RECENT DEVELOPMENTS IN THE METABOLIZABLE ENERGY FEEDING SYSTEM FOR RUMINANTS

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SUMMARY

Equations presented predict the metabolizable energy (ME) content of feeds, and ME requirements for maintenance and production. New approaches are described for defining the maintenance requirements of penned and grazing animals, and the composition and energy of liveweight gains. The latter employs the concept of a Standard Reference Weight (SRW) to characterise the various breeds of cattle and sheep and their sex types. The SRW are also used to define the change in liveweight equivalent to unit change in condition score, and in the procedure for predicting feed intake which is outlined.

INTRODUCTION

More than 50 years ago, E.B. Forbes and other were discussing the nutritional significance of the metabolizable energy (ME) content of diets in relation to the efficiency of energy utilisation by the animal (for reviews, see Blaxter 1956 and Mitchell 1964). Discussion, and arguments, revolved around the concept of 'balance' in diets, and the proposition that “the utilisation of the metabolizable energy of well-balanced rations approaches constancy for the same kind of animals in approximately the same condition of physiological functioning” (Mitchell 1942). Balance was perceived as an adequacy of all nutrients, including protein, minerals and vitamins, such that no addition increased the efficiency of energy utilisation or, as the corollary, decreased the’calorigenic effect of the feed. The arguments became less semantic in nature, and more objective, as knowledge accrued. It became evident that the utilization of ME for any particular function (i.e., maintenance, growth, reproduction, lactation) varied with its concentration in the diet and not simply the actual amount provided. Because variation in ME concentration reflected differences in the chemical composition of the feed, as for example in a forage at various stages of maturity, there would be substantial variation in the composition of the mixture of end products of digestion, thence in the spectrum of metabolites absorbed and available for tissue metabolism, and consequently in the efficiency with which their energy was used.

It has long been recognised that although ME is a convenient single measure of energy value, it does not take account of chemical variation in the sources of the ME and variation in their net energy value singly and as mixtures. Indirect allowance is made when ME values for feeds and rations are used to establish the quantities required for desired animal production or to predict animal performance with given feed intake. For example, variation in the net efficiency of use of ME for growth and fattening (NE/ME = k_g) with metabolizability of the gross energy of the feed (ME/GE measured at the

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maintenance level of feeding, or more conveniently as MJ of ME per kg dry matter = M/D) was described by the ARC (1965) for all diets with a single equation. With the results of further calorimetric studies then available, the ARC (1980) **presented four equations** to predict k_g **from ME/GE, each one being applicable to a** part**icular class of feed** (pelleted; first growth forages; **aftermath forages; mixed** diets). In practice the ARC (1980) recommended a fifth **"all** diets" equation derived from a conflation of all the information used to derive the other four; this simplification was presumably adopted because animals in the UK may often, but not always, be fed a ration comprising feeds from more than one of the classes.

By presenting four equations to predict k_g, the ARC (1980) makes indirect and frankly empirical allowance for **variation** in the chemical source of ME. Much work has provided, and continues to provide, increasing understanding of how and why there is variation in NE/ME. Last century, Henry (1898) stated "while it is important to study, from a scientific basis, the fuel value of rations,. for practice a statement of the several nutrients themselves is more explicit and satisfactory". This perceptive statement identifies the desirable goal, being pursued by many, of describing objectively with dynamic computer models of digestion and metabolism the responses of animals to varying types and amounts of feeds; Examples are the model of Black et al. (1982) which simulates the digestion by the ruminant animal of known or estimated intake of foods, characterized by details of their chemical composition, and predicts the amounts of the various products of digestion; and the model of Gill et al. (1984) which simulates the metabolism of absorbed nutrients and predicts fat and protein deposition in the animal's body.

These approaches will replace existing feeding systems in a variety of applications, but not yet. Replacement will occur when the new procedures are clearly superior in operation to, in particular, feeding systems based on ME. A major impediment is the lack of the large volume of high quality information on ruminant feeds that is required to operate models of digestion such as that of Black et al. (1982). This difficulty applies especially, but not exclusive-grazing animals because of the need to define the quantity of feed consumed as well as the detailed composition. A model of nutrient **metabolism in** pigs and predictions of their performance (Black et al. 1986) is being adopted in the Australian pig industry, and is in fact a modification of a similar model for sheep. The reliability of results from use of the model with sheep, even though they may in themselves be rather exact, will inevitably be substantially reduced by the 'noise' from uncertainties about the amount and composition of feed eaten and the outcomes of its digestion in the **rumen.**

For all its recognised imperfections and simplifications, practical experience of the ME feeding system as developed by MAFF (1975, 1984) from ARC (1965, 1980) has proven its serviceability. Favourable reports on its use with dairy cows have been given by Broster and Thomas (1981) and, in Australia, by Fulkerson et al. (1986). It has appeared to be somewhat less satisfactory when applied to beef cattle and sheep; reasons for this and modifications of the system to improve its reliability, are discussed in following sections.

It is to be hoped that the ME system, or any other, is now nowhere regarded as a set of standards that determine inflexibly what an animal *ought' to be fed. Its purpose is to facilitate the description in quantitative and monetary terms of the responses of animals to changes in the supplies of nutrients from their feeds, providing realistic answers to many practical problems in animal feeding. For example:

what production may be expected from an animal given a particular ration, or what ration is necessary to achieve a given production with the proviso that the formulation must be least-cost?

The ME system has been used with success in drought-feeding to compare real costs of available forages, grains etc, and to identify the cheapest means of meeting the needs of animals for survival, also defined in terms of ME (e.g., Clark 1980; Freer *et al.* 1977). The ARC (1965, 1980) and MAFF (1975, 1984) publications were, of course, primarily concerned with the feeding of animals in conditions to be found in the UK, just as corresponding publications from Europe, the USA etc relate primarily to conditions in those countries. Much of the basic information is applicable to Australia, but practical application is problematical; a major reason is the dependence of Australian sheep and cattle production on pasture, and the publications from oversea give scant attention to the problems associated with pastoral systems of production.

The Animal Production Committee (APC) established a Working Party on the Introduction of Nationally Uniform Feeding Standards for Livestock; among its terms of reference was the instruction “to implement feeding systems for ruminants ... based on ME”. The work of the Ruminants Sub-Committee is approaching completion and, as for the Pigs and Poultry Sub-Committees, its Report is to be published by the APC.

This paper outlines main features of the chapter on Energy in the Report, with a compendium of the equations used to predict the ME content of feeds, and the needs of cattle, sheep and goats. Material in four of the other main chapters (Protein, Minerals, Vitamins and Water) will generally not be mentioned, but some reference will be made to the chapter on Prediction of Feed Intake.

It should be noted that the conclusions of the Ruminants Sub-Committee described here are still subject to scrutiny by members of the organisations represented on the APC, and thus may be subject to some modification.

RECENT DEVELOPMENTS

Origins of the equations given in the next section are fully documented in the Report and will generally not be given here. A few innovations will be discussed, in particular the approach developed to assess the energy requirements of animals for maintenance, including the additional requirements of those grazing compared with those housed; and the concept of a ‘Standard Reference Weight’ (SRW) to characterise the various breeds and sex-types of cattle and sheep. The SRW are used to assist definition of the composition and energy content of liveweight gains, the liveweight changes (kg) equivalent to unit change in condition score, and as a reference base in the scheme for predicting feed intake.

Maintenance

As the feed intake of the animal increases from zero, the ME is perceived first as being used to spare body tissues from the catabolism that would provide the energy required by the animal for viability. The net efficiency of use of ME for this purpose (k_m) is usually, for convenience, described by a straight line between fast and 'maintenance' intake (Fig. 1), its slope varying with feed quality (M/D). Above the maintenance intake, energy is retained by the animal and is manifest as liveweight gain, or milk secretion. Efficiencies of

ME use for these purposes (k_g, k_l) are also conveniently represented as straight lines, as for k_g in Fig. 1, but biological processes are rarely represented truly in this way. In fact, calorimetric studies do show curvilinearity in the relationship between ME intake and energy balance.

There has been much discussion of the causes of this phenomenon and its implications in animal feeding. It is not accounted for by a decrease in the metabolisability of the feed (ME/GE, or M/D) with increasing level of feeding. The ARC (1980), for example, points out that it could reflect either (1) a decrease in the efficiency of utilisation of increments of ME above a constant maintenance, or (ii) a constant efficiency of utilisation but with a progressive increase in a component of the total energy expenditure analagous to a maintenance cost. The ARC (1980) adhered to the first viewpoint and, in common with other energy feeding systems current oversea, the notional maintenance component of the total energy expenditure of animals of any given type is set at an invariant value per unit of liveweight (W, kg) whether the animals are growing, pregnant, lactating or fed for survival.

There is, however, much direct and indirect evidence that the inescapable non-productive energy expenditures of animals, their notional maintenance requirements or 'support' metabolism, vary directly with their feed intake. The causes probably include changes in both the size of and rates of metabolism in organs and tissues (Armstrong and Blaxter 1984; Ferrell et al. 1986) with alterations in the rates and energy costs of blood flow, protein turnover, sodium-potassium ion transport and other essential processes (Milligan and Summers 1986).

It is known that during inanition there are decreases in the basal metabolic rate of non-ruminants, including man, and in the fasting heat production of cattle and sheep. Direct evidence of practical importance is provided by the drought feeding trials with sheep at Glenfield, NSW, summarised by CSIRO (1958), and with cattle in Queensland summarised by Morris (1968). Results from these trials with both species showed that for survival the animals required only 84% of the energy allowances for maintenance recommended by the ARC (1980) and other authorities.

The corollary, that the maintenance or support metabolism increases with feed intake, probably accounts in large part for the differences between energy systems based directly on calorimetric studies (e.g., ARC 1980) and those (NRC 1984, 1985) derived from the results of comparative slaughter (CS) trials. Graham (1982) has suggested that, because the response to change in feed intake is rather slow, this effect is not allowed time for full expression in short-term calorimetric studies in which the amount of feed given to animals is usually changed at intervals of about three weeks. Consequently, when animals in these studies are fed at production levels they will tend to use a smaller fraction of their ME intake for maintenance, and will have a greater amount of ME available for production, than when the same intake is sustained over longer periods as with animals in CS trials. Values for k_g obtained by CS with cattle (e.g., Garrett 1980) and sheep (e.g., Thomson et al. 1979) are generally less than those obtained for similar feeds by calorimetric measurements of energy balance (see Fig. 1). Consequently the energy gain by animals in CS trials from a given intake of a feed is generally found to be less, and the derived estimates of ME allowances for a given liveweight gain tend to be greater, than the gain and allowances determined calorimetrically. For example, the NRC (1984) values for the ME

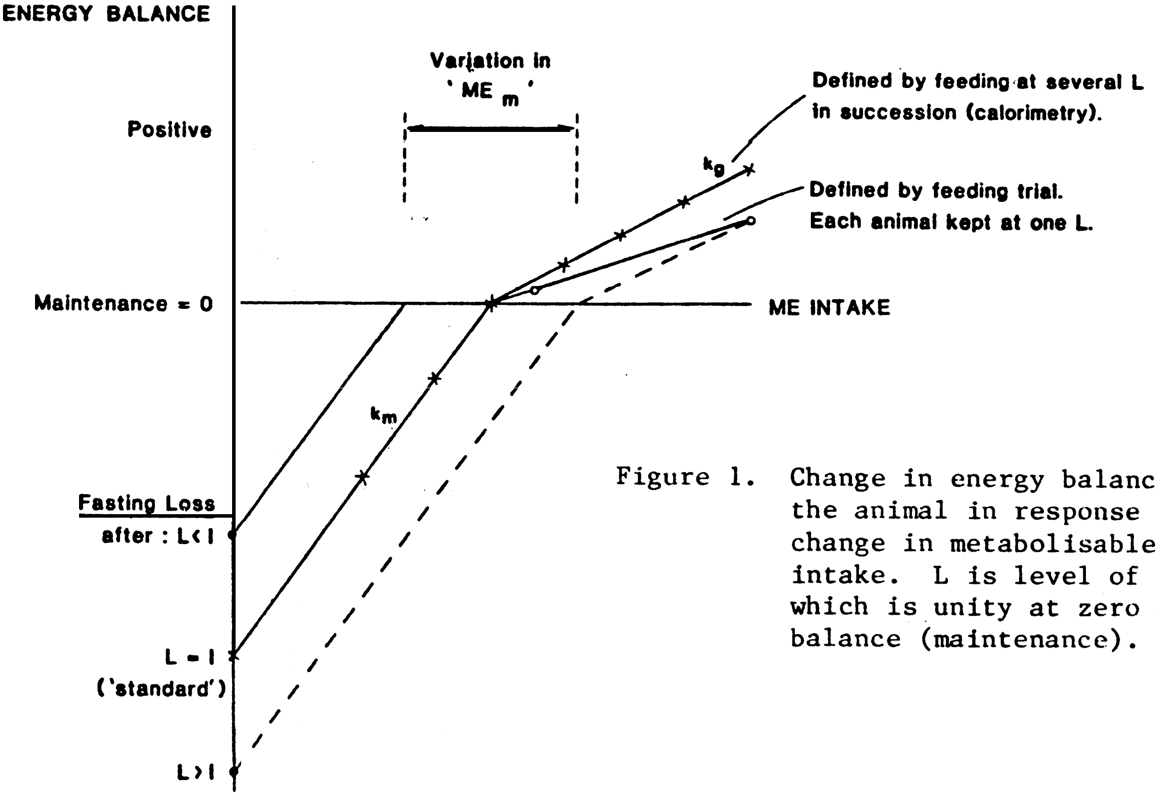

Figure 1. Change in energy balance of the animal in response to change in metabolisable energy intake. L is level of feeding which is unity at zero energy balance (maintenance).

Table 1. Examples of ME requirements for maintenance and production of penned cattle and sheep (EWORK = 0), not cold stressed.

	Cow	Ewe	Hereford steer	Dorset wether
Liveweight (kg)	600	50	300	30
Age (years)	5	4	1	0.5
SRW (kg)	-	-	600	66
Milk yield	30	1.5	-	-
Fat (g/kg)	36	75	-	-
Solids-not-fat (g/kg)	86	-	-	-
Day of lactation	-	21	-	-
Liveweight gain (kg/d)	0	0	1.0	0.2
Energy of gain (MJ/d)	0	0	16.4	3.1
Diet M/D	11	11	11	11
ME (MJ/d): Maintenance	56.8	6.5	38.1	4.9
Production (ME_p)	141.0	11.4	34.9	6.6
Plus 0.1 ME_p	14.1	1.1	3.5	0.7
TOTAL	212	19	76.5	12.2
Other estimates: ARC (1980)	207	18.2	67	11.0
MAFF (1984)	210	17.4	73	12.8
NRC (1975)	215	-	-	-
NRC (1984)	-	-	78	-
NRC (1985)	-	20.5	-	14.2

requirements of beef cattle are larger than those given by ARC (1980) and MAFF (1984). The latter two sets of recommended ME have been found to be too low in practical feeding (Alderman et al.. 1974; G. Alderman, pers. comm.; R.A. Edwards, pers. comm.), and in experimental studies which indicate that the ARC (1980) values for maintenance (ME,) are too low when used for the formulation of production rations (Anon 1985; Smith and Mollison 1985).

Estimates of ME_m obtained by the two techniques are similar, because those derived by CS for cattle, and for sheep (e.g., Thomson et al. 1979), from the regression of energy balance on ME intake, will reflect the performance of the animals that are fed for approximately maintenance to a much greater extent than the performance of other animals in the studies that are fed at or near ad lib. Consequently the values obtained will differ little from ME_m calculated from measurements of fasting metabolism (FM) as (FM/k_m). The measurements of FM are made in standardised conditions. In particular, the animals are fed at about the maintenance level for about three weeks before fast because, otherwise, the results are highly variable (Fig. 1). The standard FM values may consequently be viewed as defining the minimal energy requirements for maintenance of animals that are to be fed for maintenance only, but are generally used as an operational definition of the maintenance moiety at all levels of feeding. The ARC (1980) makes an allowance for additional physical activity of the fed compared with fasted animal, and progressively discounts the value of k_g (but not of k,) as intake for production increases.

Graham et al. (1974) measured the energy loss during fast of sheep as they grew at various rates from one week of age. Much of the variance in the results was accounted for by bodyweight, but age, growth rate and level of feeding, and the proportion of the energy intake provided by milk, were also significant. The regression equation they derived was not immediately applicable in practice for a number of reasons, but an algebraic rearrangement and a number of modification made by Corbett et al. (1985) have yielded a generalised equation to predict ME_m for cattle and sheep of all ages, breeds and sex types; it is probably also applicable to goats. Its use is recommended by the Ruminants Sub-Committee which has accepted that there is real variation in the maintenance metabolism. The variation is defined in the following equation (1) with the term 0.09 MEI; this equation is used when total ME intake (MEI) is known, or predicted, in order to calculate ME_m and the ME available for production (= MEI - ME,), and thence to predict animal performance.

$$ME_m(MJ/d) = \frac{K.S.M.\ (0.26W^{0.75}\ .e^{-0.03A})}{k_m} + 0.09MEI + \frac{EWORK}{k_m} + ECOLD \quad (1)$$

where: K = 1.0 for sheep and goats, or 1.2 for B. indicus, or 1.4 for B. taurus, or a value intermediate between 1.2 and 1.4 for crosses between these breeds (e.g., 1.3 for first cross, 1.25 for 3/4 B. indicus).
S = 1.0 for females and castrates, or 1.15 for entire males (rams, buck goats, bulls).
M = 1 + (0.23 x per cent diet DE from milk) = 1 + (0.26 - Ba) with B = 0.015 for suckled lambs and kid goats or = 0.01 for suckled calves, and a is week of life. Minimum value of M is 1.0.
W = liveweight (kg)
A = age in years, with a maximum value of 6.0, when ($e^{-0.03A}$) equals 0.84.

k_m = net efficiency of ME use for maintenance = 0.02 M/D + 0.5
MEI = total ME intake
EWORK = energy expenditure on muscular work
ECOLD = additional energy expenditure in cold stress.

The calculation of ECOLD will not be described here. For animals fed in stalls, pens or yards it can generally be assumed that EWORK = 0 because ME_m already allows for the energy costs of the normal physical activities in these conditions. The maintenance requirement of grazing animals not cold-stressed is higher by 10 to 20% in best grazing conditions and by a maximum 50 to 60% for animals on extensive undulating or hilly pastures with sparse feed. Their physical activities will certainly not cause a two or three fold increase in ME_m as some earlier studies (e.g., Lambourne and Reardon 1963) had erroneously suggested (Corbett 1980).

Equation (2) has been developed to predict the additional net energy requirements for maintenance when animals are grazing.

$$\text{EWORK, MJ net energy per day} = [(C.DMI(0.9 - D)) + (0.05T/(GF + 3))]W \qquad (2)$$

where: C = 0.08 (sheep, goats) or 0.01 (cattle)
DMI = dry matter intake kg/d
D = digestibility of the dry matter (decimal)
T = 1.0 or 1.5 or 2.0 for respectively level, undulating or hilly terrain
GF = availability of green forage, tonnes DM/ha (quantity when cut to ground level; if only dead forage is available, then GF = 0 and the divisor = 3)
W = liveweight kg.

The first term defines the additional net energy expenditure in eating (MJ/kg W) incurred by grazing compared with housed animals. It is assumed that the energy expended in ruminating for a given quantity and quality (D) of feed does not differ between grazing and housed animals, and no allowance is made for this activity. The values of the coefficient C imply that the relative rates of DMI (kg/h) from pasture by sheep and cattle are 1:8 (i.e., energy costs per kg DMI are 8:1 respectively).

The second term defines the net energy expenditure on walking (MJ/kg W) which decreases as forage availability increases and the animals have to walk shorter distances to gain their feed. This expenditure also varies with the terrain, and with T = 1, the maximum value for this term is 0.017 MJ/kg W which implies a distance walked of 6.5 km/d. In arid or semi-arid areas with rather few watering points, animals may regularly walk longer distances to drink in addition to those walked during grazing, and EWORK should then be increased by 0.0026MJ/kg W for each extra km (horizontal) and 28MJ/kgW/km (vertical component).

Equation (3) is an alternative form of (1), to be used for the formulation of rations.

$$ME_m(\text{MJ/d}) = \frac{K.S.M.\ (0.28W^{0.75}\ .e^{-0.03A})}{k_m} + 0.1ME_p + \frac{\text{EWORK}}{k_m} + \text{ECOLD} \qquad (3)$$

ME_p is the amount of dietary ME to be used directly for production, and with this term in place of 0.09 MEI the coefficient in the first term is 0.28 instead of 0.26.

Care has been taken to ensure that it is valid to use the ARC (1980) equations to predict k_m, k_g and k_l when using equations (1), (2) and (3). They have been modified for prediction from M/D rather than ME/GE and are given below. Three points should be noted:

(i) M/D values are not adjusted for level of feeding (L)

(ii) the value of k_g predicted for any particular diet is also not varied with L

and (iii) the term $0.1ME_p$ is not to be used in assessing ME requirements for pregnancy because the value for the efficiency of use of ME for conceptus growth is a gross and not a net efficiency. It allows for all energy costs of gestation including the growth and maintenance of uterine and other tissues, the maintenance of the foetus, and any augmentation of the maternal metabolism.

The first term in equation (3) yields values for the net energy requirements for maintenance of cattle and sheep that, are similar to those predicted with the corresponding ARC (1980) equations, which were derived by comprehensive examination of calorimetric results. It is recommended that the amounts of feed required for survival by animals in drought should initially be calculated with the first term. Their performances should be monitored to determine whether, and to what extent, their rations could subsequently by reduced. A potential for a 10 to 20% reduction might not be realised if the animals expended considerable energy in foraging widely for residual herbage, or there was risk of or actual cold-stress, or a significant proportion of the animals was gaining a barely adequate share of the feed provided.

When using equation (1), the net energy gain by the animal (growth, milk production) is (MEI-ME_m) divided by k_g or k_l. This gain is converted into terms of liveweight increase or milk yield with information on the probable heats of combustion (gross energy) of these products.

When using equation (3), for ration formulation, the increase in the maintenance metabolism with increasing intake is, for convenience, regarded as a charge on the energy cost of the production. Thus with ME_m calculated with the first term (plus EWORK and ECOLD if appropriate) , a liveweight gain of 1 kg/d which is, say, 20MJ net energy will require 1.1 x $(20/k_g)$ MJ of ME where k_g is variable with diet M/D. Similarly the ME required for given milk production is the gross energy of the milk divided by k_l, then incremented by 10%.

Table 1 gives examples of ME requirements calculated in this way. It will be seen that the requirement for the lactating dairy cow is similar to those given by the ARC (1984) and MAFF (1984) which have both been found to be reliable in practice. The requirement for the beef animal is greater than those given by either of the UK sources, known to be inadequate (see above), but is similar to the NRC (1984) estimate which was based on studies with animals in practical conditions of feeding and management. The requirements calculated for sheep are broadly similar to those given by the other systems, but the discrepancies reflect a number of uncertainties in the latter which include imprecise definition of conditions of management and type of animal. MAFF (1984) values for ME_m for sheep are certainly too low.

Composition of Liveweight Gains and Standard Reference Weight (SRW)

The relative proportions of fat and protein deposited during growth, and thus the energy content of gains, vary with the breed, sex and age (or liveweight) of the animal. The ARC (1980) equations to predict the composition of gain by cattle allow for this variation, but require identification of breeds as "small", "medium" or "large" mature sizes ; what these are is not specified. In addition to this difficulty, Garrett (1985) has demonstrated that some of the values predicted are rather improbable from a biological standpoint. There are also difficulties with the ARC (1980) predictions for sheep, which do not allow for variation with rate of gain. Energy values of gain appear to be low for young lambs, and to be overestimates for sheep with liveweights exceeding about 60 kg.

Equations have been developed to predict the protein, fat and energy contents of empty body gains and liveweight gains of sheep and cattle which allow for variation with their breed, sex and rate of gain. This versatility is achieved by identifying a Standard Reference Weight (SRW) appropriate for each type of animal. In concept, the SRW for any particular breed and sex of cattle or sheep is approximately the weight that would be achieved by that animal when skeletal development is complete and the empty body contains 250 g fat/kg. Approximately equivalent condition scores are 3 for beef cattle and sheep, in the 0-5 scales defined by Lowman et al. (1976) and Russell et al. (1969) respectively, and 5 for dairy cattle in the 1-8 scale defined by Earle (1976). The SRW for breeds sometimes described as "small" (ARC 1980) , "small-frame" (NRC 1984) , or "early-maturing" (Robelin and Daenicke 1980) are lower than those for "medium","large", or "late maturing'@ breeds. Within a breed the SRW increase in the order: females, castrates, males. Suggested values for the SRW to be assigned to various breeds of cattle and sheep are shown below, but genotypic variation within a breed will not be encompassed by a single generalised set of values. In practice, the conceptual SRW may need to be adjusted so that the range of predicted values for any given type of animal is consistent with observed values.

It was found that the empty weight of the animal expressed as a proportion of its SRW can be used in a single set of equations (Set A) to predict the fat and protein, and hence the energy, in gain for all breeds of sheep and cattle that are currently of commercial importance in Australia. However, to accommodate the "large" European breeds (Charolais, Simmental, Chianina, Maine Anjou) which deposit relatively more protein than other-cattle breeds, it would have been necessary to assign SRW that were considerably greater than the conceptual values. Consequently, to maintain a range in SRW that approximated to biological reality, the Set A equations are modified for application to these "large" cattle breeds and are identified as Set B. Provision is also made for intermediate equations for crossbred cattle such as Charolais x Hereford.

Condition Score

Condition scoring is an important aid in optimising the nutritional management and performance of animals. "Target" condition scores for particular stages of the production cycle, for example joining, are specified in a number of publications but, especially in pastoral production, may be difficult or impossible to achieve. The Report reviews available information on relationships between condition score and reproductive and lactation performances, and if it is desired that there should be one unit increase in mean condition score of a group of animals in order to improve their performance the corresponding change in liveweight must be identified in order to assess the amount of feed necessary to achieve this goal.

With SRW assigned to each type of animal, it appears that when condition score is defined on a scale of 0-5 (beef cattle, sheep), the change in liveweight (kg) per unit change in score may be estimated as **0.15 SRW.** For dairy cattle (scale **1-8)** it may be estimated as 0.08 SRW.

Prediction of Intake and Nutritional Management

When formulating rations it is necessary to know what animals can eat before realistic estimates can be made of what they should eat in order to achieve the desired level of production. With grazing animals, knowledge is required of their feed intake and the quantities of energy and nutrients it provides, and of the quantities needed to achieve the desired production, in order to determine what change in nutritional management would be effective, and practicable, and profitable in the prevailing nutritional, economic and sociological conditions.

The procedure described by Freer and Christian (1983) for predicting the intake of **herbage** by grazing sheep and cattle, provided with supplementary feeds or not, has been further developed. In brief, the potential intake (PI) of any particular class of animal is defined as the amount of feed that would be eaten when abundant feed is offered, and a diet with an adequate content of all nutrients (e.g., protein, minerals) and a digestibility of at least 0.8 (M/D approximately 11.5) can be selected. PI is related to the animal's current weight expressed as a fraction of the SRW value assigned to its **type,** and is adjusted for the effect of lactation and if the prediction is for unweaned young. Actual intake is the proportion of PI that the animal can be expected to achieve under the existing conditions of grazing and is, in general, determined by physical features and the chemical composition of the pasture. These two factors are described by, respectively, the amount (kg/ha) of **herbage** dry matter available and its digestibility, not as a whole but as a number of classes each of defined amount and digestibility. It is assumed the animal attempts to satisfy its PI first from the most digestible class, and then as necessary from successively less digestible classes. Summation of the quantities grazed from each digestibility class yields a predicted intake of digestible feed which can then be expressed readily as ME.

The function relating PI to the animal's current weight **as** a function of SRW allows for variation in intake of a given W between breeds of sheep, or cattle, which differ in mature size. If breed size was ignored, then a predicted intake, at say **60 kgW,** for a large breed of sheep would probably be inappropriate for a smaller breed. The function also allows for the probability that PI per **kgW** is higher when animals are young then when they approach maturity. The ARC **(1980)** predictions of intake do not make such allowances and are simply functions of **W.**

PREDICTION EQUATIONS

Several of the following equations are incorporated in the **CAMDAIRY** model for formulating and analysing dairy cow rations developed by Hulme et al. (1986). The **GRAZFEED** model developed by Dr M Freer of the CSIRO Division of Plant Industry predicts feed intakes by the procedures outlined above, and uses the following equations to predict resulting animal performance.

Energy of Feeds

DMD, **OMD,** DOMD = respectively **dry and organic** matter digestibilities, and digestible organic matter in the feed dry matter (as percentages). M/D = MJ of ME per kg feed dry matter.

$OMD = 1.05\ DMD - 1.0$
$DOMD = 0.9\ OMD = 0.95\ DMD - 0.9$

$M/D = 0.18\ DOMD - 1.8 = 0.16\ OMD - 1.8 = 0.17\ DMD - 2.0.$

Net efficiency of use of ME:

for maintenance, $k_m = 0.02\ M/D + 0.5$
for milk, $k_l = 0.02\ M/D + 0.4$ **(average value 0.60)**
for conceptus, $k_c = 0.133$ **(average <u>gross</u> efficiency)**
for growth and fattening

- first growths of temperate and Mediterranean pastures, fresh or conserved, with M/D = 9.5 or more, for temperate legumes, and for "mixed diets" of forage + concentrates:

  $k_g = 0.042\ M/D + 0.006$ (or $= 0.043\ M/D$)

- for all other forages (including all tropical **grasses and** legumes)

  $k_g = 0.063\ M/D - 0.308.$

Energy Requirements of the Animal

Maintenance: see equations (1), (2) and (3) in text.

Pregnancy: ME requirements (in addition to maternal maintenance) for a 4 kg lamb and 40 kg calf (requirements for other birthweights are pro rata).

		Weeks before term					
		12	8	6	4	2	0
MJ/d:	Ewes	0.4	1.1	1.7	2.6	3.8	5.3
	Cows	8.2	14.2	-	24.7	-	42.9

Milk:

Net energy (i.e., heat of combustion; divide by k_l to express as ME)

Cows: MJ/kg = $0.0386F + 0.0205SNF - 0.236$
or = $0.0458F + 1.222$

Sheep: MJ/kg = $0.0328F + 0.0025D + 2.203$

Goats: MJ/kg = $0.0492F + 1.309$

where: F and SNF are fat and solids-not-fat g/kg milk and D is days after lambing.

Liveweight change of cows during lactation: 1 kg loss in W used for the production of milk assumed equivalent to **28** MJ of dietary ME, and 1 kg gain equivalent to **33** MJ of ME.

These values assist interpretation of discrepancies between observed yields and those anticipated from the ME intake and, when there is loss in W, facilitate appropriate adjustments to the intake.

Growth:

Equations **(4)** to **(8)** predict the composition of empty body gain (EBG), and in practical application the liveweight (W kg) of the **animal** is first converted to empty body weight (EBW kg):

$$EBW = [W - b\,(1-m)] / (1.09 - 0.02m)$$

where : **b** (sheep) = **3;** b (cattle) = **24**

m - has a maximum value of 1.0 for young animals consuming milk only (i.e. their first week of life)

- decreases to a minimum value of zero at weaning (i.e. with increasing age there are increases in the intake of other feeds and in gut fill).

The value of m may be determined as:

m (sheep) = **1.06 - 0.06 a**

m (cattle) = 1.04 - 0.04 a

where: a - is week of life; thus suckled lambs and calves **are** assumed to be weaned at respectively 18 and 26 weeks, **but if** weaned earlier then **m** becomes zero.

In some applications it may be advantageous to define m as a function of W **instead** of age:

m = 2 - (5W/SRW)

where: SRW (kg) is the value assigned to the particular type of animal.

Given (i) that energy retained (ER,MJ) by the animal **as body tissue** = k_g x (ME intake surplus to other needs)

and (ii) that the energy content of empty weight gain (EVG, MJ/kgEBG) can be predicted from EBW

then LWG = ER/(EVG x 0.92).

Set A equations:- applicable to all breeds of sheep, and to all breeds of cattle including _Bos indicus_ and crosses with _B. taurus_ except **Charolais,** Chianana, Maine Anjou, **and Simmental.**

$$\text{Energy (MJ/kg EBG)} = (6.7 + R) + (20.3 - R) / [1 + e^{-6(P-0.4)}] \qquad (4A)$$

where: P = (current EBW kg)/SRW kg with SRW as the value assigned to the particular type of animal

R = (adjustment for rate of gain)

when gain is known: $R = [(EBG\ g/d)/4(SRWkg^{0.75})]-1$;

when ME intake is known and gain must be predicted: $R = 2[NE_p/NE_m)-1]$

where: NE_m is net energy for maintenance, calculated with equation (1) and NE_p is net energy available for gain $= k_g\,(MEI-ME_m)$.

$$\text{Fat (MJ/kg EBG)} = (1.7 + 1.1R) + (23.6 - 1.1R)/[1 + e^{-6(P-0.4)}] \qquad (5A)$$

$$\text{Protein (MJ/kg EBG)} = (5.0 - 0.1R) - (3.3 - 0.1R)/[1 + e^{-6(P-0.4)}]. \qquad (6A)$$

It will be seen that (4A) equals (5A) plus (6A) which, with 39.3 MJ/kg fat and 23.6 MJ/kg protein, lead to:

$$\text{Fat (g/kg EBG)} = (43 + 28R) + (601 - 28R)/[1 + e^{-6(P - 0.4)}] \qquad (7A)$$

$$\text{Protein (g/kg EBG)} = (212 - 4R) - (140 - 4R)/[1 + e^{-6(P - 0.4)}]. \qquad (8A)$$

Set B equations:- applicable to the Charolais, Chianina, Maine Anjou and Simmental breeds of cattle.

Each equation differs in only one respect from the corresponding Set A equation: the value of one coefficient in the second term is changed.

	For (Set A)	Read (Set B)	(Eqn. No.)	Coefficients for crossbreds (A x B)
Energy MJ/kg	20.3	16.5	(4B)	18.4
Fat MJ/kg	23.6	19.3	(5B)	21.5
Protein MJ/kg	3.3	2.8	(6B)	3.0
Fat g/kg	601	490	(7B)	545
Protein g/kg	140	120	(8B)	130

The equations are not intended to be applicable to obese animals, which are of no more than minor commercial interest, and predictions with P exceeding 1.2 are uncertain.

The maximum energy content of gain (equation 4A) is: (6.7 + 20.3) = 27 MJ/kg EBG and this value is approached at P = 1.1. The corresponding value from equation (4B) is 23.2MJ/kg EBG. The range of values from birth (say P=0.07 or 0.1 for cattle and sheep respectively) to P = 1.0 is as follows.

	P	Set A	Set B	Crossbreds (A x B)
MJ/kg EBG:	0.07	9.2	8.7	8.9
	0.1	9.6	9.0	9.3
	1.0	26.5	22.8	24.6
Fat g/kg EBG:	0.07	116	102	109
	0.1	128	113	120
	1.0	628	519	574
Protein g/kg EBG:	0.07	195	197	196
	0.1	192	195	194
	1.0	76	95	86

Values predicted with equations (6A) or (6B) are of course estimates of the net amino acid N required for the gain and are used in the estimation of protein requirements.

SRW values (kg) at present suggested for various types of livestock are given in the following Table:

SRW kg:	Females	Castrates	Males
Sheep			
Merino (small - e.g. Saxon), Southdown	40	48	56
Merino (medium), Cormo, Hampshire, Polwarth, Dorset x Merino, Ryeland	50	60	70
Border Leicester x Merino, Cheviot, Corriedale, Dorset, Drysdale, Hampshire, Romney, Suffolk, Tukidale	55	66	77
Merino (large - e.g. S. Australian), Border Leicester	60	72	84
Cattle			
Chianina	700	840	980
Charolais, Maine Anjou, Simmental	650	780	910
Blonde Aquitane, Brahman, Brahman x Hereford, Limousin, Lincoln Red, Friesian, South Devon	550	660	770
Angus, Beef Shorthorn, Dairy Shorthorn, Devon (Red), Hereford, Murray Grey, Red Poll	500	600	700
Ayrshire, Galloway, Guernsey, AMZ, Sahiwal	450	540	630
Jersey	400	480	560

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