NUTRITIONAL STANDARDS FOR DAIRY CATTLE

Report of the British Society of Animal Science Nutritional Standards Working Group: Dairy Cows

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Report prepared by Dr Rosemary E Agnew, Agricultural Research Institute of Northern Ireland and Dr John R Newbold, Provimi Research and Technology Centre, Belgium.

REMIT

The remit assigned to the working group is given in Appendix 1. This was interpreted as a scoping exercise to determine if there would be justification for wider-ranging reviews culminating in documentation which could be accepted as Nutritional Standards for dairy cows.

We defined Nutritional Standards as ‘estimates of nutritional requirements and feed values and/or quantitative rules for responses of animals to feeds that are commonly accepted in the agricultural industry’. We have defined dairy cows as adult female animals, which have produced offspring and have considered the nutritional standards for both dry and lactating cows. The nutritional standards of growing dairy heifers have been considered by the beef cattle working group.

KEY RECOMMENDATIONS (in order of priority)

- An independent review of the mineral requirements of dairy cattle is required. Currently the UK does not have adequate methodology to estimate either the mineral requirements (for animal production), or feed value (e.g. lack of information on P availability) or the quantitative rules for responses (e.g. responses of animal health, fertility to, for example, cobalt, iodine or selenium). There is undoubtedly a large gap between the currently accepted standard MAFF *et al.*, (1983) and the information available.

- An independent review of the vitamin requirements of dairy cattle is required – again to incorporate a comparison of MAFF *et al.*, (1983) and the information currently available. Currently the UK does not have adequate methodology to estimate either the vitamin requirements (for animal production), or feed value or the quantitative rules for responses (e.g. responses of animal health, fertility etc.).

- Much work on energy and protein feeding standards has been moved forward to a stage, via the FiM project, where it is relevant to today’s stakeholders in terms of the context of genetic change and relevant feed characterisation methods.

- The energy system developed using calorimetric measurements from lactating dairy cows in the UK (the FiM project) is likely to be suitable for adoption as the new UK standard. However, like other energy systems it will have limitations as a standard for predicting responses.

- A critical review should be undertaken of the protein system proposed by the FiM project, with a view to its adoption as the new nutritional standard for calculating protein requirements and protein supply for dairy cows in the UK.

- The FiM energy and protein systems should be evaluated in animals in a grazing situation.

- Improvements to energy supply are needed **-** priority must be given to improving the prediction of the nutritive value of concentrates and grazed grass.

- A nutrient based response model for dairy cows be developed to predict partition of nutrient use between milk output (both yield and composition) and body tissue synthesis.

- An intake prediction system should be incorporated into Nutritional Standards. Research undertaken by the FiM project has already provided the data and relationships for during the winter ‘housed’ situation. However, research must be undertaken to provide an improved prediction of grass intake by grazing dairy cows.

INTRODUCTION

This task was been broken down into energy, protein, minerals and vitamins and each of these nutrients is considered separately. Comments are also included on dry matter intake. The tables in Appendix 3 summarise these points in an easier to follow format. In addition, more substantive information is also included in Appendices 4-8 to support the recommendations made.

Traditionally, farmers and advisers have used ‘feed evaluation systems’ to address what might be termed ‘THE REQUIREMENT QUESTION’:

> What do I need to feed to achieve X? (e.g. X litres milk/d)

In sections 3.1 and 4.1, below, we consider the ability of current energy and protein systems, respectively, to deal with this question.

The second question asked by farmers and advisers might be termed ‘THE RESPONSE QUESTION’:

> What will happen if I feed them X ? (where X might be another kg of sugar beet pulp, or a switch from soya to rape, or an extra mineral supplement)

Task 2 of the remit asks us to consider a broad set of responses: animal production, animal welfare, environmental protection and food safety. This is covered in sections 3.2 (energy) and 4.2 (protein).

To provide context, however, we begin by outlining the recent history of the use of energy and protein systems in the UK.

2. USE OF ENERGY AND PROTEIN SYSTEMS IN THE UK

- In the UK, the metabolisable energy (ME) and protein (MP) systems provided the framework for describing requirements and formulating diets for dairy cows. However, for a number of years limitations in both systems have been acknowledged. Workshops held in the early 1990s (e.g. BSAP, 1993) concluded that inadequate feed characterisation was the main factor responsible for inadequate diet formulation and sub-optimum feed utilisation. The workshops emphasised the need for a co-ordinated approach to the development of diet formulation systems and the need for the parallel development of feeding systems and feed characterisation methods which were accurate, rapid and within the financial reach of dairy farmers.

- Current advisory practice and software is based on AFRC (1993). However, a variety of *ad hoc* modifications to the published system have been made because until recently progress in feed characterisation methodology was not co-ordinated, nor was there an industry-wide system for quality control.

- The absence of a framework for the co-ordinated development of feeding and feed characterisation systems inhibited the progress in advancing the ME and MP systems. A number of UK nutritionists have turned to other European and North American diet formulation systems. Some of these provide a more sophisticated description of energy and protein supply in terms of individual nutrients, their rates of availability to the rumen micro-organisms, and digestibility in the small intestine. Of particular interest is the Cornell Net Carbohydrate and Protein System (CNCPS). However, widespread use of this system is limited by the lack of data on specific forages (particularly grass silage) and feeds in common use in the UK.

- As a result of concerns in the industry, coupled with the demise of the Inter-Departmental Working Party system, which in the past had been charged with incorporating new developments into advisory practice, a four-year research, development and technology transfer programme has been undertaken. This project entitled ‘Feed into Milk’ (FiM), commenced in October 1997 and was funded out of the DEFRA LINK Sustainable Livestock Production Programme. The work consisted of a number of elements within the context of a requirement-based system. In summary the main outputs of relevance here are:
    - ☐ the development and testing of new equations to predict DM intake.
    - ☐ new systems to predict the relationship between ME supply and milk energy output.
    - ☐ a rumen model, with microbial protein synthesis predicted from estimated ATP supply.
    - ☐ decision support for ensuring rumen stability, estimating direction of change in milk composition in response to change in diet composition and assessing the supply of key essential AA.
    - ☐ a feed database and methods of analysis appropriate to the new system.
    - ☐ diet formulation / evaluation software incorporating the whole FiM model.

- The FiM system is currently being field tested by consortium members. Apart from an overview presented at the 2002 University of Nottingham Feed Manufacturers Conference, the new system has not yet been published.

3. ENERGY

3.1. REVIEW OF INFORMATION CURRENTLY AVAILABLE ON NUTRIENT REQUIREMENTS

- The UK ME feeding system, developed by Blaxter (1962), was first proposed for use in the UK by Agricultural Research Council (ARC, 1965). This system was designed to overcome the deficiencies of the Starch Equivalent system (a net energy system) which was then used in the UK. Using the proposals put forward by ARC (1965), a simplified ME system was recommended to be adopted in UK by the Ministry of Agriculture, Fisheries and Food (MAFF, 1975). The original system (ARC, 1965) was later substantially revised by ARC (1980) and further modified by Agricultural and Food Research Council (AFRC, 1990) and a new working version was published in 1993 (AFRC, 1993). The latter forms the basis of the energy rationing methods used in diet formulation in the UK.

- The weaknesses of the UK ME system have been reviewed extensively by Agnew and Yan (2000) and these are detailed in Appendix 4. Most importantly, the system for dairy cows is not based on calorimetric data with lactating dairy cows within the UK. Estimates of maintenance energy requirement (ME_m) were based on classical energy metabolism studies with fasting animals. These were undertaken 30-50 years ago using very different animals and diets to those in use today (AFRC, 1990 and 1993). However, within the last 10 years a substantial number of dairy cow calorimetric measurements have been undertaken within the UK at the Agricultural Research Institute for Northern Ireland, Hillsborough (ARINI) and the Centre for Dairy Research, University of Reading (CEDAR).

- A review of systems used in other countries clearly shows that they are not up-to-date and relevant to extrapolate to current UK circumstances. For example, France and NL are still using systems that originated in the mid 1970's – the requirement side, especially, does not seem to have been updated. NRC (2001), while presenting a radical overhaul on the 'supply' side (calculation of NE supply), does not introduce significantly new information on NE requirements or efficiency of ME utilisation.

- The energy system developed using calorimetric measurements from lactating dairy cows in the UK (the FiM project) is likely to be suitable for adoption as the new UK standard, after its publication and review. BSAS should actively encourage this publication process.

- While the FiM project presents a real change in the calculation of ME requirement, it does not alter the fundamental way in which ME supply is calculated. This is especially true for concentrates, where little has changed since the review of MAFF (1992). Since then, new systems have appeared in the USA (where NRC (2001) presents a new system based on lignin determination) and in NL (where new feedstuff-specific equations are available, at least to the feed industry, to calculate ME from chemical composition). In addition, new information on *in vivo* OM digestibility been published in Ireland and elsewhere. While we accept that our remit was to consider nutrient requirements, not nutrient supply, there is, potentially, much to be gained by reviewing whether these new methods apply to modern UK diets.

- The majority of dairy cows in the UK spend at least 50 % of their time on grazed pasture. Given lower milk price and other EU animal welfare guidelines etc., it is likely that grazing will be increasingly important in the future. New models must be able to address the following:
    1. Improved systems to characterise the nutritive value of grazed grass and interactions with the provision of supplements

2. Reassessment of the energy requirements of grazing animals, particularly that associated with ‘activity allowance’
3. Testing the FiM energy systems with animals in a grazing situation

3.2. IS THE CURRENT PROVISION OF INFORMATION ADEQUATE TO MEET THE FUNCTIONAL NEEDS OF STAKEHOLDERS?

Animal production responses

- In order to be relevant to the needs of the dairy farmer, a dairy cow feeding system should, as defined by AFRC (1998), predict short and long-term effects on:
    - Voluntary feed intake
    - Partition of nutrient use between milk secretion and body tissue synthesis
    - Yields of milk fat, protein and lactose

- A system based on the currency of energy cannot be developed to predict responses in nutrient partitioning (milk versus body tissue) or milk composition. This functional need of farmers and advisers can only be met by developing a nutrient-based response model for dairy cows. We are aware of on-going research at the University of Reading in this area and a recent DEFRA funded scoping study on nutrient partitioning. This latter study reviewed current knowledge and proposed strategic approaches to fill gaps in knowledge. Therefore, whilst being able to predict nutrient partition is a vitally important area, we do not see it as a priority for BSAS.

- Many current rationing systems also utilise lactation curves as a diagnostic tool to identify nutritional and other disorders and to predict lactation rations. It is our view that these are based on very old data and should be updated so as to ensure they are relevant to today’s dairy cow.

Animal welfare responses

- Feeding cows the correct level of energy is probably the single most important thing we can do to ensure good animal welfare and avoid ‘production’ diseases. However, a nutrient-based model would improve our ability to diagnose and prevent sub-clinical conditions such as acidosis and ketosis.

Environmental protection

- A nutrient-based model would also improve our ability to manage, nitrogen, phosphorus and methane excretion by dairy cows.

Food safety

- Feeding dairy cows a more balanced diet of known composition ensures that the milk produced is safe for human consumption.

4. PROTEIN

4.1. REVIEW OF INFORMATION CURRENTLY AVAILABLE ON NUTRIENT REQUIREMENTS

- The metabolisable protein system first proposed by ARC (1980) and revised by AFRC (1992) provided an improved description of protein and energy supply to the rumen and protein supply to the host animal but had a number of weaknesses. A review of other published protein systems, undertaken during the early stages of the FiM project, highlighted the differences in the estimates of requirements for metabolisable protein between the MP system and other systems. While values for the efficiency of utilisation of absorbed amino acids for milk protein synthesis and for pregnancy, dermal losses and liveweight change were broadly similar, maintenance requirements were significantly lower in the MP system. The main difference between the MP and other systems appeared to be that the latter included in their calculations of maintenance requirements, either implicitly or explicitly, allowances for metabolic faecal N (MFN) losses. In most of the other systems, estimates of MFN are based on DM intake. In the MP system (AFRC, 1992), estimates of requirements were based on basal endogenous N losses, but *at a maintenance level of feeding*, and no adjustment had been made to account for losses at higher intakes.

- The current MP system describes the supply of absorbed α-amino nitrogen simply in terms of protein with no recognition of requirements for specific amino acids. Given the substantial data on responses in milk protein output to post-ruminal supply of individual amino acids, especially lysine and methionine, this area also needs to be addressed. Again the FiM project has partially addressed this.

- Systems in use in many other countries date from the 1980's (France) or mid-1990's (NL). The new system proposed by NRC (2001) represents, in many ways, a 'catching up' with European systems. Although individual elements have relevance (e.g. the FiM review took note of NRC's approach when calculating maintenance requirements, and used the French approach when assessing needs for individual amino acids), we do not feel that there is merit in the wholesale adoption of any one of these systems as a 'nutritional standard', in preference to the existing AFRC (1993).

- The FiM project has proposed a new protein rationing system for dairy cows in the UK based on elements from both the current UK system and NRC (2001). This protein rationing system has been evaluated using recent dairy cow experimental data from ADAS, Bridgets and ARINI, Hillsborough. However, the system has not yet been formally published.

- It is likely that the protein system proposed by the FiM project will be suitable for adoption as the new nutritional standard for calculating protein requirements for dairy cows in the UK, following publication. Again, BSAS should actively encourage publication.

4.2. IS THE CURRENT PROVISION OF INFORMATION ADEQUATE TO MEET THE FUNCTIONAL NEEDS OF STAKEHOLDERS?

Animal production responses

- A protein evaluation system that addresses separately the N needs of rumen microorganisms and the animal can, in principle, help maximise efficiency of N use.

- The new FiM MP system contains an improved method of assessing the supply of fermentable energy and an improved method of optimising the amino acid balance of undegradable protein, therefore it is suggested that the FiM MP system merits consideration.

- As in 3.2 the FiM protein system should be evaluated with animals in a grazing situation.

Environmental protection

- A protein evaluation system that addresses separately the N needs of rumen microorganisms and the animal can, in principle, minimise N losses to the environment.

4. INTAKE

- The ability to accurately predict food intake is viewed by many as an important first step in rationing, as small errors in intake prediction can result in major effects on estimates of nutrient supply and hence animal performance.

- Much research effort has been expended over the last 30 years in developing food intake prediction models. These range from relatively simple multiple regression to complex mechanistic models embracing animal, food and environmental factors. However, given the major changes in the types of diet now offered to dairy cows, coupled with progress in genetic merit/milk production potential, it is important to examine if the food intake prediction models are appropriate for today's dairy cow.

- A key objective of the FiM project was to examine the performance of existing predictions for feed intake and, if necessary, to develop new models which cope better with modern cows and production systems. The FiM project identified the inability of current models to accurately predict the intake of dairy cows and developed a new intake prediction system, which should be critically reviewed and incorporated into a new feeding standard.

- For grazing animals an improved prediction of grass intake is required.

5. MINERALS

- Underwood and Suttle (1999) provide a comprehensive review of the literature on the mineral nutrition of livestock. NRC (2001) uses much of the information contained in NRC (1988). The UK standards have not been revised since 1980, 1983 (many use the recommendations of ARC (1965)) and many UK nutritionists now use the NRC values or the values recommended by Underwood and Suttle (1999). An independent review of all of these needs to be undertaken to enable up-to-date Nutritional Standards for the UK to be produced. Currently the UK does not have adequate methodology to estimate either the mineral requirements (for animal production), or feed value (e.g. lack of information on P availability) or the quantitative rules for responses (e.g. responses of animal health, fertility to, for example, cobalt, iodine or selenium).

- In addition, improved calcium, phosphorus and magnesium ‘models’, incorporating ‘requirement’, ‘response’ and ‘feed evaluation’ sub-models are required.

  Trace Elements (cobalt, copper, iodine, zinc, iron, manganese, molydenum, selenium, chromium and fluorine)

  - Whilst reliable information is sparse on these areas at production level there is increased interest in whether or not responses in milk yield and perhaps more importantly fertility are observed when supplemental trace elements are added to the diet. The recommendation is therefore that there is a need for an independent review of the literature on the supply of additional trace elements to dairy cows.

6. VITAMINS

- An independent review of the vitamin requirements of dairy cattle is required – again to incorporate a comparison of MAFF *et al.* (1983) and the recently published NRC (2001). The term ’vitamins’ could be thought of as an empirical term, since an up-to-date review must go beyond the A, D and E vitamins. There are many reports in the scientific literature, particularly in relation to B vitamins and an up-to-date review is clearly required.

- Currently the UK does not have adequate methodology to estimate either the vitamin requirements (for animal production), or feed value or the quantitative rules for responses (e.g. responses of animal health, fertility etc.).

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APPENDIX 1 – REMIT OF SUB-CONTRACTOR GROUP

1. **To form a species working group with, in addition to the academic sub-contractor, a representative of the feed supply industry and the species production sector who will act as assistant reviewers.**

2. **To review for their livestock species the information currently available internationally on nutrient requirements.**

- Identify the published standards currently available for that species nationally and internationally and the extent to which they are used in practice.
- Assess the extent to which they cover the full range of nutrients and factors that influence availability.
- Assess the extent to which these are up to date in relation to the information available for the different nutrients.
- Assess the scientific quality of any modelling approaches used, and hence the validity of conclusions
- Assess the extent to which the scientific basis of the information makes it relevant to extrapolate to current UK circumstances (e.g. genotypes, production systems)

3. **To identify areas in which the current provision of information is inadequate to meet the functional needs of UK stakeholders**

- Review the current needs of UK stakeholders in relation to their species in the context of genetic change, and societal concerns relating to animal welfare, environmental protection and food safety.
- Identify the extent to which current published standards meet these needs, and prioritise the areas in which information is inadequate or areas of requirements that are not addressed.

4. **To make this information available to the BSAS Nutritional Standards Group for dissemination to interested parties in UK government, industry and academia**

- Produce a written report covering areas 2 and 3 above by 15 January 2002
- Respond to feedback from the BSAS Nutritional Standards Group and clarify any points arising in a final version of the report which will be posted as a pdf file on the BSAS Nutritional Standards website.
- Deliver an oral presentation at the Annual Meeting of the British Society of Animal Science in York, April 2002.
- A meeting of the steering group will be held in London on 13 February 2002 to which subgroup representatives will be invited to answer points of clarification.

APPENDIX 2 - REFERENCES

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APPENDIX 4 – ENERGY

The current authors gratefully acknowledge the FiM project for access to review undertaken within FiM.

Background to UK System

The UK metabolisable energy (ME) feeding system, developed by K. Blaxter (1962), was first proposed for use in the UK in 1965 by Agricultural Research Council (ARC, 1965). Using the proposals put forward by ARC (1965), a simplified ME system was recommended to be adopted in UK by the Ministry of Agriculture, Fisheries and Food (MAFF, 1975). This was known at Technical Bulletin 33 and whilst it was adopted in practice, it failed to incorporate two of the main elements of the ME system originally proposed. The original ME system (ARC, 1965) was later substantially revised by ARC (1980) and further modified by Agricultural and Food Research Council (AFRC, 1990) and a new working version was published in 1993 (AFRC, 1993). These modifications were based largely on the extensive work on energy requirements of lactating dairy cows by Van Es at Lelystad and by Flatt, Moe and Tyrrell at USDA, Beltsville (Van Es *et al*., 1970; Moe *et al*., 1972; Van Es, 1978). Terms were included to allow for energy released from or deposited in body tissues of lactating cows and it also recognised that tissue energy gain was more efficient in the lactating rather than the non-lactating animal.

At the same time a number of NE systems have been developed in Europe (Van Es, 1978; Institut National de Recherche Agronomique (INRA), 1978) and North America (National Research Council (NRC), 1978). Van Es (1978) developed the unit Net energy for lactation (NEL), whereby energy requirements for maintenance were expressed in NEL terms. Similar studies in North America (Moe et al., 1972) resulted in the adoption of a NEL unit (NRC, 1978) which also predicted NEL from the ME value of the feed. This approach was refined by French and Dutch scientists by expressing NEL values in terms of NEL of barley, thereby relating energy contents to a fodder unit value. Currently NEL values (either MJ or Mcal) are used in Germany, Switzerland, Netherlands, Denmark, France, Ireland and North America.

There is no difference in principle between the ME and NE systems, with both systems recognising that the energy requirement of cattle is the sum of their energy requirements for maintenance, production (milk and liveweight gain) and foetal growth. The only difference between them is where the energetic efficiencies are embodied within the calculation. In the ME system the energetic efficiencies are used for ration formulation and the prediction of animal performance, while in the NE system the efficiencies are included as part of the energy evaluation of feeds.

Over the last two decades a considerable volume of research in the energy metabolism of dairy cows has been undertaken. These studies have highlighted a number of concerns over current energy feeding systems. The purpose of this scoping documents is to reflect on the impact of recent research on energy feeding standards. The areas which will be addressed in the present review include the energy requirement for maintenance, efficiency of ME utilisation for milk production and the energy value per unit of liveweight change.

Energy requirement for maintenance

Methods of estimating energy requirement for maintenance

The NE requirement for maintenance (NE_m) in energy feeding systems presently used in Europe and North America was derived from calorimetric data. In the UK ME system the NE_m was based on fasting metabolism data (fasting heat production (FHP) plus fasting urinary energy output) from beef steers and dry non-pregnant dairy cows after a prolonged period of restricted feeding (usually at maintenance level). Using this approach ARC (1980) reported a curvilinear relationship between fasting metabolism (FM) and liveweight (LW) ($FM=0.53*(LW/1.08)^{0.67}$) from a review of 8 sets of data. This relationship, plus an activity allowance (0.0091*LW), is taken as NE_m for use at present in UK (AFRC, 1990). This approach would suggest a fasting metabolism of around 0.30 (or NE_m of 0.35 if an activity allowance is included) $MJ/kg^{0.75}$ for an adult dairy cow. The ME requirement for maintenance (ME_m) is calculated as NE_m divided by the efficiency of utilisation of ME for maintenance (k_m, $=0.35*ME/GE+0.503$) (AFRC, 1990). Alternatively, the NE_m can be estimated using regression techniques relating ME intake to milk energy output, adjusted to zero energy balance, with dairy cows offered diets at production levels. Using this approach, Moe *et al.* (1972) and Van Es (1975) reported NE_m values of 0.305 and 0.293 $MJ/kg^{0.75}$ respectively from large sets of calorimetric data. The former value is used to form the American NE system, with an activity allowance of proportionately 0.10 being added (NRC, 1988). The latter value is adopted in the European NE systems used in the Netherlands, France, Germany and Switzerland. No activity allowance is adopted in the Netherlands (Van Es, 1978), while an activity allowance of proportionately 0.10 is added for loose housed cows in France (INRA, 1989).

The use of fasting metabolism data to determine NE_m may have limitations. It has been suggested that fasting after a long period of restricted nutrition can result in deamination of amino acids from tissue protein for the supply of essential glucose (Chowdhury and Ørskov, 1994). This can induce a range of metabolic disorders in the animal, such as hypoglycaemia, hyperlipidaemia, hyperketonaemia and hypoinsulinaemia. However, the maintenance metabolic rate obtained by fasting metabolism (0.30 $MJ/kg^{0.75}$) (ARC, 1980) is similar to that derived from regression techniques (0.305 or 0.293 $MJ/kg^{0.75}$) (Moe *et al.,* 1972; Van Es, 1975). It thus seems unlikely that the detriment of fasting to animal health influences greatly the heat production.

Recent research on energy requirement for maintenance

The NE_m values currently used in Europe and North America were developed from data published 30 years ago. However, a recent study reported by Birnie (1999) revealed a FHP value of 0.39 $MJ/kg^{0.75}$ for dry, non-pregnant dairy cows fed at maintenance level prior to measurement of FHP. Assuming a fasting urinary energy output of 0.05 of FHP (Van Es, 1972), the derived fasting metabolism is proportionately 0.36 higher than that adopted in current energy systems (Van Es, 1978; NRC, 1988; INRA, 1989; AFRC, 1990). Similar higher FHP values were also reported by Yan *et al.* (1997b) and Birnie (1999) when dairy cows were offered respectively diets at near *ad libitum* and at twice maintenance levels prior to fasting (Table 1). FHP data published using studies with beef and dairy steers since 1985, as presented in Table 1, are in accord with the above dairy cow results. The mean derived fasting metabolism, when assuming a fasting urinary energy output of 0.05 of FHP (Van Es, 1972), is proportionately 0.19 higher than that proposed by ARC (1980).

The ME_m values derived from regression techniques have also been reported to be higher in recent studies. The ME_m values obtained in 6 studies are presented in Table 2. The mean ME_m value derived in recent studies (Unsworth *et al.,* 1994; Hayasaka *et al.*, 1995; Yan *et al.,* 1997a) is proportionately 0.28 higher than that reported over 20 years ago (Moe *et al.,* 1970; Van Es *et al.,* 1970; Van Es, 1975). As Van Es (1975) used a total of 1148 data from across the world, the NE_m derived from his study is thus adopted in a number of European NE systems. Agnew and Yan (2000) have reviewed calorimetric studies with lactating dairy cows published since 1976. A total of 42 studies (more than 1500 individual animal data) were selected, in which the liveweights of the animals and the energy intake and outputs were available. The experimental mean data from these 42 studies were used to examine the relationship between ME intake and energy outputs. The linear and multiple regression equations obtained are:

$$E_{l(0)} = 0.637_{(0.0358)}\ MEI - 0.371_{(0.0557)} \qquad R^2 = 0.89 \qquad (1)$$

$$MEI = 0.664_{(0.0471)}\ MW + 1.452_{(0.0755)}\ E_l + 1.079_{(0.1200)}\ E_g \qquad R^2 = 0.92 \qquad (2)$$

Where E_l, E_g, MEI and MW are respectively milk energy output, energy balance, ME intake and metabolic liveweight ($kg^{0.75}$); $E_{l(0)} = E_l + E_g$ for positive E_g or $= E_l - 0.84^* E_g$ for negative E_g. The units for equation (1) and (2) are respectively $MJ/kg^{0.75}$ and MJ/d. The values in brackets are standard errors. The mean ME_m derived from these two equations is 0.62 $MJ/kg^{0.75}$, a value which is proportionately 0.27 higher than that derived from Van Es (1975), or calculated from AFRC (1990).

The higher ME_m may reflect differences in both the diet and the cow now used, particularly the considerable improvement in cow genetic merit during the last two decades (Coffey, 1992). The latter has led to an increase in milk yield of approximately 62 kg/lactation per year (Agnew *et al.*, 1998). Indeed, high producing dairy cows were found 30 years ago by Flatt *et al.* (1969b) to require proportionately 0.20 more ME for maintenance than cows producing moderate yield, as reported at the same time by Moe *et al.* (1970) and Van Es *et al.* (1970). The higher ME_m obtained in the recent studies may be attributable to a higher proportion of liveweight as body protein mass. This is evidenced in that high genetic merit cows had a lower backfat thickness at a similar liveweight to medium and low genetic merit animals (Ferris *et al.*, 1999a), and a higher estimated lipid-free empty body weight as a proportion of empty liveweight (Veerkamp *et al.,* 1994). The ME_m has been reported to be a function of body protein mass (discussed later).

Factors affecting the energy requirement for maintenance

Body condition (fat v. lean)

In all currently used energy systems the energy requirement for maintenance is related to the liveweight of animals. However, there has been increasing evidence to suggest that maintenance metabolic rate depends on body lean mass, rather than whole liveweight (Noblet *et al.,* 1998; Pullar and Webster, 1974). A series of fasting studies reported by Birnie *et al*., (2000) would support the above results. Cattle were fattened from condition scores (CS) (Edmonson et al., 1989) below 2.0 to over 4.5, or restricted feeding to reverse CS change. While FHP (MJ/kg$^{0.75}$) was significantly higher for cattle with low than high CS, the former animals required a similar amount of estimated ME for maintenance (MJ/d) although they had a much heavier weight (Birnie, 1999). A regression of FHP (MJ/kg$^{0.75}$) against CS (from 1.0 to 5.0) ($R^2 = 0.83$, n=28) indicated that FHP was 0.483 MJ/kg$^{0.75}$ at CS of 1.0 and an increase of CS by 1.0 would reduce FHP by 0.029 MJ/kg$^{0.75}$.

The above findings support the view of Oldham and Emmans (1990) that the major part of the energy cost associated with tissue ‘maintenance’ results from the continual process of synthesis, degradation and replacement of those parts of body tissues which ‘turnover’. This is particularly the case with body protein for which the process of ‘turnover’ is substantial, although variable (Reeds, 1989). It has been suggested that fat tissue does not ‘turnover’ at all in animals fed regularly, although there does appear to be an extent of fatty acid turnover which is obligatory and which might be presumed to represent a degree of turnover of body fat (Oldham and Emmans, 1990). The energy cost of maintaining body protein would, however, be expected (on stoichiometric grounds) to exceed that of fat even if their rates of turnover were similar. Against this background it is biologically unreasonable to expect maintenance to be directly related to scaled liveweight when the composition of the body may vary.

It may not be realistic to exactly measure protein mass in a live animal. However, some modern techniques can be used to indirectly predict body fat and protein masses. For example, the ultrasonic scanning technique can be used to measure the back fat thickness of an animal (Ferris *et al*., 1999a).

Dietary concentration of fibre fraction

All currently used energy systems for cattle assume that dietary fibre concentration has no effect on NE_m, although it may influence k_m in the UK ME system since k_m is set to be positively related to energy metabolisability (AFRC, 1990). Recent studies have however suggested that increasing dietary fibre concentration could increase maintenance metabolic rate. Cattle offered a high fibre diet have been shown to consume more feed to have a similar amount of ME intake to those given a low fibre diet (Reynolds *et al.,* 1991; McLeod and Baldwin, 1998). Feeding of high fibre diets has been also shown to increase the metabolic activity in organs of animals. Reynolds *et al.* (1991) reported higher blood flow rates at portal-drained viscera (PDV), liver and kidneys, and greater oxygen use at PDV and whole body in heifers offered a high compared to a low fibre diet.

Dietary fibre concentration can also influence k_m, because k_m is predicted from energy metabolisability in the UK ME system. Increasing fibre concentrations in diets can reduce energy metabolisability by reducing energy digestibility (Flatt *et al.*, 1969b; Beever *et al.*, 1988) and increasing methane energy output as a proportion of total DE intake (Yan *et al.*, 1999). The effects of dietary fibre fraction on maintenance metabolic rate and k_m can thus result in a higher ME_m for a high compared to a low fibre diet (Flatt *et al.,* 1969b; Tyrrell and Moe, 1972; Yan *et al.,* 1997a).

Activity allowance associated with grazing

Grazing of dairy cows on pasture is a common practice in many parts of the world. Grazing cattle expend more energy in consuming the same amount of feed when compared with prehension from a trough for housed cattle. The energy expenditures in eating 1 kg DM of pelleted feed, hay/dried grass or in simulated grazing were reported to be 0.23, 1.03 or 3.42 kJ/kg liveweight in cattle (Adam *et al.,* 1984). Heat production was nearly double in growing cattle for eating a total of 1 kg DM of forage in standing pasture rather than as cut pasture (fresh and dried) (Holmes *et al.*, 1978). The higher energy expenditure during grazing can result from greater physical effort for eating feed from the sward and more time in selecting and getting into its mouth the feed that it eats. In addition, lactating dairy cows grazing on pasture are usually required to walk a distance twice a day for milking.

NRC (1988) recommend a proportionately 0.10 increase in maintenance allowance for cows grazing on good pasture and up to 0.20 on sparse pasture. SCA (1990) suggest that increases in maintenance requirement for grazing cows are in a range of 0.10 to 0.20 in intensive grazing conditions, to approximately 0.50 for animals grazing extensive, hilly pastures where they walk considerable distances to preferred grazing areas and to water. However, these allowances are not included in the current UK ME system (AFRC, 1993) and there is a requirement to address this deficiency in the future.

Efficiency of ME utilisation

Methods of estimating the efficiency of ME utilisation for lactation

The efficiency of ME utilisation for lactation (k_l) can be determined using a range of regression techniques on large sets of calorimetric data. In the literature two regression equations have often been used; i.e., the linear regression relating milk energy output (adjusted to zero energy balance) to ME intake, and the multiple regression relating ME intake to metabolic liveweight, milk energy output and energy balance. Using these two methods the present review would suggest an average k_l of 0.66, as presented in equations (1) and (2), derived from calorimetric data of dairy cows drawn from 42 studies from across the world. This value is within the range of k_l values (0.60 to 0.67), as presented in Table 2, which were derived from regression techniques reported in a number of studies with dairy cows.

For individual calorimetric studies, k_l has often been determined by assuming a ME_m value which is deducted from ME intake to provide the ME available for production (ME_p), and then relating this to adjusted milk energy output ($E_{l(0)}$, k_l

= $E_{l(0)}/ME_p$). The k_l estimated from this approach is thus influenced by the accuracy of ME_m. Using this method, and ME_m of AFRC (1990), k_l values have often been estimated to be low (0.50 to 0.58) with data of dairy cows given diets based on either grass silage (Unsworth *et al*., 1994; Gordon *et al.,* 1995; Yan *et al.,* 1996; Ferris *et al.,* 1999b), or maize silage or whole crop wheat (Sutton *et al.,* 1998 ab and 1999; Beever *et al*., 1998). However, the above k_l values could be increased (0.59 to 0.65, mean of 0.62) by using a ME_m of 0.62 MJ/kg$^{0.75}$, as obtained from present equations (1) and (2). The latter mean k_l (0.62) is similar to that (0.64) predicted from AFRC (1990) (k_l = 0.35*ME/GE + 0.42) using ME/GE obtained in these studies.

A further method has been adopted by some workers (mainly in Germany), in which k_l is derived as a proportion of NE of total ME intake, where NE is the sum of milk energy, retained energy multiplied by a constant and assumed NE_m. However, the efficiency calculated using this method is a mixture of efficiencies of ME utilisation for lactation (k_l) and maintenance (k_m).

Effects of dietary nutrients on the efficiency of ME utilisation for lactation

The composition of a diet can shift the microbial population in the rumen and consequently influence the production of VFAs. In general a high fibre diet produces VFAs with a high proportion of acetic acid, while a concentrate diet normally generates more propionic acid. It has been well documented that VFAs produced in the rumen can influence milk composition, i.e. molar proportions of acetic and butyric acids are positively related to milk fat concentration. The rumen VFAs can also alter energy partition between milk and body tissue. A number of feeding studies (e.g., Flatt *et al*., 1969a; Sutton *et al*., 1993) and infusion trials (e.g., Ørskov *et al*., 1969; Huhtanen *et al.,* 1993) have demonstrated that increasing propionic acid proportion can result in more energy partitioned into body tissue and less into milk.

The effects of VFAs produced in the rumen on energy utilisation have been studied extensively in sheep and steers. The results are not conclusive, with some workers reporting a lower efficiency of utilisation of energy derived from acetic acid for body tissue synthesis, while others noting equal efficiencies between acetic and propionic acids (Tyrrell *et al*., 1979; Ørskov and Ryle, 1990). The research on the influence of VFAs production on k_l with lactating dairy cows is limited, but there is no evidence indicating a relationship between k_l and the molar proportion of acetic or propionic acid produced in the rumen (Ørskov *et al*., 1969; Tyrrell et al., 1979; Ørskov and MacLeod, 1982). The k_l obtained using the linear regression technique on large sets of calorimetric data also indicates little differences with forage proportions in diets.

Effect of cow genetic merit on the efficiency of ME utilisation for lactation

Dairy herds in the British Isles have been undergoing a period of rapid increase in cow genetic merit since mid 1980's, with Coffey (1992) reporting current rates of genetic gain of proportionately 0.013 per year in milk fat plus protein yield for the indexed population in UK and Ireland. This increase is approximately 4.5 kg/year of fat plus protein yield, a value which is about 62 kg/year of milk yield when assuming milk of standard composition (Agnew *et* *al.,* 1998). It has been reported extensively that gross energetic efficiency (milk energy output as a proportion of ME intake) is higher with high than low genetic merit cows during early, mid and late lactation (e.g., Grainger *et al.,* 1985b; Gordon *et al.*, 1995; Ferris *et al.*, 1999b). The magnitude of this increase in the efficiency was higher in multiple lactation than first lactation cows (Veerkamp *et al.,* 1994). However, when tissue energy retention and ME_m are taken into account, the partial efficiency for lactation (k_l) appears to be similar between high and low genetic merit cows. The difference in milk energy output between high and low genetic merit cows could almost entirely be explained by differences between genotypes in energy intake and tissue energy retention (Grainger *et al.,* 1985b). When using the equations of AFRC (1990) to estimate ME_m, neither Gordon *et al.* (1995) nor Ferris *et al.* (1999b) detected any significant difference in k_l between high, medium and low genetic merit cows. Veerkamp and Emmans (1995) in a literature review also indicated little difference in the partial efficiency with which ME is utilised for lactation between Holstein and Jersey cows.

The discrepancy in effect of cow genetic merit on gross energetic efficiency and k_l may partially be derived from the difference in ME_p between high and low genetic merit cows. The main factor may however be because high genetic merit cows have the ability to shift the partition of ME absorbed, i.e. more into milk and less into body tissue. A number of long term feeding studies have demonstrated this effect (Grainger *et al.,* 1985a; Gordon *et al.,* 1995).

Energy value per unit of liveweight change

Energy value per unit of liveweight change for lactating dairy cows is fixed in NRC system and each of European systems, but varies with a range between 19 to 30 MJ/kg of liveweight change. A number of recent studies have reported different energy values within the above range (Chilliard *et al.*, 1991; Gibb *et al.,* 1992; Tamminga *et al.,* 1997). The reason for this discrepancy may be attributed to the effects of body condition and lactation stage.

Body condition factors have been recognised to influence the energy value of liveweight change. These factors include gain or loss of body fat or protein, replacement of body fat with water and changes in gut fill. The lack of precision in these factors can result in errors in ration formulation and the prediction of animal performance, especially in early and late lactation when liveweight change of dairy cattle can be large. It may not be realistic in practice to distinguish the effects of gut fill on gain or loss of liveweight and how much water is contained in the weight of change. However, a number of studies have related the energy value of liveweight change to body condition. In a serial slaughter study with Holstein-Friesian cows, Gibb and Ivings (1993) reported that the body fat and energy contents of animals were positively related to their liveweight and condition score and body protein content was positively related to their liveweight. Fat-free mass of Holstein cows remains similar during the dry period, early and late lactation stages, while water content of fat-free mass is greater during the dry period and early lactation than late lactation stages (Andrew *et al.*, 1994). These relationships are reflected in the Cornell Net Carbohydrate and Protein System (Fox *et al.,* 1992). In this system the energy concentration per condition score is linearly and positively related to body condition score and liveweight of dairy cattle. In Australia a linear regression equation for dairy cattle has been developed to relate the energy value of liveweight change to body condition score (SCA, 1990).

Another factor affecting energy value per liveweight change is stage of lactation. During early lactation dairy cows can mobilise both fat and protein from their body reserves for milk production, but protein mobilisation decreases faster than fat (Bath *et al.*, 1964; Reid and Robb, 1971; Tamminga *et al.*, 1997). Protein mobilisation is stopped at about 4 weeks after calving, while fat mobilisation is not stopped at 8 weeks (Tamminga *et al.*, 1997). This may be due to a considerable hypertrophy of both gut and liver during early lactation in response to increased feed intake (Reynolds and Beever, 1995). The composition of mobilised tissue (fat and protein) can thus differ during the first 4 weeks of lactation, i.e. the ratio of fat:protein would increase. If the water content in the mobilised tissue is assumed to remain unchanged, the energy value per unit of liveweight loss would be higher as lactation progresses. On the other hand, energy balance is not always related to liveweight change of dairy cows. Beever *et al.* (1998) reported that high genetic merit cows were still in negative energy balance at 20 weeks of lactation, but liveweight of the animals was maintained after 5 weeks. This can be partially explained by the findings of Tamminga *et al.* (1997) as changes in the water content in mobilised liveweight. The total water loss was proportional to the mobilised liveweight during the first 4 weeks of lactation. Afterwards the animals retained water in their bodies and liveweight loss was very small, but energy loss was still high (Tamminga *et al.,* 1997). Energy value per unit of mobilised liveweight thus increased substantially from 1 to 8 weeks of lactation (Tamminga *et al.*, 1997).

The fixed energy value for liveweight change in NRC system and European systems is therefore incorrect and can result in errors in practice, especially for high genetic merit cows which have a high liveweight loss during early lactation. There is a need to develop more appropriate measures of energy status in dairy cows. If liveweight change continues to be used as an index of tissue energy change, it must be related to both body condition and stage of lactation.

Conclusions

The present review has highlighted a number of concerns about energy utilsation in dairy cows. Recent studies have shown a higher ME_m for the cattle of today (probably reflecting an improvement in cow genetic merit), the influence of dietary fibre concentration and grazing activity on ME_m and a relationship between ME_m and body protein mass (heat production is a function of protein mass). The k_l is relatively stable over a number of dietary (fibre concentration) and animal (cow genetic merit) factors. The energy value per unit of liveweight change varies with body condition and stage of lactation. These effects are important for dairy cattle feeding and should therefore be incorporated in the future revision of an energy feeding system.

Table 1 Fasting heat production of steers and dairy cows offered dried forage-based diets published since 1985

Reference	Feeding Fasting Level	Live weight (kg) (MJ/kg$^{0.75}$)	Forage proportion	HP
Beef and dairy steers				
Birkelo *et al.* (1991)	1.2 * Maintenance	344	0.40	0.357
	2.7 * Maintenance	344	0.40	0.383
Hotovy *et al.* (1991)	Near maintenance	373	0.55	0.337
Carstens *et al.* (1989)	Maintenance	236	0.40	0.350
	Maintenance	372	0.55	0.331
Gill *et al.* (1989)	Near maintenance	210	1.00	0.353
	Near *ad libitum*	200	0.15	0.398
Smith & Mollison (1985)	Near *ad libitum*	200	0.30	0.389
Dairy cows				
Birnie (1999)	Maintenance	571	1.00	0.408
	Maintenance	557	0.14	0.382
	2 * maintenance	614	1.00	0.414
	2 * maintenance	613	0.14	0.410
Yan *et al.* (1997b)	Near *ad libitum*	501	1.00	0.454
	Near *ad libitum*	550	0.80	0.452

Table 2 Summary of the ME requirement for maintenance (ME_m) and the efficiency of ME utilisation for lactation (k_l) by lactating dairy cattle, calculated by a range of authors using regression techniques and pooled calorimetric data

Reference	Cow No	Forage	Method	ME_m (MJ/kg$^{0.75}$)	k_l
Moe *et al.* (1970)	350	Lucerne/grass hay	Multiple	0.51	0.64
Van Es *et al.* (1970)	198	Hay/silage	Linear	0.49	0.62
Van Es (1975)	1148	A range of forages	Linear	0.49	0.60
Unsworth *et al.* (1994)	108	Grass/silage	Linear	0.64	0.67
Hayasaka *et al.* (1995)	53	Hay/silage	Linear	0.59	0.64
Yan *et al.* (1997a)	221	Grass silage	Linear/multiple	0.67	0.65
Present study	>1500	A range of forages	Linear/multiple	0.62	0.66
Mean				0.57	0.64
s.d.				0.075	0.024

APPENDIX 5 - PROTEIN

Introduction

A number of new systems have been developed during the last three decades which have attempted to address the deficiencies of the digestible crude protein (DCP) system. In the UK, proposals by ARC (1980, 1984) led to the development of the Metabolisable Protein (MP) system (AFRC 1993), and this is now widely used within the UK for estimating the protein requirements of ruminant livestock and in diet formulation.

The purpose of this scoping study is to:

(a) summarise the strengths and weaknesses of the UK MP system
(b) summarise key strengths of other systems.

The current authors gratefully acknowledge the FiM project and Dr Bruce Cottrill for access to the review undertaken within FiM.

The Metabolisable Protein System - strengths and weaknesses

The main strengths of the MP system (in comparison with other published systems) are:

a) It contains dynamic elements that take account of rumen turnover rate (level of feeding) in predicting degradation of dietary protein and microbial protein synthesis in the rumen.

b) It assumes a variable digestibility of undegraded dietary protein.

c) The efficiency of utilisation of metabolisable protein (and hence estimates of requirements) can be easily adjusted in a biologically logical fashion to take account of information relating to specific feeding situations.

The main weaknesses of the MP system are:

a) The description of the energy supply to the rumen microorganisms (FME) is biologically unsound.

b) The adoption of a single outflow rate for liquid and solid particles (of different sizes) is likely to result in inaccurate prediction of ERDP supply.

c) The assumption that all ADIN is indigestible is wrong.

d) It is known that, particularly when fed low protein diets, the ability to recycle nitrogen is important in maintaining MP supply. The MP system acknowledges the contribution of recycled N (in calculations of maintenance requirement) but this is clumsy and inadequate.

e) Calculation of maintenance (Basal Endogenous Nitrogen, BEN) requirement is fixed and does not include metabolic faecal losses occurring as a result of feeding and digestion. This is biologically unsound, but recent evidence suggests that an estimate of maintenance is probably accurate.

f) The adoption of a constant efficiency (0.85) for the utilisation of an ideal protein (k_{aai}) for all protein synthetic functions is biologically unsound. Data published in the UK tends to confirm that k_{nl} is not a constant.

g) Studies undertaken to validate the MP system suggest that it under-predicts requirements for, or over-predicts responses to MP (AFRC, 1992; Newbold 1994). It has not been possible to determine, from production data alone, whether the discrepancy between MP requirement and supply in these studies arose from an underestimation of the former, an overestimation of the latter, or some combination of the two.

The MP, in common with most other published systems, uses the *in situ* technique to estimate rumen degradability of dietary protein. Huntingdon and Givens (1995) have described the limitations to this technique. Currently, nitrogen solubility is used by some laboratories to estimate degradability of grass silage protein, but the relationship is poor. For the PDI and AAT/PBV systems, degradability is determined routinely using *in vitro* enzyme techniques, but these provide single point values of degradability and do not permit the use of variable degradability as influenced by rumen outflow rate. In the CNCPS all the degradability characteristics are determined using *in vitro* analyses, but the derivation of some of the data have been questioned (Alderman, 1997).

Until reliable *in vitro* techniques are developed which determine degradation *rates* (the ‘c’ value in Ørskov and McDonald, 1979), this is likely to be a major limitation to refining the MP system.

Key strengths (and some weaknesses) of other systems

A number of protein systems have been published in Europe, N America and Australia. In North America, the CNCPS is an accepted model for evaluating contributions of rations and requirements for beef and dairy cattle in the US. There are, however, a number of alternative models (many of them developed by private industry (eg Cargill, Purina). These use NRC Requirements for Dairy Cattle (1988) as the base reference, but have introduced ‘in house’ modifications to accommodate novel feeds and advanced genetics in current dairy systems.

Some of the key strengths of these systems are identified below.

PDI (French)

- Individual feeds have tabulated supply of nitrogen and energy to rumen microorganisms. In the system as currently used, fixed outflow rates and microbial yields are adopted. However, predicting microbial protein yield from individual feeds (rather than calculating metabolisable protein supply from the whole diet, as is currently the case with the MP system) would permit different outflow rates to be used for individual feeds (e.g. to account for different particle size).

- *In theory*, the use of fermentable organic matter (FOM) as a measure of energy supply to the rumen micro-organisms is more defensible than FME. In the PDI system data for individual feeds are calculated from *whole tract* digestibility studies in which faecal OM is corrected for nutrients that do not yield energy for rumen micro-organisms (UDP, fat and fermentation products) but not microbial OM. Values derived are therefore *potential* FOM; not *actual* rumen fermented organic matter.

- The issue of recycled nitrogen is addressed by reducing the efficiency of capture of all RDP (0.90)

- Adopts a higher value for BEN to account for MFN but this is related to liveweight ($W^{0.75}$) and not adjusted for DMI.

AAT/PBV (Scandanavian)

- Energy supply to rumen microorganisms is related to totally digested carbohydrate (rather than OM), calculated as DNFE + DCF (omitting DEE and DCP, since these make no contribution to microbial protein synthesis). Note that fermentation acids still appear in DNFE. As with the PDI system, digestibility is determined from *whole tract* studies, giving potential rather than actual DNFE.

- No specific allowance is made for recycled N, but model permits a negative value for PBV (implying recycled N available to make up the deficit.)

DVE/OEB (Dutch)

- Based on the PDI system, but estimates of FOM are adjusted for rumen undegradable starch, and allow 50% of fermentation products as energy available for microbial protein synthesis.

- Estimation of the N contribution of individual feeds includes endogenous faecal nitrogen. There is a philosophical appeal in attributing the metabolic cost of excretion to the feed itself, rather than the animal.

- No allowance is made for recycled N.

- Adopts a variable efficiency of utilisation of MP for milk production (Figure 1). Efficiency varies from 0.69 at 300 g milk protein yield to 0.59 at 1,500 g milk protein yield (c.f. MP = 0.68).

CamDairy (Australian)

- Based largely on ARC (1980) but includes an allowance for metabolic faecal nitrogen (MFN, based on dry matter intake) and endogenous urinary N (EUN, based on metabolic live weight) and also adopted a lower efficiency of utilisation of absorbed amino acids. As a consequence, metabolisable protein requirements are higher and more in line with NRC (1978) values.

- k_{nl} is not a constant, but decreases with increasing milk protein yield.

NRC (1988)

- Considers metabolic faecal nitrogen component separately from maintenance. MFN is a function indigestible dry matter, and not the weight of the animal.

- Includes an allowance for recycled N

CNCPS

Alderman (1997) has comprehensively reviewed the CNCPS, and this report will be presented to the Consortium meeting in June. The main strengths have been summarised as follows:

- Complex, but in a format that is operational on conventional software and hardware;

- Output of the model supplies information on rumen conditions, assisting with diet formulation;

- User friendly, allowing easy adjustments of input data;

- Published tests show that the model works well with dairy cows, and predicts first limiting amino acids for beef cattle.

- A semi-mechanistic model

APPENDIX 6 – INTAKE

Accurate prediction of food intake is an essential component of rationing, as small errors in intake prediction can result in major effects on estimates of nutrient supply and hence animal performance. Within the United Kingdom, grass silage remains the major forage component of dairy cow diets during the winter feeding period, yet its intake characteristics are particularly variable. Nonetheless, research at ARINI and SAC has shown that improved silage characterisation methods (Near Infrared Spectroscopy (NIRS) and electrometric titration) can substantially improve the accuracy of prediction of silage intake when grass silage is offered as the sole forage (Offer *et al*., 1998 and Steen *et al*., 1998).

However, in practice any food intake prediction model must be able to accommodate the effects of offering grass silage in combination with other forages (such as maize silage, whole crop wheat, brewers grains) and also with differing types and levels of concentrate supplement. Consideration must also be given to the effects of feeding system (complete diet versus separate feeding of forage and supplement) and there is a particular need to incorporate appropriate animal factors (such as genetic index, milk yield, stage of lactation, condition score, linear traits) into the model. Consequently, much research effort has been expended over the last 30 years in developing food intake prediction models. These range from relatively simple multiple regression to complex mechanistic models embracing animal, food and environmental factors. However, given the major changes in the types of diet now offered to dairy cows, coupled with progress in genetic merit/milk production potential, it is important to examine if the food intake prediction models are appropriate for today's dairy cow.

A key objective of the FiM project was to examine the performance of existing predictions for feed intake and, if necessary, to develop new models which cope better with modern cows and production systems. The FiM project identified the inability of current models to accurately predict the intake of dairy cows and developed a new intake prediction system which should be critically reviewed and incorporated into a new feeding standard. In addition, research must be undertaken to provide an improved prediction of grass intake by grazing dairy cows.

APPENDIX 7 MINERALS

During the last 50 years much progress has been made in the analytical methodology for mineral research. Vastly greater numbers of both research and farmer samples are now analysed for mineral elements resulting in much better understanding of variability of content in feeds. Important progress has been made in dairy cattle in understanding the nutrition and metabolism of certain mineral elements including zinc, copper, iodine, selenium, manganese, iron, magnesium, potassium, chlorine, calcium, phosphorus and sulphur. The interrelationship between minerals and vitamins has also been amongst prominent accomplishments. Especially noteworthy is the relationship between selenium and vitamin E and the role of vitamin D in calcium metabolism. An excellent review by J T Reid on mineral and vitamin nutrition in dairy cattle was published in 1956. This reviewed work undertaken during the previous 50 year period, a time during which mineral and vitamin nutrition were actively investigated. For instance, many of the data on the calcium requirements of dairy cattle were published prior to 1940. During the past 50 years it is our view that dairy cattle requirements for mineral and vitamins have not been given the primary attention of researchers.

Estimates of requirements have been derived in a number of ways. The classical approach (ARC (1965), ARC (1980), NRC (2001)) is firstly to estimate net requirements for various functions (e.g. growth, lactation, pregnancy), and make adjustments to these to account for the fact that ingested minerals are not completely absorbed or utilised, to produce estimates of gross requirements. Gross requirements may then be estimated using factorial models which summate the components of net requirements and divide the total by an absorption coefficient. An alternative approach is to feed livestock with diets containing minerals in a range of concentrations above and below minimum requirements, and then measuring the responses to a given variable, e.g. milk yield, fertility etc. This approach requires less sophisticated research facilities and as a result is more widely used in field studies, but its use could lead to erroneous conclusions. For all minerals considered essential, detrimental effects on animal performance can be demonstrated from feeding excessive amounts. Generally, the dietary amount required for optimal performance is well below amounts found to be detrimental to performance.

The adoption of different approaches in estimating requirements has led to wide variation in tables of requirements in different countries. This problem has then been compounded by the fact that while some report minimum *requirements*, others define need in terms of *allowances*. These are, essentially, requirements with a built in safety margin, with the objective of ensuring that the recommendations accommodate the wide range of genetic, feed and management factors that exist on farms and ensure that individual animals are not at risk from deficiency.

The Inderdepartmental Working Party set up in 1983 (MAFF *et al*., 1983) to consider the findings of ARC (1980) and to translate their findings on minerals, trace elements and vitamins into allowances for use in advisory practice and in the formulation of rations identified a number of issues which have not been addressed. These are listed below:

- The determination of the requirements of the major minerals should be given a priority area for cattle research, particularly in relation to phosphorus.

- The Working Party recommended that long term trials using appropriate numbers of animals to assess, in the first instance, the phosphorus requirements of dairy cattle be initiated. It is perhaps relevant to indicate to the reader that work is currently on-going in Northern Ireland, some work has been undertaken in the Netherlands and in US. The results of this work need to be reviewed in light of the recommendations of the Interdepartmental Working Party.
- The Interdepartmental Working Party concluded that in spite of voluminous literature on minerals, trace elements and vitamins, it was extraordinary how little work had been devoted in recent decades to defining requirements, particularly using practical diets.
- There is a paucity of information on which to base requirements particularly in relation to endogenous losses and availability or absorbability of minerals. Given the major increase on productivity of today's dairy cattle, the information is required if allowances are to be determined with precision.

These are all very relevant today. MAFF *et al.* (1983) recommendations are based on those given by ARC (1980). Rather than specifying minimum dietary concentrations, NRC (2001) provide equations to calculate trace element requirements (mg/d) for specific functions, i.e. maintenance, growth, pregnancy and lactation, and applies appropriate absorption coefficients. Given acceptable estimates of requirements, Underwood and Suttle (1999) have suggested that "the provision of extra minerals beyond the animal's needs is economically wasteful, confers no additional benefit on the animal and can be harmful." Clearly the word "need" requires careful definition. Estimates of *requirements* or *allowances* are frequently interpreted as being the amounts required to maintain normal digestion, metabolism, growth, production and reproduction. In the last decade or so there have been a number of studies, the results of which suggest that there may be improvements in health, reproduction and / or milk yield or quality when cows are provided with certain minerals at dietary concentrations above those that are generally accepted as requirements. Since these are areas that directly affect the profitability of milk producers, they have understandably attracted considerable attention. A review undertaken for the MDC by Cottrill and Rymer (2001) considers some of the evidence and makes recommendations in respect of the supply of additional trace elements to dairy cows. This review was made available to dairy cow subcontractor group of BSAS and provides a very useful base.

Excessive supplementation of minerals and vitamins is also to be avoided and interactions between certain minerals can result in deficiency situations. For example, excessive zinc, iron, sulphur or molybdenum can render copper unavailable and lead to secondary copper deficiency (Radostits *et al*., 2000). Excessive magnesium can lead to scour and mineral imbalances. High potassium (and possibly sodium) intakes during the dry period may increase the incidence of udder oedema and excessive dietary sulphur has been associated with lesions of cerebrocortical necrosis in cattle and sheep.

In summary, an independent review of the mineral requirements of dairy cattle is required. Currently the UK does not have adequate methodology to estimate either the mineral requirements (for animal production), or feed value (e.g. lack of information on P availability, uncertainty over the value of chelated minerals) or the quantitative rules for responses (e.g. responses of animal health, fertility to, for example, cobalt, iodine or selenium). There is undoubtedly a large gap between the currently accepted standard MAFF *et al*., (1983) and the information available. In addition, improved calcium, phosphorus and magnesium ‘models’, incorporating ‘requirement’, ‘response’ and ‘feed evaluation’ sub-models are required.

APPENDIX 8 – VITAMINS

With a few notable exceptions, vitamin nutrition of dairy cattle has not been an active research area during the past 25 years. Possibly the most important exceptions to this are vitamins D and E. Bieber-Wlaschny (1988) reviewed the vitamin requirements of dairy cattle and concluded that whilst one could legitimately speak of requirements, the level of that requirement varied with the author. The reason given for the variation was a difference in the definition of requirements. Adult ruminants are different from monogastrics with respect to their dependence on an exogenous supply of vitamins. Synthesis of B group vitamins (thiamine, riboflavin, niacin…) and vitamin K occurs during the degradation and fermentation of feed ingredients by rumen microorganisms. Vitamin D is synthesised by the action of UV radiation on the sterols present in the skin of ruminants, vitamin C is synthesised from C_6 sugars (glucose and galactose) and niacin from tryptophan (if the amino acid is present in excess). It is therefore with respect to vitamins A and E that ruminants have specific dietary dependence. Thus, in addition to the standard classification of vitamins according to their solubility in either water (C and B group) or in lipid solvent (A, D, E, and K) vitamins for dairy cows can be divided according to:

- Self supply (K, C, D and B group)
- Supply from feed (A and E)

The physiological requirements for these vitamins are difficult to define and can vary appreciably depending on the reference, particularly whether the criterion is to prevent deficiency symptoms or the requirement is to maximise animal performance. Standard tables of requirements tend to ignore the additional needs that have been identified as a result of different repeated stressors occurring during livestock production (unfavourable conditions, infection etc.).

For example the following are a list of inadequacies identified by NRC (2001)

- Presently available data are not adequate to define a specific requirement β-carotene for dairy cattle.
- The amount of dietary vitamin D required to provide adequate substrate for production of 1,25 dihydroxyvitamin D is difficult to define.
- Several factors are known to influence vitamin E requirements, but limited data makes these difficult to define.

- Research in the area of water soluble vitamins for dairy cows has increased in recent years, for example, niacin (essential for carbohydrate metabolism) supplementation has been shown to decrease the incidence of ketosis and increase milk production in early lactation. Biotin supplementation (20 mg/cow/day) during the prepartum period has been shown to decrease the incidence of lameness, specifically white line disease in cows. Although it appears that adequate data to quantify bioavailability, ruminal synthesis and requirements for most water soluble vitamins are not available.

It is clearly evident that a comprehensive review of the vitamin requirements and nutrition of dairy cattle is urgently required to provide a basis for the dairy industry in the United Kingdom.