

ADVANCES IN PRACTICAL FEED EVALUATION SYSTEMS FOR THE RUMINANT PRODUCTION INDUSTRIES OF AUSTRALIA

V.H. ODDY*

INTRODUCTION

Feeds evaluation refers to an assessment of the capacity of a feed to meet an animals nutrient needs, i.e. its nutritive value. This is not a simple characteristic of a feed as it is a function of the amount of feed ingested, and the quantity and quality of nutrients released upon its digestion. Moreover, nutritive value should not be considered a characteristic of a feed alone, as it may be altered by ingestion of other feeds, the physiological state of the animal, and is likely also to differ between ruminant species and perhaps genotypes within species.

The purpose of feed evaluation is to enable farmers, graziers and advisors to answer questions like "What level of production is possible on this pasture?", "How can I improve it, and at what cost?". These simple but searching questions tax the best of us, and our response has been to try to devise systems which, although simplified, allow some quantitative means of ranking feeds. To achieve this we have had to develop some relationships between nutrient supply and animal performance (i.e. a feeding system, viz. hay equivalents, total digestible nutrients, starch equivalents, **metabolizable** energy (ME), net energy). It is important to realise that a feed evaluation system and feeding system are interdependent. The basic rules which relate nutrient supply to animal performance require description of a feed in terms from which nutrient supply may be calculated. Thus, a system which expresses animal requirements in terms of ME, requires an assessment of ME in a feed.

ENVIRONMENT IN WHICH FEED EVALUATION SYSTEMS OPERATE

The type of feed evaluation system used depends on the questions asked. Most ruminant production in Australia is from grazing animals. Here the role of feed evaluation is to determine which component of a feed may be limiting animal production, and to a lesser extent provide a preliminary screening of new pasture plants. A major difficulty in this area is to determine which plant species are grazed, and the factors which affect how much of each can be eaten. The scope for application of laboratory feed evaluation is limited without knowledge of intake of the pasture species under study; nonetheless a useful set of guidelines for selection of more nutritious pasture plants has been suggested by Black (1987).

Where the quantity and/or quality of pasture is limiting animal production, the scope for feed evaluation increases, but it is not the only tool used. Assessment of nutrient deficiency is based on a combination of parameters; including current animal performance compared to that expected, and feed analysis. Mineral deficiencies may be more readily determined from blood,

* NSW Agriculture & Fisheries, Nutrition and Feed Evaluation Laboratory, Glenfield, 2167

tissue or urine analysis from the suspect animals than from pasture analysis although this can at times be useful. The major feed analyses carried out to determine nutrient deficiency include an estimate of the amount of feed present, its digestibility, protein, and sometimes sulphur and phosphorus content, but the interpretation is fraught with difficulties in sampling what the animals are eating, and in turn calculating the **amount and pattern** of nutrients provided by the feed relative to the animals requirements. This latter area can be resolved, in part, from computer simulation of the interaction between feed and animal needs (see Black **1984**), but the necessary information on the feed ingested is rarely available.

Under these conditions feed supplements are often used to provide rate limiting nutrients. The selection of these feeds is made on the basis of availability, cost, ease of use and digestibility and/or protein content. Although good information is often available on digestibility and protein content of feeds likely to be used **as** supplements, information as to the interactions between supplements and pasture intake is not so readily available. We have **some** information on the content of starch, fat and the form of protein in some of the more commonly used supplements, but don't have an adequate description of **the** digestion characteristics, or of the manner in which they influence digestion of pasture. More importantly we don't **have** an adequate picture of the behavioral factors which influence supplement intake, and intake of pasture on which the supplement is offered (see Doyle, 1987).

The situation in which feed evaluation systems are most useful, are those where no grazing is available (ranging from feeding for production to **survival**). It is here that the questions asked above are able to be answered with some confidence, although the errors involved can be large, particularly where feeds behave in non additive ways, and where the diet **contains an imbalance** of either energy or protein relative to the **needs** of the **animal to** achieve the desired objective. **Metabolizable**, or Net, energy systems, in conjunction with some description of requirements for protein and major minerals, provide a suitable way for ranking most commonly used feeds, although there is additional scope for consideration of specific nutrients in special cases (e.g. starch content with grains, potential degradability of protein with some **meals**).

PRESENT FEED EVALUATION SYSTEMS

Digestibility of feed is the primary currency of those feed evaluation systems presently in use. In some cases this may be extended to an estimation of **metabolizable** energy value. Additional measurements include the quantity of nitrogen, usually expressed in terms of crude protein.

The published information readily available is **a pot pourri** of data gathered over the past century, predominantly from Europe and North America-. Data on digestibility of Australian feeds is less comprehensive, and available in scattered publications. Recent attempts to incorporate information on Australian feeds into **a** national database by the Australian Feeds Information Centre (see

Leche, 1983) are long overdue. Comprehensive information on crude protein and mineral content of Australian feeds is also in short supply. The disadvantage of using compilations of such data is that the large variations in nutritive value between feeds of the same description are masked, and the use of tabulated values is therefore prone to serious error in application, chiefly with forages, and also with oat grain.

This deficiency is recognised, and laboratories routinely carry out analysis to make some estimate of digestibility of a feed, either using proximate analysis, the modified fibre determinations introduced by Van Soest, or *invitro* procedures (including incubation in rumen fluid (Tilley & Terry, 1963), or pepsin/cellulase (Clarke, Flinn & McGowan, 1982)). Each of these procedures estimate digestibility, and the errors can be large. For instance, the RSD of the dry matter digestibility estimated from ADF and N content of 64 feeds and their *in vivo* dry matter digestibility (Oddy et al, 1983) was 3.3%, and in routine use with forages the error is even greater. The error (RSD) in prediction of *in vivo* dry matter digestibility from rumen fluid *in vitro* procedures is about 4.5% in a practising feed evaluation laboratory (J.F. Ayres, unpublished data). Factors contributing to the variation in the estimate of in-vitro dry matter digestibility include; type of feed offered to the animal from which rumen fluid inoculum is obtained, time after feeding, between animal variation (some animals have better bugs than others) and variations in rumen fluid activity between days. Pepsin/cellulase procedures remove some of these sources of variation. Clarke et al (1982) reported RSD of 1.2-1.8% for regression of pepsin cellulase digestibility against *in vivo* DMD, However, these procedures are slow, taking up to one week for analysis.

Accurate assessment of the components which influence nutritive value requires that any sample of feed taken for analysis has the same composition as what the animal eats. The temperature at which samples are dried can have a major effect on many of the laboratory measurements associated with nutritive value (Table 1), as can the time between cutting of pasture and cessation of respiration of the plant (Table 2).

TABLE 1. The effect of method of drying a sample of feed on nitrogen and acid detergent fibre content. Data shown for fresh Clover/Ryegrass pasture (S.G. Low, unpublished data)

drying method	N %	ADF %
Fresh	3.73	
Microwave + 50C	3.46	26.7
50C	3.26	29.9
Microwave + 70C	3.41	25.8
70C	2.89	29.2
Microwave + 100C	2.97	43.2
100C	2.97	41.8

These results indicate that to obtain a sample of pasture of the same composition available to the animal, respiration of the plant must be stopped (preferably by freezing) at the time of sampling.

TABLE 2. Time between cutting and freezing of pasture affects composition. A sample of lucerne pasture was cut and frozen in liquid CO₂ (Colebrook et al, 1984) at various times after cutting. Frozen samples were freeze dried prior to analysis. Values for oven dried samples shown for comparative purposes (S.R. Edwards, unpublished data).

Drying Method	Time after cutting (hr)	Nitrogen % DM	ADF % DM
Freeze Dried	0	4.53	17.6
	0.5	4.46	19.3
	1	4.50	19.3
	2	4.27	22.1
	4	4.39	21.2
Microwave then Oven Dried @ 70C	0.7	4.45	22.5

An additional, and major, constraint on use of feed information is to estimate how much of a feed is likely to be eaten. Proposed methods for estimating feed intake for prediction of performance of grazing ruminants (SCA, 1989 based on proposal of Freer & Christian, 1983) require the user to determine the amount and quality of pasture mass available. From an estimate of pasture mass, and the digestibility of green and dead fractions intake is calculated on the basis that the animal selects green rather than dead material, young rather than old, and leaf rather than stem. This is computed by dividing the pasture into pools of pastures of differing digestibility and protein content, and satisfying the animals needs first from the pool of greatest digestibility, then from subsequent pools of decreasing digestibility until rumen load limits intake (Christian et al, 1978). This procedure, which is incorporated within the computer program "Grazfeed" (Donnelly & Freer, 1988), provides a reasonable simulation of the quality of intake of sheep on temperate pastures, but is less accurate with cattle on tropical pastures.

TOWARDS A BETTER FEED EVALUATION SYSTEM

Digestibility is the result of complex interactions between ingested feed and many processes within the digestive tract of an animal. Factors which influence digestibility include; rate of digestion of different fractions of the feed and their flow from the rumen, microbial activity and the resulting pattern of fermentation end products, and interactions induced by supply, or lack, of nutrients utilised by rumen micro-organisms. This latter category includes amino acids, precursors of branched chain VFA, nitrogen, sulphur and phosphorus, and also the quantity and form of long chain fatty acids ingested.

Digestibility of a feed is not always a good indicator of the likely nutrient supply and intake of that feed by ruminants. Although organic matter digestibility and intake of forages can be correlated (Freer, 1981) there are notable exceptions. Intake of legumes is greater than that of grasses at the same digestibility (see e.g. Thornton & Minson, 1973), but such differences are not apparent when digestible organic matter intake is related to

retention of organic matter in the **rumen**. Differences in pattern of nutrient supply and flow from the **rumen** influence both the efficiency of production, and the feed intake. They are not solely attributes of the feed, but interact with the physiological **state** of the animal to introduce significant variation in performance (Table 3).

TABLE 3. Approximate variation in animal performance contributed by animal and forage diets (from Van Soest, 1982)

Parameter	Coefficient of variation %	
	Diet	Animal
Digestibility	30	3
Intake	50	30
Efficiency (of energy use for productive purposes)	50	20

If digestibility is not an adequate measure of a feeds ability to supply specific nutrients or likely intake, what laboratory measurements add to our information on nutrient supply and feed intake?

A range of chemical analyses and animal-feed interactions which could form the basis of future feed evaluation systems have been suggested (Preston & Leng, 1987; Black, 1987). Black (1987) summarised the characteristics of plants which were associated with improved nutritive value. These form a useful check list for methodology likely to be required for any comprehensive laboratory feed evaluation scheme.

* Cell wall constituents should be as low as feasible without destroying the structural integrity of the plant, and the cell wall should be easily fractured during mastication. Moreover, the lignin content of plant fibre should be low relative to cellulose and hemicellulose.

* Protein content should be appropriate for the form of production. A high proportion of plant proteins should escape fermentation in the **rumen**, while remaining readily digested in the small intestine. The amino acid **composition** of escape plant protein should be appropriate for the form of **animal production**. e.g. high levels of sulphur-**containing** amino acids for wool growth.

* Tannin content should be about 60 g/kg DM and of MW "22,000, . This will assist dietary protein to escape **rumen** fermentation.

* Storage and soluble carbohydrates should be as high as feasible and balanced with amino acids for the form of production.

* Lipids should make up to 15% of the energy in the dry matter because of their high efficiency of utilization.

* High levels of soluble ash to stimulate outflow from the **rumen**, improve protein flow to the intestine and enhance feed intake.

This list of desirable characteristics of feeds was devised for guidance of plant breeders. If ruminant nutritionists are to use these guidelines to resolve practical problems a means of

quantitatively assessing feeds in the terms described above, and of relating the results of such quantitative assessment to animal performance, is required. Integration of knowledge, relating animal performance to nutrient supply, by computer simulation is a possibly the best way of achieving this.

Black et al (1980-81) and Murphy et al (1987) outlined a simulation modelling approach to prediction of nutrient supply. Components of ingested feed required to drive these models were essentially as described above. The nutrient supply thus calculated was then used to provide interactive input into a model of animal requirements (Black & Faichney, 1981; Gill et al, 1984; Baldwin et al, 1987a,b). Models of **rumen** function include simplifications of more complex relationships between **chemical** constituents of feeds and fermentation patterns **described by** Baldwin et al (1970). They incorporate relationships **between flow** of **digesta** from the **rumen** and subsequent supply of nutrients to the lower digestive tract (Hogan & Weston, 1970; Faichney, 1975).

Most of the methods of feed analysis required as inputs to a **rumen** model have been described (Faichney and White, 1983). The analyses are laborious and time consuming and unlikely to come into routine use in their present form, although there is scope for many to be carried out by near infrared reflectance analysis. Methods missing from the analysis scheme of Faichney & White (1983) are; measurement of the rate of degradation and the maximum extent to which dietary protein and B-hexose could be degraded in the **rumen**. In most feeds starch is readily digested within the **rumen**, but there are reports that ruminal degradation of starch is incomplete and glucose is absorbed from the small intestine where diets with large proportions of grain **are** fed (Judson et al, 1968). It may also be important, at times, to have a measurement of the rate of starch degradation in the **rumen**.

We, among others, have been attempting to estimate, from laboratory measurements, the potential rate of degradation of feed proteins in the **rumen**. Although *in sacco* procedures (Mehrez & Orskov, 1977; Orskov & McDonald, 1979; Orskov et al, 1980) are recommended for estimating **rumen** breakdown of proteins (ARC, 1984; SCA, 1989), and appear to rank protein degradability in the same order as *in vivo* experiments, nylon bag estimates of protein degradability are at times less than *in vivo* values, even after accounting for differences in fractional outflow rate from the **rumen** (see e.g. Amaning-Kwarteng et al, 1986). This discrepancy may not be important if a ranking of protein degradability is all that is desired, but to achieve a quantitative description of protein available to the animal requires greater precision - particularly when amino acid supply is limiting production.

In our laboratory, Steve Neutze has used a wool growth assay (see for example Ferguson, 1975; Leng et al 1984) to estimate degradability of protein (Neutze, 1989; and Figure 1). The procedure in our hands is of low precision and can be used only for ranking protein supplements. Lack of precision comes from between animal variation in efficiency of wool **growth, the small** proportion of **absorbed** amino acids incorporated into wool (9-12%, see e.g. Black, Robards & Thomas, 1973), the pattern of absorbed amino acids and their utilization by tissues other than for wool growth. Routine use is precluded by the large sample size, and

long time - typically 8 weeks - required for an estimate. Laboratory methods, although indirect, offer the best chance of rapid evaluation of degradability of protein in the **rumen** and are likely to be descriptive of the feed rather than the interaction with the animal assay system.

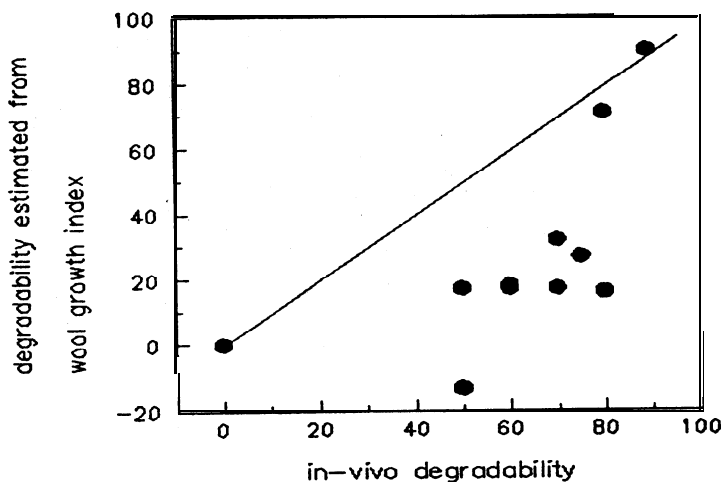


FIGURE 1. Comparison of degradability of dietary protein supplements estimated by a wool growth assay, and published estimates of *in vivo* ruminal protein degradability (Neutze, 1989).

Methods employing bacterial and **fungal** proteases (Pichard & Van Soest, 1977; Mahadevan et al, 1980) have been investigated (Figure 2). The procedure appears to rank feeds in an order similar to that from published *in vivo* experiments, but it is difficult to obtain quantitative comparisons without accounting for variation associated with the *in vivo* values. The **protease** procedure, however, shows considerably more promise than estimation of protein degradability from an index of wool growth.

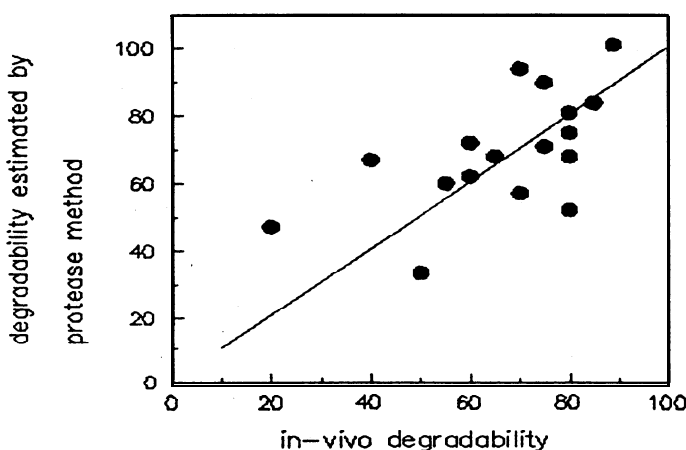


FIGURE 2. Degradation of feed protein after incubation in bacterial and **fungal protease** solution for 24 hrs, compared to estimates of degradability of feed protein *in vivo* (S.A. Neutze, unpublished).

Apart from development of *methods. to determine rumen protein degradability with high precision and accuracy, the responsiveness of the animal to amino acid supply, and the errors associated with estimation of the-amino acid requirements for various levels of production, should also be considered.

The disparity in responsiveness of animals on low energy / low protein diets to supplementation with escape protein is holding back acceptance of the principle that amino acid supply limits animal growth on such feeds. Many experiments (e.g. Hennessy, 1987) have demonstrated significant liveweight responses to escape protein, whereas others (e.g. Redmann et al, 1980) have been unable to demonstrate any response (Table 3).

TABLE 3. Disparate growth responses to escape protein in Hereford steers. Data from Hennessy, 1987 and Redmann et al, 1980.

Treatment	DMI	LWG	Final LW
Hereford steers 340kg, 25 months old basal diet chaffed carpet grass hay 505 g DOM, 5.8 g N / kg DM (Hennessy, 1987)			
Nil	4.8	-129	335
+casein	6.3	90	349
+urea+F-casein*	6.6	329	364
Hereford steers 288 kg, 12 months old basal diet chaffed oaten hay 520-590g DOM, 4.1 g N / kg DM (Redmann et al, 1980)			
Nil	6.12	356	308
+urea	7.41	798	334
casein:F-casein*			
100:0	7.32	843	336
50:50	7.63	842	336
0:100	7.41	805	334

* F-casein, casein treated with 1.5% (w/w) formaldehyde

One possible explanation of the difference in response to escape protein is that the animals which responded were previously undernourished as a result of long term grazing of energy/protein deficient pastures and weighed less at the same age than those in the studies which did not show a response to escape protein, in which previously "well grown" animals were used. The data which suggests that this might be the explanation was presented by Orskov et al (1976). In that work sheep previously fed a low protein diet (12% CP), upon switching to a high protein diet (20% CP) which contained substantial escape protein, increased their rate of protein deposition relative to those fed the high protein diet throughout (Figure 3).

It is important that these observations be incorporated into practical feeding systems. Present feeding systems (ARC, 1980,1984; SCA, 1989) do not account for responses to absorbed nutrients other than energy. In many practical situations in

Australia energy may not be the first limiting nutrient, and failure to account for this results in serious errors in performance prediction, and in calculation of economic response to supplements.

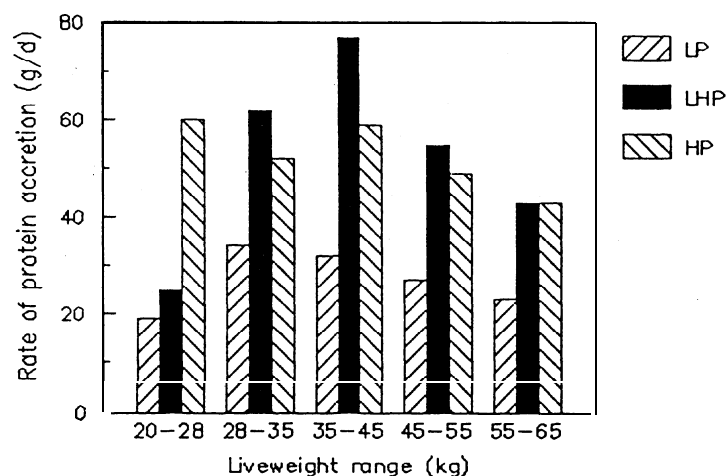


FIGURE 3. Rate of protein **accretion** in previously undernourished, refed, lambs is greater than well fed lambs of same weight. Lambs previously fed a low protein (LP) diet were offered a high protein (LHP) diet at 28 kg. The rate of protein **accretion** of lambs fed high protein diet throughout is shown for comparative purposes (Orskov et al, 1976).

Difficulties **also** surround our present application of knowledge on utilization of energy. The feeding systems presently in use correlate efficiency of energy use in an animal **with the** digestibility / metabolizability of the feed **i.e** there is a **tacit** assumption that the mix of nutrients available does influence efficiency of energy deposition, **and** this is **largely predictable** from an estimate of the digestibility of the feed. **While this is a** suitable first approximation, for many feeds this simplification is inadequate. There is now overwhelming evidence **that a major** cause of variation in efficiency of energy utilisation is the manner in which acetate is utilised in the body (see Preston & Leng, 1987, for an extensive review). Utilisation of acetate is dependent on both the supply of glucogenic nutrients, and **the** physiological state of the animal. Tyrell et al (1979) **clearly** showed that efficiency of acetate utilisation by mature cattle, "eating similar amounts of **metabolizable** energy, could **vary** from 28 to **71%**, **depending** on the composition of the basal diet. The more efficient utilisation of acetate occurred on diets containing the greatest supply of starch and soluble cell contents, which on fermentation give-rise to more propionate in the **rumen**, and upon absorption, glucose. It is important therefore that future feed evaluation systems describe feeds in terms which **allow prediction** of the pattern and quantity of VFA produced in the **rumen**.

The minimum measurements required **of a feed to allow** estimation of **VFA** supply are content of cellulose, **hemicellulose** and lignin -(cell wall or **B-hexose**), **a-hexose** (**starch and pectins**) and soluble carbohydrates, and an estimate of degradation of the **B-hexose** fraction. Limitations with methods for estimating degradation of **B-hexose** are similar to those for estimation of

ruminal degradation of protein, although there may be correlated components of feeds which are more easily measured (Smith et al, 1972). The theoretical basis for predicting amount of VFA produced requires further work, for although there is reasonable agreement between calculated and observed proportions of VFA in the rumen, the simulations are as yet unable to consistently estimate total VFA production (Murphy et al, 1986). A practical difficulty with not knowing the pattern of VFA produced can be illustrated by the results of Tudor & Minson (1982). These workers estimated efficiency of energy use for growth and fattening (kf) in pangola and setaria grasses to be 0.28 and 0.17 respectively, despite similar chemical composition of the grasses. They presented evidence that more propionate was produced on the pangola grass than the setaria. To account for such a difference, information about the feed additional to that listed above may be required, for example the content and digestibility of various sugars of hemicelluloses may vary (Nandra et al, 1983), and this will influence the ratio of propionate to acetate produced. In addition a measurement of the ease of breakdown of a feed, and packing density in the rumen may be required to account for differences between feeds of similar chemical composition. Practical application of description of a feed in terms which allow VFA supply to be calculated will ultimately depend on the precision with which we can estimate the effects of variation in VFA pattern and supply on animal performance.

There is no complete description of the interaction between supply of energy yielding nutrients and amino acids and growth of ruminants. It has been believed that the major influence of an increased efficiency of acetate is on fattening, but Tyrell (1979) found acetate infusion could both enhance, and decrease N balance depending on the basal diet. Part of this inter-relationship has been incorporated into a computer model of the energy - protein interactions affecting the efficiency of fattening (Gill et al, 1984). This simulation model, which requires inputs to be described in terms of quantity of acetate, propionate, amino acids and lipid, accounts for variations in efficiency of fattening in a more realistic manner than feeding systems presently in use (see Black et al, 1987a,b).

If we are to obtain quantitative relationships between chemical constituents in a feed and animal performance, there still remains the question of what feed and how much of it is likely to be eaten by the freely grazing ruminant. It is here that individual animal preferences for feeds confounds our ability to predict nutrient intake. This may not be such a problem if performance can be calculated in a stochastic manner with the "mob" as the animal unit. Arnold (1982) indicated that while individual animals may show wide differences in preference for feeds, as a mob the variation in individual preferences irons out the bumps and the general principles that animals eat leaf in preference to stem, young to old as currently implied in the principles embodied in SCA (1989), is sound. It is important nonetheless to consider that sheep can be more selective in their grazing habits than cattle. Some of the principles by which sheep might select between forages have been recently clarified (Black et al, 1987c), and the potential rate of intake of a feed has been shown in laboratory studies to have a major influence on preference, with those feeds of higher intake rate being

preferred. **Intake** rate was found to be influenced by **water** content (Kenney et al, 1984), sward characteristics (height and **density**, Black & Kenney, 1984) and palatability (Gherardi et al, 1987), although differences in palatability **did not influence the overall** intake if there was no choice of feeds available.

Inclusion of measurements which influence preference for a feed in a feeds evaluation system will provide an interesting challenge to ruminant nutritionists.

CONCLUSION

Measurement of digestibility and protein content of a feed **are no** longer a sufficient description of its potential to promote animal production. Future methods of ruminant feed **evaluation** should aim to describe feeds so that the supply of major **energy** yielding nutrients, and amino acids to the intestines, may be calculated. Utilisation of this information dictates **that animal** requirements be expressed in complementary terms. Practical application will almost certainly be through integration of **this** information in the form of computer simulation models.

Assimilation of this methodology into industries **as** diverse as the ruminant production systems in Australia will be a patchy process, with at times the pace being frustratingly slow. The major factor affecting uptake by industry will be **immediate need**. If the methodology solves readily definable problems it will be accepted. However, if feed information is not available **in the** appropriate form, then users will have no option but to **fall back** onto older, well established, but less accurate systems. It is important that as nutritionists and animal scientists we work towards providing information and technology for future problems, **rather than rely upon the efforts of our predecessors**.

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