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A PRACTICAL FEEDING SYSTEM FOR RUMINANTS

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The objectives and desirable properties of a practical feeding system are discussed, and a distinction drawn between performance prediction and ration formulation. A brief history of events in the research and advisory fields following upon the publication of the ARC Technical Review No. 2 in. 1965 is given. A working party reported their findings to a joint conference of interested parties in 1972. They used mathematical modelling techniques and a large data base of selected experimental results to simplify and improve the accuracy of the proposed systems in predicting animal performance. The dairy cattle system was made linear and additive, with the addition of liveweight change into requirement calculations.

The beef cattle system for performance prediction was also simplified, but for ration formulation, the Animal Production Level of MacHardy was introduced' to calculate the appropriate net energies of feeds, thus also making ration formulation additive. No modelling was done on the sheep systems but thesefollow the same rules for simplification. Metabolizable energy values of foods were calculated from tabulated proximate digestible constituents using the Rostock equation.

The successful changeover from Starch Equivalent to Metabolizable energy was largely due to a consensus having been achieved by consultation and discussion amongst all prospective users and teachers of the new system. Retention of the basic ARC model attracted additional support, and the ease of operation facilitated training of advisers in the use of new systems. for advisory work.

I. INTRODUCTION

Arguments about the relative values of feeds as sources of energy for ruminant livestock and the rival merits of feeding systems using particular units have been going on for nearly a century. The need for a practical feeding system in any particular country will depend both on the nature and technological state of agriculture therein. Thus in the UK, with a short grazing season, livestock are commonly indoors and fed stored feeds for over 6 months. Livestock are therefore heavily dependent on the feeds made available to them. Quantitative ruminant nutrition is a very necessary applied science.

In a more pastoral or range, situation this strong emphasis on quantitative nutrition has to be replaced by other technical parameters such as expected yield of forages under various climates and fertiliser regimes, optimisation of stocking density and measurement of animal production as an estimate of feed intake. Responses to feed supplements are often complex to evaluate and subject to strong economic pressures. Both of these situations still exist in the UK, but the feeding systems to be described are intended for use in indoor rather than the pastoral situation.

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II. OBJECTIVES OF A FEEDING SYSTEM

The basal energy unit of a feeding system, whether digestible (DE), metabolizable (ME) or net (NE), must accurately represent the relative values of feeds as extreme as cereal straw or maize grain in a wide range of diets fed to cattle or sheep over the range sub-maintenance to levels of 4 times maintenance. Substitution of one feed by another in the ratio indicated by this unit, should result in little change in animal performance. Using this unit as a building block, the practical feeding system must enable the nutritionist or livestock farmer to:

(a) Formulate animal diets to give specified levels of performance

(b) Predict animal performance from a specified dietary intake of energy

(c) Indicate the relative values of feeds in different feeding situations.

A subsidiary objective of a feeding system might be to assist in increasing the understanding by the users of the complex interactions between feeds and ruminants.

The cost element can be introduced into ration formulation to enable least cost formulation of a specified diet, or better, a least cost per day diet for a specified level of animal performance. The technique of linear programming is,. now in widespread use in feed compounding industries and its use by agricultural extension services is also developing.

A practical feeding system that meets these needs will also have a wide range of users from academic staff either in research or teaching, and specialist nutritionists in feed companies or extension services, to general livestock advisers and ultimately to livestock farmers and their dairy or stock men. What pleases one may well be scorned or ignored by the other!

III. DESIRABLE CHARACTERISTICS OF A PRACTICAL FEEDING SYSTEM

. Arising from these considerations, it can be suggested that a successful <u>practical</u> feeding system should possess the following characteristics:

(a) Be scientifically and conceptually sound

(b) Be easy to understand

(c) Be free of areas where subjective interpretation is necessary

(d) Be capable of fairly rapid manipulation without computer aids

(e) Be easy to update with new data from later research findings.

It would be foolish to claim that the present UK systems outlined in Technical Bulletin 33 (MAFF 1976) possess all these characteristics in full measure but the group responsible for their development certainly kept these ideals in mind throughout their work. The experience of implementing the systems during 1975/6 gave us encouragement to believe that we had achieved some success in these areas.

IV. HISTORY OF UK DEVELOPMENTS 1965-1977

The foreword to 'Section 6, 'Requirements for Energy', in the ARC Technical Review No. 2, Ruminants (ARC 1965)suggested that the system described therein should' gradually replace the existing Starch Equivalent (SE) system. No details will be given here of the original ARC energy requirements system, except to note that it is a three compartment model consisting of:

(1) Food values measured as ME at maintenance

(2) Animal requirements measured as true net energies

(3) A set of rules for the conversion of ME to NE.

This basic model, so attractive to nutritionists, was designed for the calculation of energy requirements, or alternatively, for performance prediction. Ration formulation is cumbersome and iterative because of the effects of food ME upon ration ME per kg dry matter (M/D values), and thus upon the calculated efficiencies of converting ME to NE for maintenance (k_m), fattening (k_f) and lactation (k_l) as well as the complications introduced by the plane of nutrition correction factor.

Following a special conference in 1966, a working party was set up to consider the problems raised by the ARC's publication. It was given two particular terms of reference (amongst others) namely:

"To examine the validity of the proposed ME system by assessing its ability to predict animal performance.

The application of the proposals to practical rationing and their modification into a form suitable for farm advisory work".

In effect, advisers were insisting on two things; firstly proof that the new system was more accurate than'the old, and secondly that the difficulties of manipulating the ME system for ration formulation purposes should be solved.

The required comparison between the existing SE system as exemplified by Bulletin 48 'Rations for -Livestock' (MAFF 1960) necessitated the usual sequence of events:

(1) Data collection and validation

(2) Mathematical modelling of the two systems

(3) Computation and analysis of results

(4) Revision of models

(5) Final results.

Details have been published (Alderman _et al._ 1974) of how this was done. Comment need only be made here that the mathematical modelling presented as much difficulty in the case of the SE system as the ME system, due to the areas of subjective interpretation. Specifically, these were crude fibre correction factors for the calculation of SE values of feeds, and estimates of SE requirements for gain in cattle.

Once some successful runs had been made on the data base, and the' bias between actual and predicted performances was considered, progress was more rapid. Suffice it to say that the beef cattle system was the eighth variant to be tested, wherein considerable simplification had been achieved but overall accuracy marginally improved. As the result of proposals first drafted by Professor William Holmes of Wye College, major simplifications were 'also made to the dairy cow system.

V. DAIRY CATTLE ME SYSTEM

The range of dietary-energy concentrations that can be used in diets for productive dairy cows can only vary over a rather narrow range, e.g. 9-12 MJ of ME per kg of dry matter. The consequential variation in the calculated values of k_m and k_l are therefore fairly small. It was decided to use average mean values for k_m and k_l and to ignore dietary energy effects upon them. The values chosen were 0.72 for k_m and 0.62 for k_l, the latter value being revised in-the light of subsequent research from van Es (1969) and Moe and Tyrrell (1974). The effect of these two decisions was to make the system linear, and the energy requirements of dairy cows could be expressed directly as ME in the requirementtables.

In addition, using the findings of van Es (1961) and Moe and Tyrrell (1974), values for the efficiency of gain in lactating cows, 0.62, and for its subsequent mobilisation and utilisation for milk production of 0.80 were agreed. This enabled systematic account to be taken of the energy exchanges in the cow moving through her lactational cycle. The plane of nutrition correction factor was also discarded, since later work by Blaxter (1967) gave a function with a smaller and a reverse effect at higher energy concentrations.

Finally, all calculated energy requirements were increased by 5% overall as a safety margin, to make them-allowances for practical use. This was done with all the system published by the MAFF working party.

The effects of this fairly brutal treatment upon calculated requirements compared with the original ARC requirements were fairly small except at extreme levels of production or dietary energy concentrations. The mathematical modelling showed both ARC and MAFF systems to more accurate than the SE system. The latter was often predicting milk yields 3 kg above actually achieved performance even after correcting for liveweight change. Thus, significant underfeeding of our dairy cows had become institutionalised. Comparisons of MAFF 1976 ME requirement values with those of ARC 1965 are given in Table 1.

TABLE 1: Daily ME requirements of a 500 kg cow giving milk of 4% fat content, MJ/day

Origin	Level of milk production (kg/day) 5	10	15	20	25	30
ARC 1965 Diet ME concentration (MJ/kg DM)	Calculated ME Requirements (MJ/day)					
7.5	80	120	-			
9.2	74	104	139'	-		
10.9	70	96	125	156	190	-
12.6	68	94	120	147	176	206
14.2	69	96	123	151	180	209
MAFF 1976 Liveweight change (kg/day)						
-0.5	67	93	120	146	173	199
0	81	107	134	160	187	213
+0.5	97	123	150	176	203	229

The advantages obtained with this simplified system are several:

(a) Ration formulation is simple and fast

(b) Least cost ration formulation is facilitated

(c) The stage of lactation can be brought into the calculation

(d) Ration checking is also simple

(e) Comparative values of feeds are represented directly by their ME values.

A note here, about the reason for putting all feed values onto a dry matter basis. Admittedly, it introduces an extra step into the calculations if starting from the weight of fresh feed, as many advisers do. There are two points of interest here, the first being that farmers and advisers had become used to talking about the 'digestibility' of foods, mostly using 'D' value or digestible organic matter in dry matter, DOMD %. These values arose from the widespread use of the 'in vitro' digestibility procedure of Tilley and Terry (1963). Since ME values parallel D values fairly closely (ME/DOMD values ranging from 0.14 to 0.17), conversion from one to the other would be facilitated. The second reason arose from the wide variation in the dry matter content of grass silages in the UK. SE (or ME) values calculated on to a fresh weight basis could often give a misleading impression as to which silage had the better nutritive value.

The clinching argument was that by expressing ME values on a dry matter basis, the quantitative aspects of the dry matter intake of the animals would be highlighted, because the dry matter contribution from each food would have to be calculated. Many users of the SE system (based on as fed SE values) were rarely calculating the dry matter intakes of the rations they advised. A proportion of the rations advised were in fact impracticable - the animal could not eat the ration placed before it.

In the UK, a major part of the demand for advice on ruminant rations arises from our dairy farmers. They make extensive use of forage evaluation services and critically evaluate their cows' performance upon rations advised. The dairy cattle ME system has been rapidly taken up, probably because it enables lactational effects upon milk yields and liveweight to be taken into account in a quantitative manner.

VI. BEEF CATTLE SYSTEM

Although the range of dietary ME concentrations varies more widely than for dairy cows, it was decided to retain a fixed value for k_m of 0.72. The variation in k_f was accepted but recalculated from the original data to be best described by

$$k_f = 0.0435\ M/D \qquad \text{..........(1)}$$

which gives values 4 units lower than ARC (1965) but in agreement with Blaxter (1974).

The plane of nutrition factor was omitted from the calculations of energy retention. The energy value of liveweight gain was calculated from one function which made it dependent upon liveweight and energy retention, but which omitted any corrections for gut fill.

This function $EV_g = 6.28 + 0.3\ E_g + 0.0188\ W$ ....(2) can easily be manipulated so that:

Predicted liveweight gain, $LWG = E_g/(6.28 + 0.3\ E_g + 0.0188\ W)$..(3)
and Energy stored, $E_g = LWG\ (6.28 + 0.0188\ W)/(1 - 0.3\ LWG)$ .....(4)
where EV_g = energy value of gain, MJ/kg

E_g = energy stored, MJ/day

W = liveweight, kg

LWG = liveweight gain, kg/day

Both equations are necessary for any practical feeding system, (3) for performance prediction and (4) for ration formulation, i.e. calculation of required net energy.

As' a result of these simplifications, performance prediction from a given diet could be achieved by using three tables in sequence, maintenance requirement, energy stored and thence predicted liveweight gain. Alternatively, interpolation in a large table of calculated requirements could be used. This system speeded up the calculation of predicted performance of growing and finishing cattle but did little to solve the problems of ration formulation if one started from the ME value of feed alone.

Tested on the data base used, this simpler system (ME 8) was more accurate than the ARC (1965) proposals (ME 1) as Table 2 shows.

TABLE 2: Summary of experimental data for diets containing forages

Diet*	No. of fodders	No. of animals	Range of average live-weights (kg)	Actual liveweight gain kg/day	Differences: predicted-actual liveweight gain			
					ME1†	SD	ME8†	SD
Fodder concentrate experiment								
Rearing								
FC	8	168	117-156	0.55	-.15	.09	.00	.08
CF	8	168	126-172	0.81	-.04	.08	.03	.06
Final yarding								
F	8	98	290-396	0.54	.00	.23	.03	.16
FC	12	139	306-402	0.94	.15	.12	.10	.11
CF	12	127	309-407	1.09	.35	.12	.24	.11
C	9	99	314-401	1.21	.34	.06	.20	.05
Liscombe winter feeding experiment								
F	6	30	230-302	0.45	-.06	.11	.01	.09
FC3	12	60	230-302	0.52	.01	.14	.11	.12
FC6	12	60	311-342	0.86	.01	.11	.06	.08

*F = Forage (hay or silage) C = Concentrate

† Predictions by ARC 1965 (ME 1) and by MAFF 1976 (ME 8) - see text.

VII. RATION. FORMULATION USING THE VARIABLE NET ENERGY SYSTEM

MacHardy (1966), put forward a concept which was originally applied to the ARC 1965 system by Harkins, Edwards and McDonald (1974). This offered a solution to the problem, by the use of the concept of Animal Production Level, which is the ratio of net energy stored, EC_Y, to the net energy for maintenance, E_m:

$$\text{Animal Production Level, APL} = \frac{E_m + E_g}{E_g} \text{ or } 1 + \frac{E_g}{E_m} \text{ ....(5)}$$

Thus maintenance has an APL of 1.0 whilst high rates of gain can reach values of 2.5 Values are given in Table 3. Note that APL is a function of W and LWG only and the E_m and E_g are calculated exactly as in the performance prediction system.

TABLE 3: Animal production levels* for cattle

Liveweight W, kg	Liveweight gain LWG, kg/day					
	0.25	0.50	0.75	1.00	1.25	1.50
100	1.19	1.40	1.66	1.98	--	--
200	1.15	1.33	1.54	1.79	2.11	--
300	1.13	1.29	1.47	1.70	1.97	2.33
400	1.12	1.26	1.43	1.64	1.90	2.22
500	1.11	1.25	1.41	1.60	1.84	2.15
600	1.11	1.24	1.39	1.58	1.81	2.13

*Based on $APL = 1 + \left[\frac{LWG\ (6.28 + 0.0188W)}{(1 - 0.3\ LWG)\ (5.67 + 0.061W)}\right]$

Instead of converting ME to NE by the use of k_m and k_f separately, the possibility of weighted mean efficiency factor k_{mp} can be visualised. It can be shown to be a function of APL and ration energy concentration (M/D only. The appropriate function for the MAFF system is:

$$k_{mp} = \frac{M/D\ .\ APL}{1.39\ M/D + 23\ (APL - 1)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

which is a great deal simpler than that required for ARC 1965. If k_{mp} is only a function of APL and M/D, then MacHardy found that it could be applied without appreciable error to the ME values of component feeds as well as the ration. We can therefore calculate the appropriate net energy NE_{mp} for any particular situation. Values for NE_{mp} for a range of ME concentrations are given in Table 4.

TABLE 4: Net energy values for maintenance and production, NE_{mp} (MJ/kg DM)

APL	Energy concentration of feed/MJ/kg DM						
	8	9	10	11	12	13	14
1.00	5.8	6.5	7.2	7.9	8.6	9.4	10.1
1.10	5.2	6.0	6.8	7.6	8.3	9.1	9.9
1.20	4.9	5.7	6.5	7.3	8.1	8.9	9.8
1.30	4.6	5.4	6.3	7.1	7.9	8.8	9.7
1.40	4.4	5.2	6.1	6.9	7.8	8.7	9.6
1.50	4.2	5.1	5.9	6.8	7.7	8.6	9.5
1.75	3.9	4.8	5.6	6.5	7.4	8.4	9.3
2.00	3.8	4.6	5.4	6.3	7.3	8.2	9.2
2.25	3.6	4.4	5.3	6.2	7.1	8.1	9.1

Ration formulation in this system has the steps:

1) Calculate Animal Production Level from W and LWG

2) convert food ME values to appropriate NE_{mp} values

3) animal requirements are still <u>true</u> net energies

4) formulate diet by summating NE_{mp} supplied by feeds

Formulation within appetite limits is now possible and linear programming for least cost also. Again only three tables are required for desk use of the system. We have been surprised at the ease which this system can be taught and accepted by advisers.

VIII, ENERGY SYSTEMS FOR SHEEP

No simplified systems for sheep were developed in our original work presented to a joint conference in 1972, and this indicates the minor importance of sheep nutrition in the UK. However, the authors of Technical Bulletin 33 put together a set of systems for sheep which parallel those for cattle in respect of most of the simplifications used, relied on ARC (1965) for much of its data but used later work, particularly that of Langlands and Sutherland (1968). No modelling and validation of the system was attempted at that time.

Subsequent work by Edwards and Lewis (1977) has studied the bias between predicted and actual gains in 110 groups of lambs. The mean bias was 72 ± 67 g/d with increasing bias at higher rates of gain. This lack of agreement may be due to an overestimate of one or both of maintenance requirements and energy value of gain. Russell et al. (1977) have commented on 'the requirements for pregnant sheep which we gave as '"likely to lead to a relatively severe degree of undernourishment in late pregnancy, and substantial reductions in lamb birthweights".

IX. METABOLISABLE ENERGIES OF FOODS

Relatively few determinations of the ME of typical UK feeds for ruminants were available in 1972, so that it was decided to convert existing tables of digestible proximate analyses to ME by the use of an equation published by the East German workers at the Oskar Kellner Institute at Rostock (D.L.V.B. 1971) in preference to the earlier Axellson (1941) equation. The equation used was (after conversion from calories to joules).

$$MEF = 0.0152\ DCP + 0.0342\ DEE + 0.0128\ DCF + 0.0159\ DNFE \quad .....(7)$$

where MEF is estimated ME/kg feed dry matter This has a claimed accuracy of ± 0.3 MJ/kg. Technical Bulletin 33 therefore contains no determined ME values, but only calculated ones, and two 'thirds of those can be traced to Kellner's original publication.

The UK now has two Feed Evaluation Units, an ARC, unit at the Rowett Research Institute able to measure either ME or NE and an ADAS unit at Drayton Experimental Husbandry Farm able to measure DE. A number of feeds have already been processed and updating of the tables will soon be possible.

THEORETICAL SOUNDNESS OF PRACTICAL SYSTEMS.

In the light of the calorimetric research carried out in the last two decades it is quite clear that any system based on either SE or TDN and which is applied to both growing or lactating ruminants will be unsound. k_m and k_l vary relatively little with M/D, whilst K_f shows large effects from 0.25 to 0.50. Increasing realisation of the theoretical unsoundness of the SE system is currently resulting in some change of feeding systems in Europe, most of which are fodder units based on SE. Whilst not following the UK example, they are nevertheless using the mechanics of our variable net energy system for growing cattle to calculate new fodder units based on NE_{mp}. They prefer to use NE_l, net energy for-lactation of Moe, Flatt and Tyrrell (1972) and van Es (1969) for lactating dairy cows: to date, Holland, France and Belgium have decided to change, whilst Switzerland and Germany are actively considering so doing.

Whilst the present UK systems may be considered to be weak in certain areas, it was felt more important to change systems using as much as possible of ARC 1965, than to wait for the perfect system. Further refinement can be introduced later once a system is in use, and in fact pressure is already building for this to be done; With a revised edition of Technical Review No. 2 at press, obviously this will be considered in the near future.

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