MENTOR; A PRACTICAL APPROACH TO THE PREDICTION OF SUBSTRATE SUPPLY FROM THE RUMEN

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SUMMARY

A system, Mentor, is proposed for the prediction of energy and amino nitrogen yield to the ruminant animal from robust measurements of feed composition available to farmers and compounders. The model distinguishes the processes of fermentation and N degradation in the rumen from post rumen digestion and absorption. It is based on functional definitions of nutrient supply which incorporate physiological variables such as rumen outflow rate and microbial yield. These concepts are relatively simple but they too are robust since they can incorporate newer and better particulars of ruminant nutrition as they emerge.

INTRODUCTION

The primary objective of animal nutrition is to match the supply of essential nutrients to animal requirement or the response target set by the producer. Nutrients are used predominantly to supply energy, with essential amino acids a distant second and the rest of the field nowhere.

The use of metabolizable energy (ME) or net energy (NE) to describe energy supply has the considerable merits that all elements of the energy balance equation can be measured with precision and most energy-yielding substrates do work and generate heat. The main limitations of this approach when applied to ruminants are

1) it assumes additivity which may not be the case, e.g. when starch and cellulose are fed together;

2) it does not distinguish between fermentable and unfermentable substrates. This does not necessarily affect ME value but will affect microbial protein yield;

3) it does not distinguish patterns of fermentation and their possible effects on efficiency of utilisation of ME or composition of milk or body tissues;

4) it does not permit a logical interpretation of effects of plane of nutrition on fermentation, yield of ME and microbial protein.

ME and NE therefore constitute excellent descriptions of the energy requirements of ruminants but inadequate descriptions of energy supply partly for the reasons stated above and partly because of our limited ability to predict energy supply from feed chemistry and other laboratory methods.

All these criticisms and more can be applied to the use of digestible crude protein (DCP). Most countries have now abandoned DCP in favour of systems which distinguish between microbial metabolism of organic N in the rumen and amino acid supply to the host animal (Alderman and Jarrige, 1987) although the various replacements for DCP differ considerably both in concept and complexity. The working group who produced the UK "Metabolizable Protein** system (where MP = 6.25 x truly absorbed amino N, (TAAN)) attempted

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to tread a middle way between the naivety of DCP and extremely elaborate models such as those by Black et al (1981) to produce a system for feed characterisation that met the following criteria:

1) It should be based on measurements of feed chemistry, physical form or in *vitro* digestion that can be adopted as routine by the feed compounder.

2) It should be deterministic, rather than empirical and sufficiently descriptive of ruminant physiology to be able to incorporate essentials of present and future knowledge.

3) It should predict the yield of the major truly-absorbed substrates for energy and protein metabolism.

4) It must, when tested in production trials, be demonstrably better than existing empirical systems.

While I was serving on this group my colleagues at Bristol, largely sponsored by Dalgety Agriculture Ltd., were attempting to improve the characterisation of both energy and organic N in ruminant feeds (Webster, Dewhurst & Waters, 1988). We have attempted to meet the above criteria with a system entitled MENTOR, a model of energy and nitrogen supply to ruminants.

MENTOR, AN APPROACH TO THE PREDICTION OF SUBSTRATE SUPPLY

Mentor predicts the supply of true metabolizable energy (ME_t) and TAAN. We assume that in making, substrates available for energy and protein metabolism the processes of ruminant digestion distinguish four fractionsof the feeds. These are:

1) Material which is quickly and completely fermented or degraded in the rumen. Material (carbohydrate and protein) which is fermented to energy-yielding substrate as volatile fatty acids (VFA) is termed quickly *fermentable* energy (QFE). Organic nitrogenous material that is rapidly degraded to ammonia is quickly degradable nitrogen (QDN).

2) Material which is slowly (S) and thus incompletely fermented or degraded in the rumen is termed SFE or SDN.

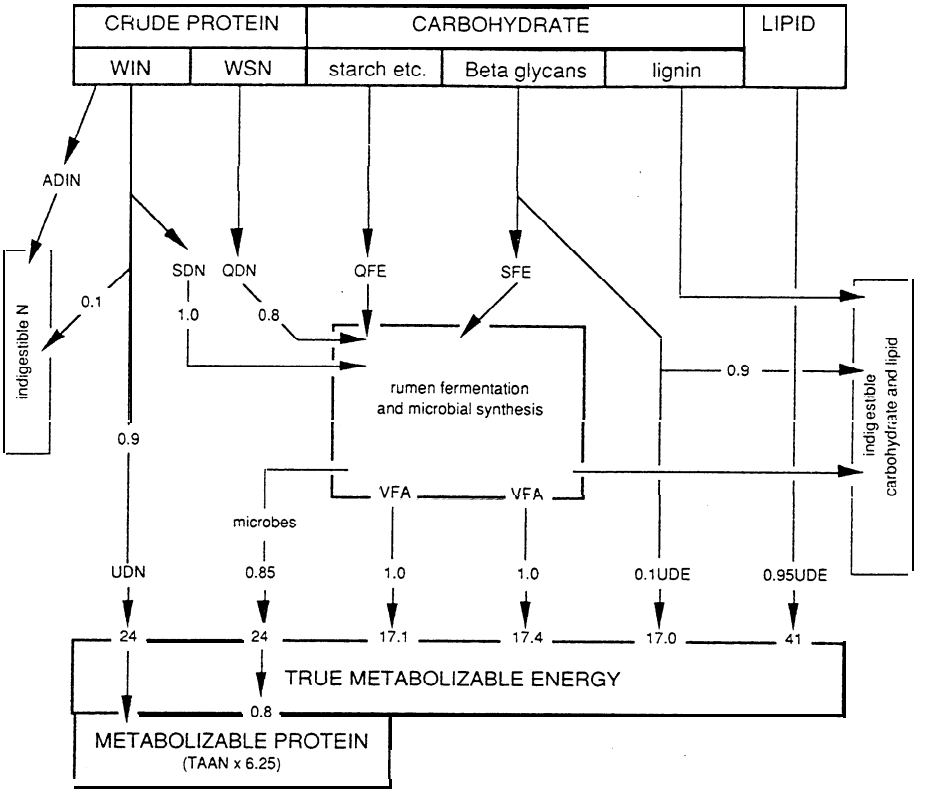
3) Material which is unfermented or undegraded in the rumen but subsequently digested is termed unfermentable, digestible energy (UDE) or undegradable, digestible nitrogen (UDN).

4) The final fraction is that which is neither fermented nor digested. Since this does not contribute to the supply of ME_t or TAAN (MP) it requires no code.

Fractions 2-4 are all influenced by physiological factors such as rumen retention time which itself reflects input variables such as plane of nutrition and the physical form of the diet.

The three contributors to ME_t (QFE, SFE, and UDE) and TAAN (QDN, SDN and UDN) constitute a sufficient description of the capacity of the rumen to ferment and degrade energy and N. ME_t differs from apparent ME in that it defines all truly absorbed energy-yielding substrates, i.e. it includes all nitrogenous compounds which will be incompletely oxidised but excludes fermentation heat. Since the feed fractions are defined functionally by the processes of ruminal and post ruminal digestion rather than (e.g.) some chemical or physical property of the diet, they are conceptually robust and

Figure 1. 'MENTOR', a Model of Metabolizable Energy and Metabolizable Protein Supply to Ruminants



can accommodate new research, e.g. partition of ME_t according to the major classes of absorbed substrates (acetate, propionate, amino acids, purines, etc.). The practical success of the system depends on how precisely we can (1) predict ME_t, TAAN (and other absorbed substrates) from properties of the diet and (2) describe the interactions between fermentation, degradation and microbial synthesis in the rumen that determine the utilisation of QDN, SDN, QFE and SFE and the supply of nutrients as VFA, UFE, microbial protein N and UDN.

PREDICTION OF TRUE METABOLIZABLE ENERGY

The carbohydrate fraction is divided into beta-glycans (SFE) and simple sugars, starch, pectin and other alpha-glycans (QFE). Dewhurst et al (1986) used the model to predict ME_t for 121 graminaceous forages originally tested at the Rowett Research Institute. Beta-glycans were defined by neutral-detergent fibre minus acid-detergent lignin (NDF-ADL). Agreement was very good. ,

Predicted ME_t = 1.03 Observed ME_t - 0.52 (r-0.95, RSD=0.58)

For compound feeds and raw materials used in compound feeds (wheat, maize and maize gluten, distiller's grains, rice bran, NaOH-treated straw, etc.) the relationships 'were (Dewhurst & Webster, 1989)

Compound feeds, predicted ME_t = 1.07 obs. ME_t + 0.84 (r-0.92, RSD=0.48)
Raw materials, predicted ME_t = 1.30 obs. ME, - 2.83 (r-0.95, RSD=0.83)

The fit is still good but both equations systematically overpredict ME_t, i.e. they are not succeeding in a deterministic sense. Further inspection of the data suggests that increasing QFE (starches and sugars)

progressively reduces the capacity of the rumen to ferment SFE. This is, of course, to be expected but the model does not yet properly take it into account. More recent, unpublished work indicates that SFE in raw materials and compound feeds is better predicted by the in vitro technique, neutral-detergent, cellulase digestibility (NCD) than from feed chemistry. For grasses (NDF-ADL) is adequate because they contain so little QFE. For grass silages, and other prefermented feeds it is also necessary to measure volatiles such as VFAs which contribute to ME_t but cannot be fermented so cannot contribute to the work of microbial protein synthesis. It may be that near infra-red (NIR) spectroscopy will prove to be a satisfactory method for predicting all sources of ME_t (including volatiles). The attraction of MENTOR is that the concept does not have to change to accommodate these developments as they occur.

The yield of SFE is, of course, dependent on rumen outflow rate (k). The usefulness of the model is enhanced if k can be predicted from DM intake and other attributes of the food. Since the model predicts (at least in theory) the rate at which digested and undigested material leave the rumen, it is only necessary to introduce constants for rumen volume and DM concentration to predict interactions between DM intake and ME_t on the eminently defensible premise that what goes in must come out.

PREDICTION OF TAAN OR METABOLISABLE PROTEIN

The UK Metabolisable Protein system (Alderman & Jarrige, 1987) differs from ARC (1980) in several respects, not least the partition of degradable protein into QDN and SDN. For practical purposes QDN is assumed to be synonymous with water-soluble N. At present we have no better nor quicker method for predicting SDN than the use of "*in sacco*" fermentation in porous synthetic fibre bags incubated in the rumen.

At present we assume that SDN is incorporated into microbial protein at an efficiency of 1.0 so long as fermentable energy is available but that QDN is incorporated at an efficiency of 0.8. There is nothing sacrosanct about this figure, it is merely that adopted by ARC (1980) for non-protein N (NPN). Since all QDN behaves, by definition, like NPN, it seems logical to assume the same efficiency for the time being. Once again the model can accommodate an improved coefficient (or variable) as new knowledge arrives.

ARC (1980) assumed that undegradable dietary N had a fixed true availability of 0.85. Van Soest (1982), however, claimed that acid-detergent insoluble N (ADIN) was entirely undegradable and indigestible. Webster et *al* (1988) examined 18 raw materials and obtained the following equation for prediction of truly available, undegraded N (UDN).

$$UDN = 0.9(UN - ADIN)$$

Further, unpublished studies from our laboratory and by Van Soest and Mason (1991) reveal however that some by-products such as distiller's grains undergo Maillard reactions following prolonged exposure to heat and moisture, which greatly increase ADIN concentration. Such ADIN appears to have a low but significant degradability. The above equation for the prediction of UDN therefore tends to undervalue the protein in products such as distiller's grains and maize gluten. We are currently working to define UDN and the biological value of UDN in these important feeds with greater precision.

MI'CROBIAL PROTEIN SYNTHESIS

ARC (1980) assume that

RDN requirement = microbial N synthesis = 1.25g/MJME

This assumption is deficient on several counts.

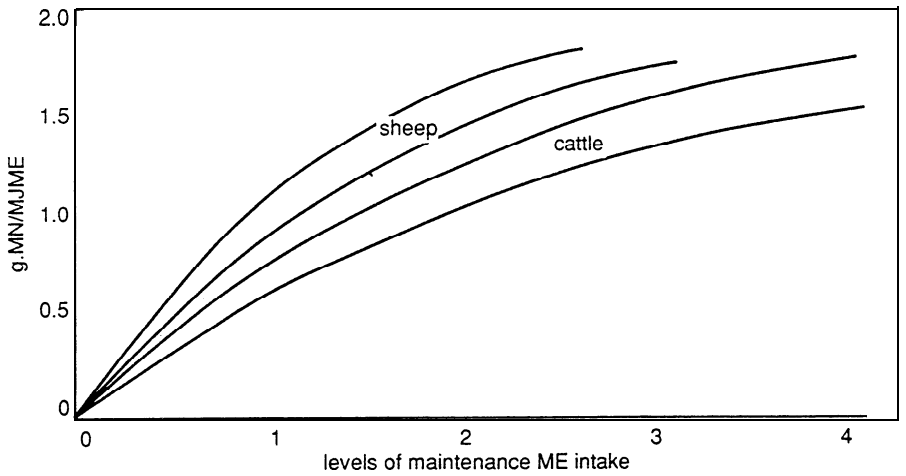
1. It does not distinguish between fermentable and unfermentable energy.

2 **It** does not account for changes in the efficiency of microbial yield attributable, e.g. to increasing plane of nutrition (thus k) or to changes in the maintenance requirements of microbes, e.g. in response to monensin.

3. It does not permit efficiency to vary according to proportions of QDN and SDN.

On the basis of literature data Webster et *al* (1988) have attempted to predict effects of increasing plane of nutrition on yield of microbial N (MN). For sheep MN ranges from approximately 1.0g MN/MJME at maintenance to 1.6 at 2.5x maintenance; for cattle 0.6 at maintenance to 1.5 at 3x maintenance. The species differences are attributable to the fact that rumen volume in sheep and cattle scales according to $W^{1.0}$ but maintenance energy requirement according to $W^{0.75}$

Figure 2. Predicted Effect of Plane of Nutrition on the Energetic Efficiency of Microbial N Synthesis in Cattle and Sheep



Microbial protein yield probably represents the greatest source of uncertainty in the prediction of substrate supply to ruminants. Attempts to relate microbial protein yield to fermented energy and degradable N have traditionally been based on measurements of N flow at the duodenum. These invasive techniques are slow, expensive and bedevilled by uncertainties as to the use of markers. An alternative, simple, cheap and non-invasive approach has been described by Chen et al (1990) and Dewhurst and Webster (1991). This is based on the fact that urinary excretion of purine derivatives is linearly related to purine supply. When intake exceeds maintenance the contribution of de novo synthesis, endogenous loss and salvage to purine exchange become trivial relative to absorbed exogenous purines from rumen microbes. Measurements of increments of purine excretion relative to

increments of fermentable energy can therefore be used to predict the energetic efficiency of microbial protein yield to the abomasum.

CONCLUSIONS

By the standards of the criteria we have set for a practical system for the prediction of substrate supply to ruminants, it is possible to conclude that

1 Mentor can be based on measurements of feed chemistry, NIR spectroscopy or *in vitro* digestion methods that are robust and available to the feed compounder. We need to improve the prediction of SDN, UDN, especially where Maillard reactions have occurred and SFE, especially where fermentation of SFE is inhibited by the presence of substantial amounts of QFE.

2 The model is deterministic and distinguishes properly between the processes of ruminant and post-ruminant digestion. We need to improve the prediction of outflow rates of solids and microbes from the rumen and microbial yield.

3 The model does not predict the supply of individual amino acids but it can distinguish different relative molar yields of the principal VFAs (acetate and propionate) from QFE and SFE (Fig. 1). It should therefore be applicable to models of nutrient requirement that partition nutrients used for growth or lactation according to the nature of the absorbed substrates.

4. Mentor can predict ME_t in grasses at least as well as any other system in common use. It is equally applicable, in theory, to the prediction of ME_t in clovers, lucerne and balanced compound feeds given an adequate description of cell wall carbohydrate. The characterisation of feeds in terms of MP gives values that are unproven and at variance with ARC (1984) but sensible and in reasonable accord with all other major systems for protein evaluation.

REFERENCES

AGRICULTURAL RESEARCH COUNCIL (1980) The Nutrient Requirements of Farm Livestock No.2. Ruminants 2nd Ed., Commonwealth Agriculture Bureau, Farnham Royal.

ALDERMAN, G. and JARRIGE, R. (1987) "Protein evaluation of ruminant feeds" Commission of European Communities, EUR 10657 EN.

BLACK, J.L., BEEVER, D.E., FAICHNEY, G.J., HOWARTH, B.R. and GRAHAM, N.McC. (1981) Agricultural Systems 6: 221.

CHEN, X.B., HOVELL, F.D.deB., OR&V, E.R. and BROWN, D.S. (1990) British Journal of Nutrition 63: 131.

DEWHURST, R.J., WEBSTER, A.J.F., WAINMAN, F.W. and DEWEY, P.J.S. (1986) Animal Production 43: 183.

DEWHURST, R.J. and WEBSTER, A.J.F. (1989) "Energy Metabolism of Farm Animals, 11" EAAP Publ. 43, Pudoc Wageningen.

DEWHURST, R.J. and WEBSTER, A.J.F. (1991) British Journal of Nutrition (in press).

VAN SOEST, P.J. (1982) Nutritional Ecology of the Ruminant. O&B Books, Corvallis, Oregon.

VAN SOEST, P.J. and MASON, V.C. (1991) Animal Feed Science and Technology 32: 45.

WEBSTER, A.J.F., DEWHURST, R.J. and WATERS, C.J. (1988) In "Recent Advances in Animal Nutrition, p. 167, editors W. Haresign and D.J.A. Cole (Butterworths, London)..