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AN EQUATION, SUITABLE FOR COMPUTER USE, BASED ON THE ARC FEEDING SYSTEM TO DETERMINE THE ENERGY REQUIREMENTS OF GROWING AND FATTENING CATTLE

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Based on the Agricultural Research Council's feeding system, equations were developed that allow the calculation of the metabolizable energy requirements for maintenance and weight gain by cattle, separately or combined. A general equation was developed for the straight-forward calculation of the total metabolizable energy requirements of growing and fattening cattle for any combination of body weight, rate of weight gain, age, level of muscular work, and metabolizable energy concentration of the diet. The estimates of energy requirement made by the use of this equation are in excellent agreement with those made by the Agricultural Research Council using an iterative method.

In addition to avoiding the awkward iterative process, the equations proposed are readily adaptable to computer use.

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AN EQUATION, SUITABLE FOR COMPUTER USE, BASED ON THE ARC FEEDING SYSTEM TO DETERMINE THE ENERGY REQUIREMENTS OF GROWING AND FATTENING CATTLE

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SUMMARY

Based on the Agricultural Research Council's feeding system, equations were developed that allow the calculation of the metabolizable energy requirements for maintenance and weight gain by cattle, separately or combined. A general equation was developed for the straight-forward calculation of the total metabolizable energy requirements of growing and fattening cattle for any combination of body weight, rate of weight gain, age, level of muscular work, and metabolizable energy concentration of the diet. The estimates of energy requirement made by the use of this equation are in excellent agreement with those made by the Agricultural Research Council using an iterative method.

In addition to avoiding the awkward iterative process, the equations proposed are readily adaptable to computer use.

INTRODUCTION

IN 1965, the Agricultural Research Council (ARC) in Great Britain published a feeding system for ruminants based upon a detailed appraisal of the existing information on nutrient requirements. This system has not yet been used much in practice though most scientists seem to accept its bases. Alderman (1966 and 1968) attempted to improve the understanding and usefulness of it, but both he and Blaxter (1967) pointed out that it is necessary to employ an iterative process to find the dietary requirements of an animal that will result in a given level of response (for example, weight gain/day), or conversely, to determine the response of an animal to a given ration.

In Blaxter's (1967) words—'The whole calculation must be repeated to obtain a new estimated gain. This has to be done because the utilization of the ration depends on its value as a whole, and because the replacement values of feed are not constant but vary with the ration with which they are given. It is not possible other than by this iterative approach to find a ration that will result, for example, in a gain of exactly 0·60 kg/day.'

The cumbersome iterative method can be avoided by equations which provide for straight-forward calculations of the requirements for any combination of body weight, rate of gain, age, level of muscular work, and quality of feed. This report describes the development of such general equations and demonstrates their effectiveness in the prediction of the energy requirements of growing and fattening cattle.

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DEVELOPMENT OF EQUATIONS

All the data employed here are quoted in the ARC (1965) report and the page references relate to that report. The terminology employed in the ARC report is also used here.

The methods by which the equations were developed will be presented under three headings: energy requirements for maintenance, energy requirements for weight gain, and total energy requirements, similar to those used by the ARC.

Energy requirement for maintenance

The maintenance requirements, described in pp. 215-222 of the ARC report, were divided into the fasting metabolic cost, muscular work, and thermal regulation.

Fasting metabolism. The ARC report (p. 215) states that 'values for the fasting metabolism of cattle and sheep tend to fall markedly with their age. Because young animals are small this also means that metabolism/kg $W^{0\cdot73}$ falls with body weight which in turn suggests that, within a species, metabolism varies with a smaller fractional power of weight than it does when computed from determinations with adult species of different size'. The ARC report recorded fasting metabolism as a function of age (Table 6.12). A quadratic equation was fitted by the least-squares method to the values corresponding to 6, 12, 18, 24 and 36 months of age, expressed in days on the assumption that each month consists of 30 days. The equation derived was:

$$FM = (141\cdot39 - 0\cdot1036A + 0\cdot000052A^2)W^{0\cdot73} \qquad (1)$$

where FM is fasting metabolism (kcal/day)
A is age (days)
W is weight (kg).

Although this equation represents an approximation of the fasting metabolism, it should be remembered that since varying degrees of mature size can be achieved over a wide range of chronological ages, fasting metabolism does not vary according to any composite of weight and age. Equation (1) describes the available data, but its biological interpretation is hazardous.

Muscular work and thermal regulation. The energy expenditure of muscular work and thermal regulation varies greatly and the causes of the variation are difficult to identify and assess (ARC report pp. 221–222). For the purpose of this report, it is important only to consider that some metabolizable energy is required for muscular work. Accordingly, the value of 2·0 kcal/kg of body weight per day, which is the approximate energy cost of cattle for muscular work as suggested by the ARC (p. 221) has been selected.

Efficiency of utilization of metabolizable energy (ME) for maintenance. Since more ME is required for maintenance when diets are of poor quality than when they are of high quality, it was assumed that the efficiency with which ME is utilized for maintenance is a function of the ME concentration of the dietary dry matter. Accordingly, this relationship is expressed by the following equation (p. 242):

$$km = 54\cdot6 + 6\cdot75\,(M/D) \qquad (2)$$

where km is the efficiency (%) of utilization of ME for maintenance
M/D is the ME concentration of the diet (Mcal/kg of dry matter).

ME requirement of maintenance. Based on the amount of energy required for fasting metabolism and muscular work, and the efficiency with which ME is utilized to support the maintenance function, the total amount of ME needed per unit of time for maintenance may be resolved by means of the following equation:

$$Mm = \frac{100}{km}(FM + MW) \tag{3}$$

where Mm is the amount of ME needed for maintenance (kcal/day)
FM is the fasting metabolism (kcal/day)
MW is the requirement for muscular work (kcal/day).

Finally, substituting equations (1) and (2) into equation (3) provides:

$$Mm = \frac{(14\,139 - 10{\cdot}36A + 0{\cdot}0052A^2)W^{0{\cdot}73} + 100MW}{54{\cdot}6 + 6{\cdot}75(M/D)}. \tag{4}$$

Energy requirement for body gain

Energy retained by the body. The calorific value of body gain is a function of the body weight of an animal and the amount of energy retained as considered in the ARC report (pp. 224–228) and as generalized for cattle in their Table 6.22. The daily body-weight gain may therefore be expressed as the ratio of the amount of energy retained and the calorific value of the weight gain:

$$G = \frac{S}{C} \tag{5}$$

where G is daily body-weight gain (kg/day)
S is the energy retained (kcal/day)
C is the calorific value of the weight gain (kcal/kg).

Body energy retention as a function of body weight was constructed by fitting two regression equations. The one equation relates the independent term of the original equations (ARC report, Table 6.22, p. 228) to body weight and the other relates the slopes of the original equations also to body weight. These are as follows:

$$C = 1425 + 3{\cdot}65W + (0{\cdot}231 + 0{\cdot}00011W)S \tag{6}$$

where W is body weight (kg)
C and S are as described for equation (5).

Then, rearranging equation (5) to:

$$\frac{1}{G} = \frac{C}{R} \tag{7}$$

and substituting equation (6) into equation (7) yields:

$$S = \frac{1425 + 3{\cdot}65W}{\frac{1}{G} - 0{\cdot}231 - 0{\cdot}00011W}. \tag{8}$$

Efficiency with which ME is utilized for weight gain. During post-weaning growth, the efficiency with which ME is utilized for body-weight gain is a function of the ME concentration of the diet. The ARC report (p. 242) records the following relationship:

$$kf = 3{\cdot}0 + 18{\cdot}4\,(M/D) \tag{9}$$

where kf is the efficiency (%) of utilization of ME for body-weight gain
M/D is the concentration of ME in the dietary dry matter (Mcal/kg).

ME requirement of weight gain. Based on the knowledge of the amount of body-energy retention desired and the efficiency with which ME is utilized for body-weight gain, the amount of ME required is determined as follows:

$$Mf = \frac{100}{kf}\,.S \tag{10}$$

where Mf is the ME required for body-weight gain (kcal/day)
kf is as described for equation (9)
S is as described for equation (5).

Then, the substitution of equations (8) and (9) into equation (10) yields an equation by which the ME requirement of a specific body-weight gain may be derived for cattle of known body weights:

$$Mf = \frac{142\,500 + 365W}{[3{\cdot}0 + 18{\cdot}4(M/D)][(1/G) - 0{\cdot}231 - 0{\cdot}00011W]}. \tag{11}$$

Total ME requirements for weight gain by cattle

Summation of maintenance and weight gain requirements. The total amount of ME required is the sum of the amounts of ME required for maintenance and body-weight gain:

$$M^{*} = Mm + Mf \tag{12}$$

where M^{*} is the 'true' ME (kcal/day)
Mm is as described for equation (3)
Mf is as described for equation (10).

Then, the substitution of equations (4) and (11) into equation (12) results in the following equation:

$$M^{*} = \frac{(14\,139 - 10{\cdot}36A + 0{\cdot}0052A^{2})W^{0{\cdot}73} + 100MW}{54{\cdot}6 + 6{\cdot}75(M/D)} + \frac{142\,500 + 365W}{[3{\cdot}0 + 18{\cdot}4(M/D)][(1/G) - 0{\cdot}231 - 0{\cdot}00011W]}. \tag{13}$$

The term 'true' ME (M^{*}) is employed here in the same sense as the ARC used it (p. 211), and it implies a correction of the 'gross' ME ingested in accordance with the feeding level. 'Gross' ME is distinct from 'true' ME as it represents the feed intake expressed in Megacalories of ME uncorrected for the decreasing biological value as the feeding level is increased.

Feeding-level correction factor. As the ARC report (p. 209) stated: 'The metabolizable energy of the feed usually decreases with increasing feeding

level because the increase in the faecal loss of energy exceeds by a considerable margin the decrease in methane production and urine energy loss'.

The ARC report (p. 212) defined feeding level as follows:

$$L = \frac{M}{Mm} \tag{14}$$

where L is the level of feeding (multiples of maintenance level)
M is the gross ME (kcal/day)
Mm is as described for equation (3).

The increase (ΔL) in feeding level over the intake of ME for maintenance is therefore described by the following equation (ARC report, p. 211):

$$\Delta L = L - 1. \tag{15}$$

Substituting equation (14) into equation (15) yields:

$$\Delta L = \frac{M}{Mm} - 1. \tag{16}$$

The correction factor (f) for feeding level which takes into account the ME concentration of the dietary dry matter is computed by the following equation as suggested in the ARC report (p. 212):

$$f = 1 + \left[0{\cdot}11 - \frac{0{\cdot}418}{(M/D)}\right]\Delta L. \tag{17}$$

Substitution of equation (16) into equation (17) results in the following equation:

$$f = 1 + \left[0{\cdot}11 - \frac{0{\cdot}418}{(M/D)}\right]\left[\frac{M}{Mm} - 1\right]$$

or

$$f = 0{\cdot}89 + \frac{0{\cdot}418}{(M/D)} + \left[0{\cdot}11 - \frac{0{\cdot}418}{(M/D)}\right]\frac{M}{Mm}. \tag{18}$$

'Gross' ME. As implied in the definition of 'true' ME, the ratio of the 'true' ME and the level of feeding correction factor is the 'gross' ME, as follows:

$$M = \frac{M^*}{f} \tag{19}$$

where M is 'gross' ME (kcal/day)
M^* is 'true' ME (kcal/day)
f is as defined for equation (17).

Substitution of equation (18) into equation (19) gives:

$$M = \frac{M^*}{0{\cdot}89 + \dfrac{0{\cdot}418}{(M/D)} + \left[0{\cdot}11 - \dfrac{0{\cdot}418}{(M/D)}\right]\dfrac{M}{Mm}},$$

which upon rearrangement becomes:

$$M^* = M\left[0{\cdot}89 + \frac{0{\cdot}418}{(M/D)}\right] + \left[0{\cdot}11 - \frac{0{\cdot}418}{(M/D)}\right]\frac{M^2}{Mm},$$

or

$$\left[0{\cdot}11-\frac{0{\cdot}418}{(M/D)}\right]M^2+\left[0{\cdot}89+\frac{0{\cdot}418}{(M/D)}\right]M.Mm-M^*.Mm=0.$$

This, solving for M as a quadratic equation gives:

$$M=\frac{-\left[0{\cdot}89+\frac{0{\cdot}418}{(M/D)}\right]Mm+\sqrt{\left[0{\cdot}89+\frac{0{\cdot}418}{(M/D)}\right]^2Mm^2+4\left[0{\cdot}11-\frac{0{\cdot}418}{(M/D)}\right]M^*.Mm}}{2\left[0{\cdot}11-\frac{0{\cdot}418}{(M/D)}\right]}. \tag{20}$$

On substituting equation (12) into equation (20) and making some algebraic transformations, the following equation is derived:

$$M=\frac{-\left[0{\cdot}89+\frac{0{\cdot}418}{(M/D)}\right]Mm+\sqrt{\left[\left(0{\cdot}89+\frac{0{\cdot}418}{(M/D)}\right)^2+4\left(0{\cdot}11-\frac{0{\cdot}418}{(M/D)}\right)\right]Mm^2+4\left(0{\cdot}11-\frac{0{\cdot}418}{(M/D)}\right)Mm.Mf}}{0{\cdot}22-\frac{0{\cdot}836}{(M/D)}}. \tag{21}$$

Only the positive sign of the square root in equations (20) and (21) was found to provide a correct solution. Either equation (20) or (21) may be used to determine the amount of 'gross' ME required for the maintenance and body gain of cattle.

Since the terms Mm and M^* in equation (20) and Mm and Mf in equation (21) each in itself constitutes a long equation, only the symbols have been used here.

VALIDITY OF THE EQUATION FOR DETERMINING THE ENERGY REQUIREMENTS OF CATTLE

For testing the derived equation (21) the values for live weights, concentrations of ME in the dietary dry matter, and rates of body gain as represented by Table 6.27 of the ARC report (p. 234) were substituted into equation (21) with the corresponding ages of animals and the energy costs of muscular work. The ages assumed for cattle weighing 200, 300 and 400 kg were 360, 540 and 720 days, respectively. The energy cost of muscular work was put at 2·0 kcal/kg of body weight per day.

In Table 1, the ME requirements of cattle as derived from the substitution of the five variables into equation (21) are compared with those estimated in the ARC report by means of the iterative process and recorded in their Table 6.27 (p. 234). The greatest difference between the ARC's original estimates and ours is less than 2·5%. This difference could be attributable to rounding errors and to the fact that the ages of animals and the costs of muscular work we employed were estimated without knowing the exact magnitude of the values used in the ARC report.

TABLE 1

Estimates of the ME requirements† of growing and fattening cattle

Live weight (kg)	Ration concentration (Mcal/kg of dry matter)	Rate of gain (kg/day) 0	0·25	0·50	0·75	1·00	1·25	1·50
200		8·5	10·4	12·7	15·7	—	—	—
	1·8	(8·6)	(10·5)	(12·9)	(15·8)	—	—	—
		8·2	9·7	11·4	13·5	16·0	—	—
	2·2	(8·3)	(9·8)	(11·5)	(13·6)	(16·3)	—	—
		7·9	9·1	10·5	12·2	14·1	16·6	19·7
	2·6	(8·0)	(9·2)	(10·6)	(12·3)	(14·3)	(16·7)	(19·7)
		7·6	8·7	9·8	11·2	12·9	14·8	17·2
	3·0	(7·7)	(8·7)	(9·9)	(11·3)	(13·0)	(14·9)	(17·3)
		7·4	8·2	9·3	10·4	11·8	13·5	15·5
	3·4	(7·5)	(8·4)	(9·4)	(10·6)	(12·0)	(13·8)	(15·7)
300		10·6	12·7	15·4	18·9	—	—	—
	1·8	(10·5)	(12·8)	(15·3)	(18·8)	—	—	—
		10·1	11·8	13·9	16·4	19·4	—	—
	2·2	(10·2)	(11·9)	(13·9)	(16·3)	(19·5)	—	—
		9·8	11·2	12·8	14·8	17·2	20·1	—
	2·6	(9·8)	(11·2)	(12·8)	(14·7)	(17·2)	(20·3)	—
		9·4	10·6	12·0	13·6	15·6	18·0	20·9
	3·0	(9·4)	(10·6)	(12·1)	(13·6)	(15·6)	(18·0)	(21·0)
		9·1	10·1	11·3	12·7	14·4	16·4	18·9
	3·4	(9·1)	(10·2)	(11·4)	(12·8)	(14·6)	(16·5)	(19·1)
400		12·3	14·9	18·0	22·0	—	—	—
	1·8	(12·4)	(15·1)	(18·0)	(22·1)	—	—	—
		11·9	14·4	16·2	19·1	22·7	—	—
	2·2	(12·0)	(14·1)	(16·3)	(19·3)	(22·9)	—	—
		11·4	13·0	15·2	17·2	20·0	23·5	—
	2·6	(11·5)	(13·2)	(15·0)	(17·4)	(20·2)	(23·9)	—
		11·0	12·4	14·0	15·9	18·2	21·0	24·6
	3·0	(11·1)	(12·6)	(14·1)	(16·0)	(18·3)	(21·3)	(25·0)
		10·6	11·9	13·3	14·9	16·8	19·2	22·2
	3·4	(10·8)	(12·1)	(13·4)	(15·0)	(17·0)	(19·5)	(22·7)

† The values without parentheses are those determined by means of equation (21). Those within parentheses are the values estimated by the ARC (1965).

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