digestion and absorption in the small intestine.

Absorption and metabolism of nutrients

Ruminants absorbs most of their energy from the rumen as volatile fatty acids (VFA's) or the small intestine as free fatty acids, carbohydrates or amino acids. Most protein is absorbed from the small intestine as amino acids.

The propionic acid portion of the VFA's is largely transformed to glucose and used preferentially by the brain, for foetal development, for production of lactose in milk, and in energy storage as glycogen in the liver, muscles and other tissues. Acetic acid becomes a major source of energy for growth and adipose tissue development, and is a major precursor for milk fat synthesis.

The amino acids are predominantly used directly for muscle growth, milk production, fibre growth, and hoof, horn and antler formation. However, some amino acids may be transformed to others in the liver, some may be used as precursors for fat production, and particularly during periods of sub-maintenance feeding some may be used as precursors for glucose production.

Fatty acids are used directly for adipose tissue development or for milk fat synthesis, but may be metabolised as an energy source when total nutrient intake is sub-maintenance.

MODIFICATION OF THE NUTRITIVE VALUE OF FORAGES

In this review the main consideration is pasture (native, natural, sown/improved). However, most of the principles can be related to the other elements of forage (forage crop, stubble, browse) which often provide alternate or supplementary grazing for livestock at strategic times.

As mentioned earlier, the nutritive value of a forage is a complex of several factors. These include the concentration of protein in the plant material, and the degradability of that protein. It also includes the proportion of carbohydrates, proteins and lipids which are present in the cell contents and so readily digestible once the cells are ruptured during chewing or as a result of enzymatic action on the cell walls. Thus, nutritive value is the sum of energy available to the host animal in the form of volatile fatty acids absorbed from the rumen, and glucose, other sugars, fatty acids and amino acids absorbed from the small intestine. Furthermore, nutritive value includes the concepts of how much of the plant's organic matter is digested by the animal, what proportion of that digestion occurs in the rumen and how rapidly that ruminal digestion occurs. These factors also combine to determine how much of the particular forage is consumed (voluntary feed intake).

Improving the nutritive value of a pasture may be achieved by a variety of means. As pointed out by Blyth and Menz (1987), the expansionary phase of pasture improvement in Australia peaked in 1971. With further expansion limited by costs, availability of suitable land in areas with favourable rainfall, and competition from alternative enterprises, further advances may be limited to improving the output or utilisation of the areas already sown to improved pastures. Such improvement could involve changing the pasture mix to increase the proportion of legumes to take advantage of their higher protein content, generally higher digestibility and higher readily digestible carbohydrate content. It could involve the addition of fertiliser to increase protein content, to improve growth rate and digestibility or to overcome a deficiency in a specific mineral.

Other options are obviously of a more long-term nature, such as breeding plants with increased protein content or an increased digestibility. A more specific aim may be to incorporate condensed tannins into a particular plant to increase the proportion on protein which will only be partly degraded in the rumen, and at the same time to decrease the potential for the plant to cause bloat. Plant breeding may also be aimed at decreasing lignin content or modifying the cell wall structure so that cellulose is more accessible to microbial enzymes.

CHANGING THE EFFICIENCY OF UTILISATION OF GRAZED FORAGES

Improved utilisation of existing pastures may be achieved by:-

- Grazing management
- Supplementary feeding

To ensure animal requirements are met as fully as possible from the pasture available, at any point in time the stock with the highest requirements generally receive the best quality grazing. Thus, grazing weaners ahead of adults, or similar priority grazing for pregnant ewes or stock being finished for market is normal practice. Similarly, set stocking of lactating ewes or cows in paddocks where intake will not be restricted by availability or rankness of feed is general practice. Less common are strategies such as heavy grazing as grasses approach maturity, to delay flowering and to prolong the availability of high quality feed. Strip grazing is practised, particularly in the dairy industry, and because daily milk production is so sensitive to fluctuations in intake of nutrients, producers are generally aware that shifts to new pastures must be frequent enough to avoid a 'saw-tooth' effect in pattern of production. Similar concern for consistency in availability of nutrients needs to be shown when rotational grazing of lucerne or other species is practised with lactating ewes, beef cows, young growing sheep, and cattle weaners.

Two different situations need to be considered in relation to supplementary feeding of grazing livestock. The first is the likelihood that young, rapidly growing ruminants (weaner lambs or calves) when grazing pasture, no matter how high in quality and no matter how accessible, cannot absorb enough amino acids from their small intestines to meet their potential for liveweight gain. Under such conditions the need is for UDP, *ie.* protein which will pass through the rumen largely undegraded. This can be supplied in supplementary rations in the form of protein meals of plant or animal origin: preferably ones which have been subjected to heat or chemical (formaldehyde) treatment to decrease the degradability of their protein. A level of 7% crude protein in the dry matter is generally accepted as the point below which intake of roughage will be limited specifically by a deficiency of nitrogen supply to the micro-organisms.

The other situation is where a large quantity of low quality roughage (crop stubble or mature pasture residues) is available for grazing, but is of insufficient quality even to maintain liveweight. The digestibility and hence intake of low quality material may be increased to a maintenance level of intake by feeding supplements containing nitrogen (for example, urea). Alternatively, a concentrate supplement may be offered to supply the deficiency of nutrients. If this is done care must be taken to ensure that the supplement does not become a costly substitute for the base pasture, either through overfeeding or by providing carbohydrate which is so readily available that it causes a rapid decline in pH and a subsequent depression in the digestibility of cellulose in the low quality roughage.

FUTURE DEVELOPMENTS

In the future, greater use will be made of simulation models which can rapidly allow options based on a wide array of environmental, pasture and animal data to be considered. For example, Donnelly *et al* (1987) described the development of a multi-program model (Grazplan), which integrates information on weather (Metaccess), pasture growth (Grasgrow), and animal requirements and production responses to varying pasture and supplement inputs (Grazfeed). The Grazfeed and Metaccess components are now on the market and being used by Departmental advisers, consultants and producers. Use of such decision-support models will almost certainly increase in the future as their applicability increases with growing input of reliable data, and as more producers become familiar with computers and the use of varying software packages.

The developing technologies of genetic engineering and biotechnology will also have an increasing impact on the grazing industries of the future. There may well be grasses that can fix their own nitrogen, pasture plants with less lignin in their cell walls, and a wide range of plants with an optimum content of condensed tannins or increased drought tolerance. Similarly, animals or their microflora may be modified to make them more efficient grazers. Livestock will have enhanced genes for production of growth hormone, reproductive hormones, resistance to disease or parasites, or tolerance of drought, heat or cold. These broader changes may be further enhanced by the introduction of genetically engineered micro-organisms into the fermentation process of ruminants. Such micro-organisms may utilise methane or lactate in the rumen, cause less saturation of fatty acids, more efficiently utilise dietary protein by incorporating amino acids rather than deaminating them to ammonia, or may be fungi which can digest lignin in the rumen.

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