REVIEW OF NUTRITIONAL STANDARDS FOR SHEEP

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KEY RECOMMENDATIONS

Specific

1. In order to achieve greater harmony with nutritional principles and current/future needs of the industry, consider the following amendments to the AFRC (1993) recommendations for metabolizable energy (ME) and metabolizable protein (MP)

a) the use of a 20% higher value for the MP requirements for maintenance

b) where there is a risk of gastrointestinal parasite infestation in ewes the adoption of a 10 to 20% increase in late pregnancy/early lactation MP requirements

c) the use of lower values for rumen outflow rates in calculating effective protein degradabilities for conserved forages

d) the use, following its acquisition, of data for rumen outflow rates for grazed grass and other succulent forages

e) a separate and higher value (~ 0.6) for the efficiency of utilization of MP for wool growth in growing and reproducing animals rather than the current value (0.26)

f) the adoption of 'change in body condition' rather than 'change in live weight' as a measure of the contribution of body reserves to nutrient supply, particularly during lactation, but also for other physiological states

g) higher and more realistic lamb birth weights when estimating ME and MP requirements for pregnancy in ewes carrying lambs sired by terminal sires, notably the Suffolk

h) the use of a variable efficiency of ME utilization for conceptus growth based on the ME concentration of the diet

i) correction of rumen outflow rates and therefore protein degradabilities for the effects of pregnancy *per se*

2. Consider the possibility that current dietary recommendations may be failing to provide adequate amounts of specific nutrients for the full expression of immune function, particularly in the cross-bred progeny of rams with high indices for lean tissue growth. An important related objective is the need to identify whether there is a nutritional component in the breed differences in susceptibility to gastro-intestinal parasites.

3. Use existing data from the world literature, augmented, where necessary, with further experimentation, to optimise the amounts and composition of supplementary concentrates for pregnant and lactating ewes and growing lambs receiving different forages *ad libitum*. For lactating ewes (suckling and dairy) this approach would embrace the attributes of the dairy cow 'Feed into Milk' model and extend it to other physiological states.

4. Using data for UK genotypes and diets, interact with the current international team that is modelling lamb growth, to provide new recommendations for the ME and MP requirements of growing lambs. These requirements should:

a) embrace the known ability of lambs that are under-nourished in energy, but have ample fat reserves, to sustain lean tissue growth when given supplementary undegraded dietary protein.

b) accommodate variable maintenance and production requirements which are dictated by previous and current nutrition, the nature of the diet and by the age and genotype of the animal

c) be based on a variable efficiency of ME utilization for weight gain that reflects its composition

General

1. Encourage mechanistic studies on the role of specific nutrients, at recommended and supra-nutritional levels, in gene activation and the expression of the metabolic pathways that affect the immune status of the ewe, the vigour and viability of her lambs and their subsequent growth, reproductive and lactational performance.

2. Before advocating the replacement of Longwool sires by more 'muscular' breeds such as the Texel to enhance carcass quality in cross-bred hill lambs, consider the possibility that foetal myogenesis and therefore the post-natal potential for lean tissue growth, in 'Texel Cross' lambs may be compromised by early post-mating ME and MP supply in the hill environment.

3. Establish strategies for dealing with:-

a) the removal of specific feeds, feed additives and chemical treatments designed to improve nutritive value

b) a reduced dependence on drug therapies and greater reliance on nutrient supply in disease prevention

c) the introduction of novel feeds for which there may be little information on their composition and nutritive value.

Introduction

The nature of sheep production systems is such that it is often difficult to achieve the desired degree of precision in the animal's nutrient supply. Nutrient recommendations therefore merely provide guidelines for the development of improved feeding strategies. It is thus more important to ensure that requirements are based on a sound understanding of the animal's physiology and how this influences net nutrient requirements and the absorption and utilization of nutrients, than the arrival at a value for the requirement for a nutrient, that is too precise to be of practical use. A good example of a 'too precise to be practical' recommendation for nutrients was the ARC (1965), available protein system, abandoned by ARC (1980), in favour of one that took on board the principles of rumen protein utilization, and in so doing, has had a major impact on improving feeding strategies for sheep.

Against this background the present review of the nutrient requirements of sheep attempts to focus on areas where current recommendations fail to embrace existing knowledge of factors influencing the absorption and utilization of nutrients and their requirements by the animal. The review also makes a plea for greater understanding of how specific dietary nutrients influence the expression of genes and the metabolic pathways that dictate production responses. With this knowledge nutritional advisers would be better positioned to meet the nutrient requirements of sheep within the opportunities arising from, and constraints imposed by, societal and market forces.

Published standards for nutrient requirements and their use in practice

(a) Energy

- AFRC Technical Committee on Responses to Nutrients, Report Number 5, Nutritive Requirements of Ruminant Animals: Energy. Nutrition Abstracts and Reviews Series B, 60: 729-804 (1990). CAB International.
- Energy and Protein Requirements of Ruminants. An advisory manual prepared by the AFRC Technical Committee on Responses to Nutrients (1993). CAB International.
- SCA (1990). Feeding Standards for Australian Livestock, Ruminants. Standing Committee on Agriculture, CSIRO Publications, Melbourne, Australia, 266pp.
- National Research Council (1985). Nutrient Requirements of Sheep. 6th Edition. National Academy Press, Washington, DC.
- Institut National de la Recherche Agronomique (1989). Ruminant Nutrition: Recommended Allowances and Feed Tables. INRA, Paris.

◊ Requirements are expressed in terms of ME (AFRC and SCA), total digestible nutrients modified to ME by conversion factors (NRC) or as NE (INRA) in which case each feed has two NE values, one for maintenance and milk production (UFL, Unité Fourragère Lait) and the other for maintenance and growth (UFV, Unité Fourragère Viande). By and large diet formulations in the UK are based on AFRC requirements and those in Australia, the US and France on SCA, NRC and INRA respectively. In the Republic of Ireland there is now a move away from the AFRC ME system in favour of the INRA NE system.

(b) Protein

- AFRC Technical Committee on Response to Nutrients, Report Number 9, Nutritive Requirements of Ruminant Animals: Protein. Nutrition Abstracts and Reviews, Series B, 62: 787-835; plus AFRC (1993), SCA (1990), NRC (1985) and INRA (1989). [see under **(a)** for details].

◊ Requirements are expressed in terms of metabolizable protein (MP) in the AFRC system, apparently digested protein leaving the stomach (ADPLS) in the Australian SCA system, absorbed protein (AP) in the American NRC system and protein truly digested in the small intestine (PDI) in the French INRA system. The published standards for protein in each of these systems are contained in the same publications as their corresponding recommendations for energy [see under **(a)**]. The AFRC (1993) recommendations are used in UK feeding systems.

(c) Minerals and Vitamins

- ARC (1980). The Nutrient Requirements of Ruminant Livestock. Commonwealth Agricultural Bureaux, Farnham Royal, Slough.
- NRC (1985) [see under **(a)** for details].
- SCA (1990) [see under **(a)** for details].
- AFRC Technical Committee on Responses to Nutrients, Report 6. A Reappraisal of the Calcium and Phosphorus Requirements of Sheep and Cattle. Nutrition Abstracts and Reviews, Series B, 61: 573-612 (1991).
- Underwood, E. J. and Suttle, N. F. (1999). The Mineral Nutrition of Livestock, 3rd Edition. CAB International.

◊ For the macro-minerals, dietary amounts for maintenance are based on estimates of obligatory endogenous faecal and urinary losses and for production, on net accretion rates combined with absorption and utilization efficiencies. AFRC (1991) expresses requirements for Ca and P in relation to the ME concentration of the diet and DM intake. Dietary requirements for trace minerals and vitamins are based on a combination of the factorial method, the prevention of clinical symptoms of deficiency or toxicity and the normality or otherwise of production and health. For the most part published requirements merely act as a guide, with actual dietary amounts varying with genotype, production system and interactions with other dietary constituents that affect their availability and utilization. In general AFRC (1991) recommendations for Ca and P are used in the UK; for the trace elements and vitamins a combination of ARC (1980) and Underwood and Suttle (1999) now provides the information used in UK diet formulations.

Extent to which current nutrient requirements cover full range of nutrients and factors influencing their availability

The combined feeding standards cover the full range of nutrients but there are major differences between published standards.

- ***Energy***

◊ For a 20 kg lamb growing at 200 g/day, the ME requirements are ~2 MJ (25%) higher in the Australian (SCA, 1990) feeding standards than in AFRC (1993) and NRC (1985). This reflects the higher fasting metabolism and higher net energy value for gain used by the Australians. For pregnancy and lactation the only major difference between the Australian and UK standards is a higher maintenance value in the Australian system. For each physiological state (maintenance, growth and lactation) both systems use the same relationships between efficiency of ME utilization and the ME concentration of the diet but neither allow for the effects of dietary ME concentration on the efficiency of ME utilization for conceptus growth (Robinson *et al* 1981; Hutchings 1997). For prolific ewes this has a significant effect on ME requirements. There is also a lack of clarity in AFRC (1993) regarding what value (pregnant or non-pregnant) to use for body weight when calculating the maintenance energy component in the factorial method used to estimate the total energy requirements of pregnant ewes.

- ***Protein***

◊ AFRC (1993) assumes that dietary MP is used with 100% efficiency in meeting basal endogenous nitrogen requirements, thus underestimating MP requirements in animals held at maintenance by ~ 20%. This has practical implications for the formulation of re-alimentation diets for growing lambs and early/mid gestation ewes kept at, or slightly below, maintenance. It may also be important in maintaining the animal's contemporary and subsequent immune function.

◊ In calculating values for the effective degradability of protein in the rumen AFRC (1993) uses single diet values (roughage + concentrate) for rumen outflow rates in relation to level of feeding that are high and more akin to those for concentrate diets. They are therefore probably over-estimates of outflow rates for the conserved forage component in mixed forage/concentrate diets given during pregnancy. Outflow rates are also required for ewes and lambs grazing grass and other succulent forages, as these values are central to the prediction of production responses to energy and protein supplements.

◊ There are also major differences between feeding standards in the values used for the efficiency of protein utilization for wool production, weight gain and conceptus growth. These result in differences between systems in protein requirements, most notably for growing animals. For example a 20 kg lamb growing at 200 g/day has an MP requirement of 75 g/day in the Australian system, 90 in AFRC (1993) and ~ 100 in NRC (1985). [See Sinclair and Wilkinson (2000) for more detailed information]

◊ The low efficiency (0.26) of utilization of MP for wool growth in AFRC (1993), while probably a true efficiency for animals kept solely for wool production, fails to recognise that in practice a pregnant ewe, for example, is drawing from a pool of amino acids and therefore those amino acids that are not used for wool production are available for other protein-requiring processes. Use of the low efficiency for wool production in diet formulation programmes (e.g. SAC's FeedByte) revealed problems in diet formulations for pregnant ewes in that additional UDP appeared to be needed much earlier in pregnancy than experience indicated was warranted. To overcome this difficulty FeedByte adopts a halving of the AFRC (1993) MP requirements for wool growth during pregnancy, bringing them into line with the Australian SCA (1990) recommendations which are based on an efficiency of MP utilization for wool growth of 0.60.

◊ An omission in all current feeding standards for protein is the evidence (reviewed by Robinson, 1990) that in the absence of any alteration in the composition and intake of a diet, pregnancy *per se* causes an approximate 15% increase in the amount of amino-nitrogen reaching the duodenum and therefore available for absorption in the small intestine. Interestingly there is also evidence in Australian studies that genetic selection for wool growth is accompanied by increased microbial protein synthesis (Oddy, 1999); genetic selection for production traits may therefore influence nutrient supply as well as alter the amino acid requirements and energy costs for the enhanced production trait.

◊ For lactating ewes differences between the current systems in MP requirements largely disappear when expressed as dietary amounts of crude protein. The main reason for this is the differences between systems in the estimates for microbial protein synthesis, protein degradability and N recycling.

- ***Minerals and Vitamins***

◊ A large increase in the assumed values for Ca and P availability by ARC (1980) has led to a major reduction in recommended dietary amounts. Tests by Wan Zahari *et al* (1990) indicate that the new 'low' levels for Ca and P are more than adequate for growing lambs and, in the case of P, appear satisfactory for pregnant and lactating ewes (Parkins *et al* 1998). Although hypocalcaemia during late pregnancy in ewes is still a practical problem all the evidence indicates that it is the result of too high an intake of calcium followed by a sudden deficit and, as a result of the initial high intake of Ca, an associated delay in the initiation of the endocrine changes (parathyroid hormone, PTH) that promote Ca absorption, rather than an inadequate Ca intake *per se*. The recent evidence presented by Sykes and Russel (2000) of an intermediate optimum concentration of plasma magnesium (~ 0.9 mM) for stimulating the activities of 1, 25-dihydroxy-cholecalciferol and PTH, thereby stimulating calcium absorption, merits further investigation.

◊ Hypomagnesaemia is also a practical problem which in many cases is triggered by dietary factors (high K and CP) that reduce absorption. Its prevention is a matter of applying existing knowledge of requirements.

◊ For many of the trace elements and vitamins the critical factor is availability which, for example, in the case of copper can result in a four-fold difference in the ability of feeds to provide absorbable copper (Underwood & Suttle, 2000), depending on the concentrations of other mineral elements. Coupled with breed differences in copper requirements, copper toxicity and deficiency still result in significant losses to the industry yet these losses are avoidable with existing knowledge of availability and requirements.

◊ In the case of selenium little is known about its dietary availability and whether its shared absorption pathway with molybdate and sulphate make these anions absorptive antagonists (Underwood & Suttle, 2000). Cobalt is another element in which the availability of its functional entity, vitamin B_{12}, may be impaired by the formation of analogues that disrupt the vitamin's biological activity (J. A. Price, personal communication), leading to high concentrations of branched-chain fatty acids and soft fat in concentrate-fed lambs.

◊ At the gamete level, there is evidence of beneficial effects of 'supra-nutritional' supplementary selenium on oocytes, embryos and sperm when animals are subjected to modern breeding technologies. Examples are the beneficial effects of dietary selenium supplements to oocyte and embryo quality following superovulation and to the quality of frozen-thawed ram spermatozoa; benefits which are not observed in spontaneously-ovulating animals or in fresh semen.

Extent to which requirements and availabilities are up-to-date

- ***Energy***

◊ Apart from the MLC's (1983) practical feeding guide for the ewe, all other recommendations assume a single value for the efficiency of utilization of ME for conceptus gain, thus ignoring the evidence of a positive relationship between efficiency and the ME concentration of the diet (Robinson *et al* 1980). For a 70 kg ewe with twin foetuses the likely difference between her estimated ME requirements in late pregnancy when given a diet of 9 as opposed to 11 MJ of ME/kg DM is ~ 20%; too high to be ignored.

- ***Protein***

◊ Understandably in view of their novelty, none of the current recommendations for protein take into consideration the recent observations that MP intakes during late pregnancy which are in excess of current recommendations are highly effective in the development of immunity to gastro-intestinal nematodes (Donaldson *et al* 2001). They estimate that current MP recommendations would have to be increased by 20% in twin-bearing ewes during late pregnancy for the acquisition of maximum immunity. On the basis of theoretical calculations involving information on the differences between infected and non-infected animals in circulating lymphocytes, immunoglobulin, mucosal mast cells, mast cell proteases and plasma loss, Houdijk *et al* (2001) estimated that the additional MP requirements are 5% but conceded that they could be as high as 10%. Estimates of the demands for other nutrients to mount an immune response to gastro-intestinal parasites during late pregnancy are not available, although it is generally accepted that nematode infections increase the dietary requirements for many micronutrients (reviewed by Lee *et al* 2002).

◊ Availabilities for protein do not take into consideration the enhancing effect (+ ~ 15%) of pregnancy *per se* on the amounts of amino nitrogen reaching the abomasum and therefore available for absorption in the small intestine.

- ***Minerals and Vitamins***

◊ The most recent edition of 'The Mineral Nutrition of Livestock' (Underwood & Suttle, 1999) provides up-to-date information on the requirements and availability of the mineral elements. Apart from recent studies of late pregnancy requirements for vitamin E for improved neonatal vigour and viability, it is assumed that long-established standards (ARC, 1980) for the other vitamins are adequate. In practice some vitamins notably vitamin A, is often included at excessively high levels with possible detrimental effects on vitamin E and D status (Suttle & Sinclair, 2000).

Scientific quality of modelling approaches and validity of conclusions

(a) **Growth and body composition**

◊ Models of nutrient requirements for growth have moved from the empirical to mechanistic level (Gill *et al* 1984; Sainz and Wolff, 1990) and are currently attempting to embrace information obtained at the tissue, cellular and sub-cellular levels. Whether they will have practical relevance remains to be seen. It will be important to note, however, the outcome of the deliberations of the international group currently working on developing a dynamic model for growth and body composition in the lamb (Soboleva *et al* 1999). To be of practical value any model for the nutrient requirements of growing lambs must:-

* be able to deal with the known ability of lambs that are under-nourished in energy to sustain lean tissue growth when given supplementary undegraded dietary protein, provided they have ample reserves of body fat

* recognise that maintenance requirement in the growing animal is not a fixed function of metabolic size but rather that it varies with both previous and current nutrition, the nature of the diet (forage vs concentrates) and with age and genotype

* use a variable efficiency of energy utilization for weight gain that is governed by the composition of weight gain. [Ultrasonic scanning has a role to play in providing this information and implementing it in production systems].

(b) **Pregnancy**

◊ Pregnancy adds a further degree of complexity to any attempt to model nutrient requirements, in that the numerous pregnancy-induced adaptations in maternal tissue metabolism (Robinson *et al* 2002) create a level of complexity in nutrient utilization that will be very difficult to transform into mathematical relationships. Before attempts are made to do so, convincing evidence of its practical value in facilitating more precise diet formulation, is required.

◊ In the current more empirical approach to modelling requirements for pregnancy, concern has been expressed regarding the relevance to some current genotypes and production systems of the assumed values for lamb birth weight in relation to ewe weight. In AFRC (1993) these values are based on the data of Donald and Russell (1970) and would appear to be considerable underestimates for lowground ewes, particularly those mated to Suffolk sires.

◊ A major aim of practical feeding systems for pregnancy and indeed other physiological states such as 'ewe lactation' and 'lamb growth' is to minimise the extent to which added concentrates suppress forage intake. In this regard, practical benefits would accrue from the further development and wider application of computer models of the type described by Neal *et al* (1986) for lowland ewes during late pregnancy. Such models would have a valuable role in making decisions on the composition of concentrate supplements and their levels of feeding for lactating ewes and weaned lambs grazing grass or other forages.

(c) **Lactation**

- ◊ During lactation body reserves, particularly fat, make a significant contribution to nutrient supply. As a result of widespread use of body condition scoring the sheep industry is much better placed to utilize a model for nutrient requirements that incorporates changes in body condition than the changes in liveweight currently used by AFRC (1993). The adoption of shifts in condition score would have the added advantage that their calorific value can be estimated with greater accuracy than liveweight changes which, in early lactation, are notoriously variable as a result of shifts in feed intake and tissue hydration.

- ◊ In view of the claimed improvements that 'Feed into Milk' brings to the formulation of rations for dairy cows (Offer *et al* 2002) it would seem worthwhile to consider a similar exercise for lactating ewes particularly as much of our existing data on the ME system has been acquired from sheep. Thus most, if not all, of the data required to develop an equivalent ewe model could probably be gleaned from the existing international scientific literature, making it a more attractive immediate option than the Cornell Net Carbohydrate and Protein System.

Scientific basis of the information and its relevance to UK circumstances

- ◊ The move to more mechanistic research approaches when defining nutrient requirements provides the means to adapt requirements for specific circumstances. The UK sheep flock is characterised by its genetic diversity but, in the case of the growth and body composition of its major genotypes, is well provided with recent relevant data (e.g. Wolf *et al* 2001; Carson *et al* 1999, 2001). Accompanying UK information on the effects of nutrient supply on growth and body composition in UK breeds (Lewis *et al* 2002) of the type already available for Australia genotypes (Hegarty *et al* 1999) should facilitate more mechanistic modelling approaches. These approaches embrace the effects of diet composition, nutritional history and genotype on the energetic efficiency of net protein disposition, a key determinant of which is the rate of protein synthesis relative to its rate of degradation (Oddy and Sainz, 2002). The question here is, will the development of mechanistic models based on improved understanding of how nutrients are used for lean tissue and fat deposition enable UK sheep producers to better meet market specifications? It seems likely that, even in the absence of a model, a more fundamental understanding of environmental and genetic influences on the efficiency of protein deposition should reveal a new degree of sophistication which will be of benefit in bringing the nutritional control of growth and body composition more into line with market specifications.

- ◊ For pregnancy and lactation, and indeed for growth, nutrient requirements are formulated from original research carried out in many countries. Progressive improvements in our understanding of the underlying biology and of the production attributes of different genotypes mean that extrapolations to UK conditions can be made with increasing confidence. For dairy sheep breeds questions have been raised in the UK regarding the validity of extrapolations for energy and protein requirements and whether the apparent inability of machine-milked ewes to achieve their presumed high genetic potential for milk production is the result of inadequate nutrition or incomplete adaptation of the ewe to machine milking. Concerns have also been expressed regarding the ability to extrapolate nutrient requirements for growth rates of 300 to 400 g/day to terminal sire breeds (such as the Suffolk) growing at ≥ 600 g/day.

Current needs of UK stakeholders in the context of genetic change, societal concerns relating to animal welfare, environmental protection and food safety

(a) **Genetic change**

* Shift to leaner genotypes (e.g. Texel) for the production of crossbred ewes and as terminal sires; greater use of terminal sires selected for improved lean tissue growth rates.

(b) **Societal concerns; animal welfare**

* Reduction in drug treatments and a greater dependence on supplying, via dietary means, the macro- and micro-nutrients in amounts that promote the expression of genetic potential for production without compromising immune function.

(c) **Societal concerns; environmental protection**

* Greater precision in meeting nutrient requirements, particularly of P and N, in order to minimise their adverse effects as environmental pollutants (Powell *et al* 1999).

(d) **Societal concerns; food safety**

* Where possible, use dietary means to alter the composition of meat and milk (for cheese making) in line with known health benefits.

Extent to which current published standards meet preceding needs and areas where information is inadequate or requirements are not addressed

(a) Genetic change

◊ Observations demonstrating early *in utero* nutritional effects on adult ovulation rate in ewes (Borwick *et al* 1997; Rae *et al* 2001) and post-natal muscle development in pigs (Dwyer *et al* 1994), raise questions regarding current recommended nutrient requirements during early and mid-pregnancy. Specifically, the move to using Texel sires on hill ewes as a way of increasing the lean meat content of the resulting carcasses may require an alteration in the feeding strategy of hill ewes in order to ensure that foetal myogenesis is optimum for the post-natal expression of genetic potential for muscle growth.

◊ Selection for increased body and lean tissue growth rates in terminal sires means that their growth performance is now well beyond that for which we have tabulated requirements. While this may cause problems for pedigree breeders and their nutritional advisers, a much more important issue is whether immune function is compromised by the failure of commercial systems to provide adequate nutrients for the expression of the genetic potential for growth of crossbred progeny from these sires.

◊ It is well recognised that Suffolk cross lambs are much more susceptible to intestinal parasite infection than, for example, Texel crosses. The scientific basis for this susceptibility is not known. Could it be genotype differences in the partitioning of nutrients leading to a compromised immune status [see preceding paragraph] or genotype differences in trace element metabolism and requirements? In this regard it may be pertinent that the Texel breed is highly susceptible to Cu poisoning whereas the Suffolk is highly resistant.

◊ Machine-milked dairy ewes create problems for the nutritional adviser in that their milk yield responses to increments of energy and protein are often lower than those predicted from current feeding standards which are based on ewes suckling their lambs. It is unclear whether this is due to a deficit of specific dietary nutrients (e.g. a specific amino acid) or failure of dairy ewes to express their full genetic potential when they are being machine milked.

(b) Societal concerns; animal welfare

◊ The public desire to eliminate the inclusion in feeds of compounds that alter metabolism and nutrient utilization is well recognised. Many are already excluded, e.g. the use of ammonium chloride in concentrate-based diets for the prevention of urinary calculi in male lambs. Already, the removal of fish meal from these diets, an ingredient that alleviates the calculi problem by producing a less alkaline urine than for example soya bean meal, (D. Scott, personal communication) creates a greater need for ammonium chloride as an acid regulator. In the absence of a European derogation allowing the use of ammonium chloride, diet formulations based on natural ingredients will be required. This will necessitate research into diet specifications for cation-anion balances (Na + K) – (Cl + S) and for Ca, P and Mg concentrations that avoid urinary calculi. Public influence could also result in similar restrictions (beyond those that already apply to organic systems) being placed on the use of formaldehyde treatment for the rumen protection of vegetable proteins.

◊ The move to organic systems and the breeding of plants with natural resistance to disease and pest attack are likely to result in increased demands for some of the micro-nutrients [see Gutzwiller (1993) for a clover variety whose natural high content of cyanogenetic glycosides interferes with selenium metabolism and foetal thyroid function leading to reduced neonatal lamb viability]. In general, novel forages and plant species for which little or no nutritional data are available are likely to find their way into organic systems on the argument that they confer 'natural benefits' in disease prevention. These dietary ingredients will require close scrutiny for their possible adverse influences on the dietary requirements for other nutrients through effects on their availability and efficiency of utilization.

◊ Public concerns regarding, on the one hand the inclusion of some ingredients and feed additives and on the other, the desire to minimise the use of drug therapies, place a new emphasis on diet formulations that, at all times, embrace the nutrient requirements for optimum immune function, as well as the production processes. An example is the estimate of a 10 to 20% increase in MP requirements above current AFRC (1993) recommendations for twin-bearing ewes in late pregnancy, in order to achieve maximum immunity against gastro-intestinal parasites. More information is needed on the amino acids and other dietary nutrients involved in this response as the original observations were made on diets supplemented with fish meal. The likelihood of a trace element involvement has already been alluded to and requires quantification. The argument has also been made, but not tested, that the omega-3 fatty acids (of which fish meal is a rich source) may have aided the immune response through their involvement in leukotriene synthesis (Donaldson *et al* 1998). Of course current nutrient recommendations for late pregnancy do not take into consideration the observation that additional MP also increases the efficiency of absorption of colostral IgG by lambs (O'Doherty & Crosby, 1997) which is clearly an important welfare benefit, but one requiring a mechanistic understanding.

◊ Neonatal lamb mortality is a major welfare concern, thus the interest in the observations that dietary supplements of Vitamin E given to ewes during the last 6 weeks of pregnancy at levels which are five fold (100 mg/day) those currently recommended (AFRC, 1980) increase the vigour of newborn lambs as measured by their reduced times to standing and sucking (Merrell 1999). Since placental transport of vitamin E to the foetus is regarded as being very low (McDowell *et al* 1996), it is not clear whether the lamb vigour effect is mediated via improved mothering ability by the ewe or via a maternal Vitamin E-induced shift in foetal and neonatal metabolism. Due to the inter-relationships between Vitamin E and selenium and, at least in calves, between selenium and iodine in the expression of thyroid function (Zagrodzki *et al* 1998), it would seem important to consider and indeed investigate, the responses in lamb vigour to Vitamin E in terms of the iodine status of the ewe. In addition the evidence for low placental transfer of Vitamin E appears to centre on low serum levels in the newborn, but these may not reflect organ and tissue concentrations. From the nutrition adviser's viewpoint, there is also a need for quantitative information on how Vitamin E requirements are influenced by the demands placed on it, in its roles as a dietary and tissue antioxidant and free radical scavenger.

◊ From a lamb vigour point of view there is evidence that nutritional programming during early foetal life may play an important role in that sub-clinical cobalt deficiency at this time reduces vigour at birth, the development of immune status and viability (Fisher & MacPherson, 1991). While confirmation of these observations is required, they are perhaps understandable in that the associated elevations in homocysteine could interfere with the embryo's neuron development by inhibiting the function of N-methyl-D-asparate receptors in its neural epithelium (Rosenquist and Finnell, 2001).

(c) Societal concerns; environmental protection

◊ Minimising environmental pollution by optimising the efficiency of nutrient utilization will require a new level of sophistication in our understanding of the function of specific dietary nutrients at the level of gene expression. Thus, effects on production traits or on immune status of, for example, additional protein, minerals and vitamins will require a mechanistic understanding of their function in order to replace the current excess blanket inclusion rates with the minimum amounts required to initiate and fuel the underlying biology. This approach, albeit at a less sophisticated level than is now proposed, enabled AFRC to reduce drastically, recommended phosphorus requirements (see AFRC 1991) without detriment to the animal but with clear advantages to the environment.

(d) Societal concerns; food policy

◊ Across the species, studies to alter, by dietary means, the fatty acid composition of meat and milk in line with perceived health benefits is, on-going. At present it seems unlikely that developments in this area will impose additional demands for nutrients outwith those involving the known higher anti-oxidant requirements. They do however call for more precise information on the effects of diet composition and feeding level on the extent to which individual fatty acids resist biohydrogenation in the rumen and are subsequently available to the animal.

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