# REVIEW NUTRITIONAL STANDARDS FOR LIVESTOCK

## NUTRIENT REQUIREMENTS AND STANDARDS FOR POULTRY

## FOR BSAS/DEFRA

## Report

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**Key Recommendations on Standards and Factors that Influence Standards**

1. All nutrients should be considered in the standards
2. There should be special emphasis on energy. Methods of assessment of energy and availability, utilisation and requirements for different species and genotypes require attention
3. The crude protein (CP) and amino acids content and balance are critically important. This requires special attention for turkeys.
4. Nutrient availability, homogeneity, method of supply, stability and composition (accuracy, variability and additivity) of ingredients
5. Effects of other dietary ingredients (anti-microbial growth promoters-removal, inclusion of enzyme supplements, individually and in combination)
6. Ingredient and nutrient interactions with the GIT and microbes
7. The nutritional requirements in early life
8. The effects of alternative antibiotic growth promoters
9. The effects of welfare issues on standards (and *vice versa*)
10. The relative relationships of various nutrients
11. Models are useful R&D tools but not sufficiently robust and reliable commercially
12. The effects of oversupply of nutrients on the environment
13. The effects of modern environmental control systems in intensive production as well as the effects of extensive and 'organic' production systems
14. The effects of vaccination and disease treatment
15. The effects of increased use of vegetable proteins in Europe

The recommendations presented above are based on information received from a variety of sources, including industry and academic (appendix 1). The document has not been seen by any of the contributors at the time of presentation, other than by Dr Paul Rose. It is intended that modifications will be made after the meeting at BSAS in York in April 2002, where the document will be presented and discussed. Further responses from contributors/respondents may be included when they have seen the document. The comments and views expressed in the document are the interpretation by the author, of the information received from individuals or companies consulted. They should not necessarily be considered as an endorsement, or otherwise of the views expressed. A list of individuals consulted and their affiliations is presented in Appendix 1. It should be noted that there are a number of similarities in the information and the principles presented in this report with those on the standards for pigs by Whittemore *et al* (2002) as part of this series of papers.

**Summary**

Commercial companies are reluctant to reveal details of the basis for the standards that they use because of commercial confidentiality.

Most companies base their formulations on the information provided by the breeders. However these companies 'adjust' the specifications based on the results of their own studies and/or observations as well as information in the literature. The production of 'a' standard would thus be impracticable but there may be some value in the production of guidance tables and principles for producers.

Vitamin and mineral concentrations are often based on the recommendations of commercial manufacturers and suppliers. These are frequently based on independent research activities as well as 'in house' studies. It is regarded that the literature is out of date for some of the vitamins, especially the B vitamins. It appears that there is an element of reliance on the recommendations provided by manufacturers, previous experience and a 'hope' that they work.

There has been a trend in increasing the concentrations and use of some vitamins and minerals in diets (especially vitamin E and Se).

Commercial producers do not use NRC or ARC. They tend to use their own 'in house' data based on the breeder's recommendations and are often adjusted to suit local conditions.

Some commercial producers use the Illinois ideal protein system (with tweaking) as the basis for their standards for amino acids. This is supported with their own and published data on digestibility coefficients as well as a combination of both.

Relatively, the diets used in Australia and New Zealand have lower energy and higher amino acid content than in the UK. However growth tends to be higher especially in New Zealand where birds are reported to be subjected to lower disease stressors.

The standards given by breeders for various nutrients tend to ensure production targets but are often considered to be excessive by some of the poultry growers and diet manufacturers. This tends to be supported by our own observations at SAC where we frequently achieve 20-30% better performance on commercial diet specifications.

The influence of the removal of meat and bone meal requires the use of alternative ingredients, usually of poorer nutrient content and availability with greater variability. This considerably influences allowances.

The removal of antibiotic growth promoters and the anticipated constraints on other in-feed medicines will continue to cause variation in nutrient demands.

The use of a variety of in-feed enzyme supplements, individually and in combination, is considered as important factors in altering nutrient availability and utilisation. Such changes will alter nutrient standards, especially at different ages.

The greater use of vegetable and lower quality and/or cheaper dietary ingredients, including micro-ingredients, alters the specifications for dietary nutrients.

The production of birds with specific traits (increased egg yield, breast meat, slower growing etc) will alter the nutrient allowances in diets. Thus genetic 'improvement' of birds alters the nutrient requirements, and thus allowances.

Consumer demands for increased quality, 'natural' products, health of birds, enhanced nutritional aspects of the product and reduced pollution will continue to cause alteration of production systems. These changes will influence the dietary allowances for nutrients.

**Remit and Aims of the Review**

It is important to state clearly at the outset that the purpose of the exercise was **NOT** to compile new lists of tables of requirements of the various poultry species. The remit was essentially a scoping exercise to ascertain the need for a more thorough review and to assess areas requiring further detailed research. Thus this report is not intended to delve in depth into the nutritional standards or requirements of individual nutrients for the various types of poultry.

The remit given by the British Society of Animal Science is presented immediately below:

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, 8-10 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.

**Introduction**

The main species of poultry for which standards and requirements are available are chickens grown for meat (broilers), turkeys for meat and laying hens. The relatively low production of ducks (about 2.5% of poultry products in the EU) may account for the note in a previous review (Blair *et al*, 1983) where there was a relative absence of data for ducks.

The production of various poultry products within the EU countries (12) for 2001, are listed below (Table 1). Thus, for the purposes of the exercise of detailing nutrient allowances and requirements we will concentrate on layers, broilers and turkeys. The nutrients considered will include energy, protein, amino acid, mineral and vitamins for the birds above at various stages of growth and under a variety of production systems.

**TABLE 1: PRODUCTION OF POULTRY PRODUCTS WITHIN 12 EUROPEAN COUNTRIES DURING 2001 (Source, FAO, 2002)**

| Product | Quantity ($T*10^{-6}$) | Proportion of total (%) |
|---|---|---|
| Chicken meat | 6.19 | 46.3 |
| Turkey meat | 1.75 | 13.1 |
| Poultry meat | 8.29 | 62.0 |
| Other meat | 0.0007 | 0.005 |
| Total eggs | 5.09 | 38 |
| Hens eggs | 5.07 | 37.9 |
| Duck meat | 0.33 | 2.5 |

There are various sources for the information. These arise from data presented in the scientific literature, in publications on nutrient requirements by national bodies (ARC, 1975; NRC, 1994), commercial producers of products (vitamins, minerals, amino acids, etc.) for inclusion in diets and information published by producers of birds. Further information can be obtained by consultation with various scientists around the world. Information from diet manufacturers and integrated companies is highly relevant but almost impossible to access because of the commercially confidential nature of the information. A fairly comprehensive study of nutrient requirements and recommended allowances was reported in 1983 (Blair *et al, 1983*). It is clear from that work that substantial differences existed in the recommended allowances in different parts of the world.

The detail herein will be for broiler, turkey and layer animals and is sourced from the literature mentioned above as well as from countries where responses were obtained to requests for information (respondents and their affiliations are presented in Appendix 1). The resulting information will cover the energy, protein, amino acid, mineral and vitamin requirements and allowances for the birds mentioned above at various stages of growth. Obviously there is requirement for information for allowances for other birds such game birds such as pheasants, partridges, grouse etc.

It should be remembered that the nutritional requirements of poultry are influenced to a considerable extent by species, genetic factors, dietary, environmental and age effects. Furthermore, the type of production system (organic, free-range, barn, etc) will affect the requirements considerably. Requirements for various nutrients change rapidly on a daily basis and thus frequent changes of diets would be ideal. However, pragmatism in the provision diets causes changes to diets to occur on a weekly or less frequent basis. The genetic variance of most commonly used poultry throughout the world is relatively small, being primarily restricted to a relatively few major international poultry companies such as Ross, Cobb, Nicholas, BUT, Lohmann, Hubbard-ISA and others.

The determination of requirements of most nutrients is on a response curve and is often difficult to define. For poultry, the optimum inclusion of a nutrient is frequently defined by economic factors rather than solely on the specific requirement for a particular nutrient. Response curves are influenced by a number of factors including temperature. Thus, environment and production systems will substantially effect requirements and recommended supplements of nutrients.

**Nutrient Requirements and Standards**

It is important to define with some clarity the terminology used in this report. The term requirement is not synonymous with allowance or standard. The purpose is to review the **standards** for nutrients, which can be defined as the dietary concentrations or intakes necessary to sustain commercially viable performance, frequently while attempting to minimise pollution. These standards are based on the requirements for individual functions plus an additional oversupply (safety margin) to avoid any adverse effects in performance, ill health and reduction in product quality. When comparing information in the literature, it is important to distinguish between the different terminologies used.

Conventionally, the nutrient requirements of poultry have been tabulated in the NRC (NRC, 1994) and ARC (ARC, 1975) books on nutrient requirements and the data used. The data presented in such publications were considered by all contributors to be outdated and of little practical use other than to provide a base to work from. Data from these publications are presented below. There are numerous other sources of information on nutrient recommendations, allowances, levels and specifications (see Blair *et al*, 1983). These are given in a variety of publications and data from various sources are presented in the tables below. The concentration of nutrients in diets is often based on requirements but adjusted on a mean basis and also on a variety of other factors. These include availability, digestibility and balances of nutrients relative to each other. Assumptions are thus made on the concentration of nutrients in ingredients, their availability and digestibility and the homogeneity of dietary ingredients from various sources and environments around the world.

Most modern breeds of poultry have lower FCR values (higher efficiencies) than older breeds. This is not entirely due to the composition of diets with higher availability of nutrients, and therefore is likely to be due to the ability of the bird to absorb nutrients.

The requirements of the birds will, therefore, be different, depending on the tissue (and rate) that is being deposited. Thus, the relative concentrations of the nutrients in the diets may be required to be different, although efficiency of use may be increased due to improved uptake mechanisms.

The use of enzymes in poultry diets within the UK (and elsewhere in commercialised poultry production) is now ubiquitous. These, in general, improve nutrient utilisation. This improvement may (or may not) be nutrient specific. In any case, dietary allowances require to be altered to suit the nutrient availability since increased availability may cause difficulties in utilisation and reduction in litter quality, especially if the nutrients become imbalanced and oversupplied.

These complications are confounded further by changes in the microflora of the GIT. These changes occur because of the use of a variety of ingredients, and dietary ingredients that have (inherently) anti-nutritional factors, as well as diets that do not have any antibiotic growth promoters.

**Energy**

Energy is (probably) the most expensive nutrient in poultry diets. Thus there is a considerable desire to utilise a system that can be accurate and robust in its use for the determination of the available energy for different types of poultry at different ages. From the various sources, recommended AME contents of diets varies considerably between sources and between countries (Blair *et al*, 1983). Other systems of defining the energy of diets and ingredients may require further investigation in order to avoid inaccuracies associated with the ME system. The polemics regarding the use of AME, TME and NE require to be resolved. However there are considered to be a substantial number of difficulties in deciding which is the best and most effective method of defining energy for poultry. These include rapid evaluation and establishing a robust database. There are discrepancies between ‘real’ values for the ME of feedstuffs and their book values. These can be attributed to variability in dietary ingredients and the lack of ready ability to predict ME values. This has been well demonstrated for wheat. Further complexities occur with the variation in additivity (or otherwise) of ME between various ingredients as well as the effects on ME, of the inclusion of supplementary enzymes which can decrease the variability and improve ME of ingredients. This is very clearly age and species dependent. The information available for different bird types is often not readily interchangeable from one type to another. It is clearly not the same for young and adult birds.

**Protein and Amino Acids**

The ideal protein system has been used to define the dietary needs of various types of birds for protein and amino acids. It has been defined as the exact balance of amino acids in the diet, such that there is no excess or deficiency of any of the amino acids and none of the amino acids will be used for energy. This allows all concentrations of amino acids to be related to lysine (table 1, appendix 2).

Most amino acid profiles are adjusted by manipulation of the constituents containing protein. The amino acid allowances for lysine, methionine and threonine can be met by adding supplemental synthetic amino acids (not in 'organic' systems). There is an area of uncertainty in this approach where formulators apply various correction factors to 'availability' and 'digestibility' of amino acids in the variety of ingredients.

Similarly to energy, protein and amino acid requirements differ significantly. Availability of amino acids differs between sources of information used to formulate diets. 'Correction' factors are sometimes applied 'within-house' to 'optimise' digestibility and availability. For lysine, the availability factors differ between Ross and Cobb recommendations. The standards from commercial literature for amino acids are considerably higher at 2001 than data in 1983.

**Major Minerals**

The recommendations tend to be similar between commercial sources and appear to be based on the manufacturers' recommendations. The recommendations for P and Ca concentrations appear to have a substantial safety margin. However different sources, methods of production, composition and presentation (different particle size, granular, powder etc) will significantly influence digestibility and availability. They are also substantially influenced by their availability in the dietary ingredients where, for example, interaction with inositol has a substantial effect on availability. The use of phytases in the diets has demonstrably increased the availability of P and Ca for poultry. In some quarters the standards for P in diets is the major element that requires to be resolved.

**Trace Minerals**

The recommendations tend to be similar between commercial sources and appear to be based on the manufacturers' recommendations. The supply of trace elements, however, has become somewhat more complex in recent years with the increasing availability to manufacturers and producers, of organically bound (chelated) minerals such as Se, Cu, Zn and Mn. Such chelated minerals tend to be more efficiently absorbed by poultry (as well as other animals) and thus may be supplied at lower concentrations in the diet. The use of chelated trace elements as well as enzyme supplements in diets may increase the utilisation of mineral elements and tend to reduce concentrations in diets, whilst reducing pollution.

**Vitamins**

These allowances tend to be similar between commercial breeding companies and appear to be based on the manufacturers' recommendations but frequently with 'in-house' modification. The modifications are based on 'in-house' information on performances as well as on the economics of supplementation. Some differences exist between recommendations by breeding companies and those made by vitamin manufacturers. There is considerable variance in the allowances recommended by publications such as NRC and ARC for some vitamins. Manufacturers of vitamin supplements often have a large quantity of information available. The discrepancies between sources of information may be attributed to a wide variety of factors, some of which follow. The scientific basis for the information (especially on the B vitamins) is somewhat dated for NRC and ARC. The conditions in which the animals are maintained have changed, as have the genetics.

The methods of manufacture of vitamin supplements have changed over the years and now more stable, homogeneous, and stable vitamin preparations are available. Processing conditions of diets can be more effectively controlled and monitored thus in feed vitamins can retain their activity. The variations in methods of production of diets strongly influence the requirement and thus the allowance of vitamins in the diets. The conditions in which the animals are reared, stressors, homogeneity and health of flocks and the demand for quality products, have a significant effect on vitamin standards as does the quality and stability of the vitamin products.

The variation in the standards for dietary nutrients may be substantially influenced by economic factors, as well as changes in requirements *per se*, caused by species, environment and production systems. Modern systems for controlling the environment in poultry houses will substantially influence nutrient allowances.

**Models**

A number of model systems are available and include the EFG, Novus, Omnipro, Reading and Flockman. The models are derived from a scientific basis but are frequently adapted from the knowledge base within companies. Although used in commerce it is considered that these are of greater interest as R&D tools and tend to provide the general direction in which responses are likely to occur. The basis of models is often unclear to commercial users. They are generally considered as insufficiently robust and lacking in sufficient detail to be reliable in commercial application. Major factors that are likely to influence the accuracy of prediction of models is the presence of antinutrients, the withdrawal and substitution of antibiotic growth promoters and the addition of enzymes to diets. From the comments received there is scope for substantial further refinement to improve robustness and accuracy of the models.

**Conclusions**

A number of conclusions can be made based on the information provided. Although NRC and ARC tables give a scientific basis for setting allowances they are generally irrelevant and redundant in the industry. It is clear that most manufacturers of diets and growers of poultry, base nutrient allowances on a number of sources of information and then do ‘in-house’ fine tuning to suit the local requirements. It is obvious that the polemics on energy systems will continue and there is a need to develop rapid and accurate assessment of the energy value of dietary ingredients and diets. A net energy system is considered promising by some but a substantial database requires to be developed. Rigorous comparison and evaluation of energy systems for poultry is required. Energy is considered by most respondents as being of high priority in assessing nutrients and diets. The changes (especially within Europe) in production systems with the use of enzymes, reduction in the use of antibiotic growth promoters and other medications will considerably affect the nutrient standards for poultry. Furthermore the removal of animal proteins from diets, and the increased use of vegetable protein sources from a broader range of ingredients, will increase the need for critical examination of allowances to ensure consumer and environmentalists satisfaction.

**Appendix 1 List of Respondents Who Provided Information**

Information from the following was gratefully received and the above report includes relevant information where appropriate.

| | |
|---|---|
| Dr J McNab | (Roslin Nutrition) |
| Dr S P Rose | (Harper Adams University College) |
| Dr C Fisher | (Aviagen) |
| Dr A Ball | (Roche Products) |
| Dr M McLeod | (Roslin Institute) |
| Dr C Nixey | (BUT) |
| Dr S Wilson | (BOCM Pauls) |
| Dr K Smith | (Grampian Food Group) |
| Dr J Glover | (ELANCO) |
| Dr T Hughes | (Roche) |
| Prof C Whitehead | (Roslin Institute) |
| Dr S van Cauwenberghe | (Ajinomoto, Eurolysine) |
| Dr M Overend | (Forum Products) |
| Dr M Bedford | (Zymetrics) |
| Dr D Robinson | (Grampian Food Group) |
| Dr E Jones | (Devenish Nutrition) |
| Dr A Fothergill | (BOCM Pauls) |
| Mr I Mackinson | (Premier Nutrition) |
| Dr M McGrane | (Trouw Nutrition) |
| Mr I Mortimer | (ELANCO) |
| Mr M Kenny | (NUTEC) |
| Dr P Blanchard | (BASF) |
| Prof D Baker | (University of Illinois) |
| Prof W Bryden | (University of Queensland) |
| Dr R Hughes | (SARDI, Adelaide, SA) |
| Dr R V Ravindran | (Massey University) |
| Dr J Foulds | (Tegel, NZ) |
| Dr C Wyatt | (Cargill, USA) |

## Appendix 2 (Tables of Requirements, Recommended Nutrient Levels, etc.)

TABLE 1: Amino Acid Profiles Expressed as Percentages of Lysine in the NRC 1984 and NRC 1994 Profiles, as Well as in Illinois Ideal Chick Protein (IICP)

| **Amino Acid** | **NRC 1984**[1] | **NRC 1994**[2] | **IICP**[2] |
|---|---|---|---|
| Lysine | 100 | 100 | 100 |
| Arginine | 120 | 114 | 105 |
| Histidine | 29 | 32 | 37 |
| Methionine | 42 | 46 | 36 |
| Cystine | 36 | 36 | 36 |
| Phenylalanine | 60 | 66 | 55 |
| Tyrosine | 52 | 56 | 50 |
| Threonine | 67 | 73 | 67 |
| Leucine | 113 | 109 | 111 |
| Isoleucine | 67 | 73 | 67 |
| Valine | 68 | 82 | 77 |
| Tryptophan | 19 | 18 | 16 |
| Glycine + Serine | 125 | 114 | 65 |
| Proline[3] | 44 | 55 | 44 |

1 Ratios based on a total requirement basis (NRC, 1984, 1994)
2 Ratios based on a digestible requirement basis
3 NRC 1984 did not specify a proline requirement, so the ratio used in IICP was used also for NRC 1984

Further tables to/can be added for information if required.

**Acknowledgements**

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**Bibliography**

ACAMOVIC,T. (2001) Commercial application of enzyme technology for poultry production. *World's Poultry Science Journal*, **57:** 225-243.

ARC (1975) in: Agricultural research Council *The Nutrient Requirements of Farm Livestock, Poultry,* 2nd, (London, Agricultural research Council).

BAKER,D.H. & HAN,Y. (1994) Ideal aminjo acid profile for chicks during the first three weeks posthatching. *Poultry Science* , **73:** 1441-1447.

BEDFORD,M.R. & PARTRIDGE,G.C. (2000) in: Bedford, M. R. and Partridge, G. C. *Enzymes in Farm animal nutrition,* CAB International).

BLAIR,R., DAGHIR,N.J., PETER,V., & TAYLOR,T.G. (1983) International Nutrition Standards for Poultry. *Nutrition Abstracts and Reviews - Series B*, **53:** 669-713.

BOURDILLON,A., CARRE,B., CONAN,L., DUPERRAY,J., HUYGHEBAERT,G., LECLERCQ,B., LESSIRE,M., MCNAB,J.M., & WISEMAN,J. (1990) European reference method for the in vivo determination of metabolisable energy with adult cockerels: reproducibility, effect of food intake and comparison with individual laboratory methods. *British Poultry Science*, **31:** 557-565.

D'MELLO,J.P.F. (1994) in: D'Mello, J. P. F. *Amino Acids in Farm Animal Nutrition,* (Wallingford, CAB International).

FIRMAN,J.D. & BOLING,S.D. (1998) Ideal protein in turkeys. *Poultry Science*, **77:** 105-110.

FISHER,C. (1998) Amino acid requirements of broiler breeders. *Poultry Science*, **77:** 124-133.

FISHER,C. & BOORMAN,K.N. (1986) in: Fisher, C. and Boorman, K. N. *Nutrient Requirements of Poultry and Nutritional Research,* (Abingdon, Carfax Publishing Company).

GOUS,R.M. (1998) Making progress in the nutrition of broilers. *Poultry Science*, **77:** 111-117.

HAN,Y. & BAKER,D.H. (1993) Effects of sex, heat stress, body weight, and genetic strain on the dietary lysine requirement of broiler chicks. *Poultry Science*, **72:** 701-708.

HAN,Y. & BAKER,D.H. (1994) Digestible lysine requirement of male and female broiler chicks during the period three to six weeks posthatching. *Poultry Science*, **73:** 1739-1745.

HONG,D., RAGLAND,D., & ADEOLA,O. (2001) Additivity and assosiative effects of metabolizable energy and amino acid digestibility in barley and canola meal for white pekin ducks. *Poultry Science*, **80:** 1600-1606.

LECLERCQ,B. (1998) Specific effects of lysine on broiler production: comparison with threonine and valine. *Poultry Science* , **77:** 123.

MACK,S., BERCOVICI,D., DE GROOTE,G., LECLERCQ,B., LIPPENS,M., PACK,M., SCHUTTE,J.B., & VAN CAUWENBERGHE,S. (1999) Ideal amino acid profile and dietary amino acid specifications for broiler chickens of 20-40 days of age. *British Poultry Science*, **40:** 257-265.

NRC (1994) in: *Nutrient Requirements of Poultry,* 9th, (Washington, DC, National academy Press).

POWER,R. & HORGAN,K. (2000) Biological Chemistry and Absorption of Inorganic and Organic Trace Metals, in: LYONS,T.P.J.K.A. pp. 277-292 (Nottingham, Nottingham University Press).

RAVINDRAN,V., SELLE,P.H., RAVINDRAN,G., MOREL,P.C.H., KIES,A.K., & BRYDEN,W.L. (2001) Microbial phytase improves performance, apparent metabolisable energy, and ileal amino acid digestibility of broilers fed a lysine-deficient diet. *Poultry Science*, **80:** 338-344.

ROCHE (2001) Vitamin nutrition compendium (CD-ROM).

SELLE,P.H., RAVINDRAN,V., CALDWELL,R.A., & BRYDEN,W.L. (2000) Phytate and phytase: consequences for protein utilisation. *Nutrition Research Reviews*, **13:** 255-278.

VAN CAUWENBERGHE,S. & BURNHAM,D. (2001) New developments in amino acid and protein nutrition of poultry as related to optimal performance and reduced nitrogen excretion. *13th European Symposium of Poultry Nutrition*, 1-12.

WHITTEMORE,C.T., GREEN,D.M., & KNAP,P.W. (2001b) Technical review of the energy and protein requirements of growing pigs: energy. *Animal Science*, **73:** 199-215.

WHITTEMORE,C.T., GREEN,D.M., & KNAP,P.W. (2001a) Technical review of the energy and protein requirements of growing pigs: protein. *Animal Science*, **73:** 363-373.

WISEMAN,J. (1987) in: Wiseman, J *Feeding of non-Ruminant Livestock,* (London, Butterworths).

**Some sources of information on the internet (at March, 2002).**

http://www.tessenderlo.com
http://www.fao.org
http://www.rossbreeders.com/
http://www.roche.com
http://www.cobb-vantress.com/ukdist/ukdiv.asp
http://www.basf.com