THE ROLE OF METABOLIZABLE ENERGY IN FEEDING SYSTEMS

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Most of the feeding systems at present in use in the world were developed in northern Europe or north America where winters are long and livestock have to be housed for a large part of every year. They were developed in-response to practical needs. Farmers wished to know how to allocate reserves of conserved feed and how to plan purchases so to maintain the productivity of their stock. They posed questions of three types, Firstly they wished to know what production they could expect from a particular ration, secondly how to manipulate quantities of feed to obtain a particular production, and thirdly how they could estimate how much of one feed could be substituted for another without affecting production of meat and milk. Each one of these questions predicates an ability to control the quantity of each feed given to the animal.

In pastoral countries the situation is rather different because there can only be a partial control of the quantity of herbage consumed by a grazing animal. The questions graziers ask mostly relate to the merits of different swards, grazing practices and other factors in providing adequate feed - adequate in the sense of maintaining productivity. In addition, they ask what feeds and in what amounts should be used to supplement pastures in times of dearth. In countries which have to house stock for long periods because of the high cost of labour, there is currently a movement to depart from rigid control of quantity and to substitute ad libitum access to the whole diet or a substantial part of it. The practical questions then relate to optimal formulation of mixtures and again the substitution value of feeds.

That the practical questions asked in these three situations are different does not mean that there are not common bases for the answers to them. We need to be able firstly to predict the voluntary intake of feed and secondly to know the quantitative relationship between the amount of feed consumed and the production of meat and milk that results. I wish to deal with this second aspect which is central to the symposium; this does not mean that I minimize the importance of the first.

The problem of describing the relationship between the heat of combustion of the feed eaten and the production of an animal is an old one. Early attempts to solve it led to the concept that the relationship was a linear one with production proportional to intake above some intercept value of maintenance. This led to the simple and convenient concept that feeds could be assigned unique values which were in effect the slopes of these linear relationships and that feeds substituted for one another in direct proportion. Starch equivalents, net energy values, Scandinavian feed units and most European feed units

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were of this nature. As more work was done it was realized, however, that the basic premise was wrong. The relationship between feed intake and production as measured by energy retention was found to be curvilinear, the slope decreasing with intake and curvilinearity varied considerably from feed to feed. Furthermore, the relationships varied from one type of production to another; they were not the same in milking cows as in growing and fattening stock, nor could the intercept of maintenance be regarded as something invariant with weight for it was found to be affected by breed, age and sex of animal and by the diet. These findings implied that a unique nutritive value could not be assigned to a feed; the nutritive value of a feed as an energy source varies with the type of feed, the amount of it that is given and the type of animal it is given to. There is no longer the possibility of using simple proportionality to work out rations or the substitution values of feeds. These advances in knowledge have clearly led to difficulties.

The solution found to these difficulties, is the adoption of the metabolizable energy system. The basic premise in this system is that the factors which give rise to curvilinearity can be isolated and expressed as a set of rules which govern the relationship between a standard measure of feed value (metabolizable energy) and the energy which an animal lays down in its body during growth or pregnancy or secretes in its milk during lactation. There are thus three components of the system, feed tables, rules and tables of animal requirement rather than as in all other systems, two - feed tables and requirement tables. This device of using three components imparts enormous advantages. As new information accrues about the relationship between feed and animal performance it can be incorporated into the system by modification of the rules. This is without effect on the primary listing of the value of the feeds or of the requirements of animals. When new breeds or crosses come into use, then the energy equivalent of their gains can be determined and added to the existing tables. Similarly, information about the primary attributes of feeds can be added to systematically without fear that advances in knowledge about the basic relationships will render the effort redundant.

Metabolizable energy of feeds

We can consider first the primary measurement of metabolizable energy. It is defined as:

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\text{Metabolizable energy (MJ)} = \text{Heat of combustion of feed} - \text{Heat of combustion of, faeces, methane and urine produced consumed,}
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It is clearly a biological assessment and questions thus arise about its variation. Is it independent of feeding level? Is it the same in different species, of ruminant? Is it an additive quantity, that is, is the metabolizable energy of a mixture the sum of its components?

As the amount of feed consumed increases, the metabolizability of feed \( q = \text{(ME/GE)} \) declines. The decline arises from an increase in faecal loss partly compensated by a fall in loss of energy in urine and as methane. The decline varies with the type of feed. A recent
analysis of 80 experiments (Blaxter and Boyne 1977) showed that with all pelleted diets and pasture regrowths q fell irrespective of chemical composition, but with first harvests the effect of intake was conditional upon the fibre content. Falls with increased intake did not occur until fibre content exceeded 238 g/kg organic matter. Clearly there are differences between feed classes in the extent of the fall with intake. These falls in q can be accommodated in the rules and to avoid any mixed significance of tabulated values of the metabolizable energy of feeds these are all specifically measured at maintenance. The primary listing is thus of metabolizable energy measured at the maintenance level of feeding.

Wainman (; 976) has compiled a list of all those experiments done throughout the world in which cattle and sheep have been given the same sample of the same feed. The results are complicated because the level of feeding of the sheep was not necessarily the same as that of the cattle, but no systematic differences were found between the two species. The results of seven experiments designed to test the supposition specifically at the maintenance level have also shown no differences (Blaxter 1974). This does not mean that the relationship between feeding level and q is the same in sheep and cattle. Indeed, there is evidence that the decline might be greater in sheep than in cattle (Blaxter, Wainman and Davidson 1966) and greater in fattening cattle than in milking cows (van Es 1975). Such differences can again be accommodated in the rules.

As far as additivity of the metabolizable energy of mixtures is concerned, the small amount of evidence in 1974 (three experiments - see Blaxter 1974) suggesting that metabolizable energy measured at maintenance is an additive quantity has now been added to considerably by a series of 64 experiments conducted at the Rowett Institute. In these, 16 samples of oats and 16 samples of barley have been used to substitute for forage and for silage at four levels (DAFS 1976). There was no evidence of any departure from linearity of substitution although on occasion methane losses showed small departures. These diets were not extreme ones. There is evidence, however, (Wainman et al. 1974) that a direct proportionality of substitution may not be true of extreme rations where substitution reduces dietary protein to below animal requirements. For usual rations, however, the assumption of additivity is tenable.

In passing it may be noted that it is possible that metabolizable energy values of feeds can be estimated with sufficient accuracy for many purposes from knowledge of the chemical composition and other attributes of the feed. This goal is indeed one of the purposes behind the Feed Evaluation Unit at the Rowett Institute, where modern analytical techniques are being used to describe all the feeds tested. Unfortunately most of the past data on the composition and metabolizable energy of feeds relates to the outmoded Weende scheme of analysis. Factors derived from 80 experiments for computing metabolizable energy from crude chemical composition are given in Table 1 (Blaxter and Boyne 1977). A better estimate (residual standard deviation $\pm 0.80$) can be obtained from a regression involving determined gross energy and fibre content alone.
TABLE 1: Factors (MJ/kg) for estimating gross energy and metabolizable energy of feeds from crude chemical composition.

<table>
<thead>
<tr>
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<th>Gross energy</th>
<th>Metabolizable energy</th>
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<tbody>
<tr>
<td>Crude protein</td>
<td>26.8</td>
<td>16.1</td>
</tr>
<tr>
<td>Ether extractives</td>
<td>27.2</td>
<td>33.7</td>
</tr>
<tr>
<td>Crude fibre</td>
<td>21.8</td>
<td>8.6</td>
</tr>
<tr>
<td>N-free extractives</td>
<td>17.4</td>
<td>13.9</td>
</tr>
<tr>
<td>Residual standard deviation</td>
<td>± 0.47</td>
<td>± 1.09</td>
</tr>
<tr>
<td>Coefficient of variation</td>
<td>± 2.3</td>
<td>± 9.4</td>
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</tbody>
</table>

The rules.

An early set of rules relating metabolizable energy intake to energy retention or secretion were given in the publication by the Agricultural Research Council of the U.K. in 1965. They consisted of a method to correct for level of feeding and a set of three equations which permitted estimation of the efficiency of utilization of metabolizable energy for maintenance, $k_m$, for growth and fattening, $k_f$, and for lactation, $k_l$, the equations summarizing the relatively small amount of information then available. The efficiency terms were all estimated from the metabolizability of gross energy, a point which emphasizes the central importance of the metabolizable energy measurement. A simplification was also suggested at that time, namely the expression of metabolizability (ME/GE) as ME/dry matter, a device which assumes constancy of the heat of combustion of the dry matter of all feeds. This ARC scheme was further simplified by the Departments of Agriculture of the U.K. (MAFF, DAFS, DANI 1975) and Mr Alderman will be describing this scheme later.

In the last few years, extensive revision of the original ARC publication has taken place and better estimates of the efficiency terms have been arrived at. These now take into account variation which can be ascribed to the nature of the diet. More recent work begins to show that the whole system of rules can be further simplified by developing the approach which Dr Graham and I made over 20 years ago (Blaxter and Graham 1955), namely by describing the relationships between feed intake and energy retention by a series of exponential equations (Blaxter and Boyne 1977). The main determinant of the constants of these equations is again the metabolizable energy of feed which emphasizes once more the importance of this primary measurement.

Further developments can be anticipated. There is considerable evidence for rats (Pullar and Webster 1977) and pigs (Kielanowski 1976) that the cost in terms of metabolizable energy of depositing energy as protein in the body is considerably greater than that of depositing energy as fat. With lambs there are some experiments to show that what is true of rats and pigs might equally apply to ruminants (Drskov and McDonald 1970; Bickel and Durrer 1974).
Again, if changes in the composition of the body during growth justify making an allowance for different rates of deposition of protein and fat, then their effect on feed energy requirements can be allowed for by adjustment of the rules which relate metabolizable energy intake to energy deposition in the body.

**Animal requirements**

The estimates of animal requirements which constitute the third part of the metabolizable energy system simply comprise estimates of the energy value of weight gains derived from body compositional data, estimates of fasting metabolic rate, and of the heat of combustion of milk. This information is being added to continuously through the many analyses of carcasses being made in many countries and by direct measurements of heat production.

One of the most critical areas at present relates to the paucity of information about the fasting heat production of growing animals. In the metabolizable energy system such information is essential because fasting metabolism is regarded as the measure, independent of the nature or amount of feed, of maintenance requirements. There appears to be general agreement internationally that the fasting metabolism of adult cattle is close to 320 kJ/kg weight raised to the power $\frac{3}{4}$, and that in adult sheep fasting metabolism expressed in a similar way is lower and declines with their age. In growing animals, however, there is as yet no such certainty; metabolic rate may vary with the extent of protein turn-over in the body and antecedent feeding. The studies made in Australia with sheep (Graham, Searle and Griffiths 1974) and those in Scotland with cattle (Webster 1976) begin to indicate the magnitude of the problem. When estimates are made - and the task is not simple - there is no reason to suppose that the same high precision of the system noted in the later stages of growth and in mature animals will not apply to young rapidly growing ones.

**Concluding remarks**

Despite the many difficulties that arise when new and even more careful measurement of energy exchanges are made, the metabolizable energy system as a whole provides a framework in which much can be built. It also provides the information base from which solutions to the more practical questions farmers and graziers ask can be devise. It is true that the system is more complicated than the simple additive systems exemplified by the German starch value system or the American TDN system, their variants or indeed the American net energy (lactation) schemes. This is inevitable since the system embraces much more knowledge about the animal's response to feed. That calculations may involve the use of a pocket calculator rather than the back of an envelope is the cost involved in acquiring greater precision, in providing better methods of estimating animal production and in achieving better use of feed resources.

**References**

ARC (1965). *The nutrient requirements of farm livestock, No. 2. Ruminants* (ARC: London)


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