The need for nutrient requirement standards for pigs

Report of the British Society of Animal Science nutritional standards working group :pigs

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Recommendations

1. In response to societal demands and in the light of shortage of robust scientific documentation, that there be review of the interactions between nutrient supply and (a) health, immunity and welfare of the pig, (b) environmental protection, and (c) safety of pig meat for human consumption. Models for nutrient budgeting should be developed. Nutrient budgeting models are called for to deal with the optimisation of diverse objectives, and the simultaneous satisfaction of efficiency of production, pig welfare, environmental protection and biosecurity. The production sector presently has no effective methodology to make informed decisions relating to the balance between nutritional requirements for cost-effective production and nutritional requirements for the satisfaction of the concerns of society [which may themselves conflict].

2. In the light of recent publications, that there be no further wide-ranging scholarly review of energy and protein requirements of growing/finishing pigs and breeding sows for purposes of production output.

3. As none presently exist, that there be produced summary tables of requirement (energy, amino acid, vitamin and mineral) suitable for the guidance of smaller and on-farm feed compounders.

4. Because there is a frank shortage of information, that the nutrient requirements of the weaned and young growing pig be the subject (a) of review with the intent of the publication of recommendations, and (b) of *de novo* research.

5. Following clarification that vitamin and mineral addition into practical diets differs widely from any presumptive ‘standard’ and is variable within and between geographical pig-keeping regions, that there be a wide-ranging review of vitamin and mineral requirement of pigs. The need for such review is widely supported throughout Europe.

Summary

1. The sub contractor formed a (pig) species working group representing United Kingdom nutritionists, feed compounders and pig producers. The working group reviewed the information currently available nationally and internationally on nutrient requirements. As a part of the reviewing process expert evidence was also sought from those involved in nutritional science and feed compounding in the Netherlands, Denmark, United States, Australia, France, Germany and Spain.

2. Nutrient provision to the pig must not only optimise the nutritional welfare of the pig, but also minimise environmental impact through polluting excretions and sub-optimal efficiency of nutrient use. There must be assurance of the safety of animal feedstuffs to the animal, and of the safety of animal products for consumption by man. However, the primary purpose of providing nutrients to pigs is to grow lean and fatty tissues and supporting skeletal and visceral organs, to initiate and maintain pregnancy, and to resource the synthesis of milk. The objective of these functions is the production of saleable pig-meat at a quality that commands an appropriate price.

3. The remit was that of a scoping exercise to determine if there may be justification for a deeper and wider-ranging review that would culminate in substantive and authoritative documentation [National Standards] presenting recommendations for optimal nutrient allowances to be offered to pigs.

4. The published National Standards presently available for pigs were seen to be non-contemporary, irrelevant, or inappropriate to circumstance. Initiatives to redress this shortcoming have been in hand in some countries for some time, but have not come to fruition; possibly indicating a relatively low priority for any update of the sort of publication typified by ARC (1981) ‘The Nutrient Requirements of Pigs’. Only the US has delivered a contemporary publication (NRC, 1998).

5. In UK, there is now no ‘National’ requirement standard for the provision of nutrients to pigs. There is a view that there is no determinant definition either of the pig, the production environment, or the production purpose.

6. Nutrient requirement should best be stated in terms of a specific pig type producing a specific end product within a specific production circumstance. The definition of these specifics to allow optimisation of nutrient supply is difficult, and the need for the means to measure pig performance potential, farm type, management level, and market needs is pressing.

7. Authoritative (UK) reviews upon which to base legitimate determinations of energy and protein requirement of breeding and growing pigs (but not newly weaned pigs) have recently been published. The presence of these reviews would not point to a case for further review.

8. Equivalent authoritative reviews upon which to base vitamin and mineral requirement are needed, but are not presently available.

9. There is agreement amongst UK and International sources that there is a particular shortfall in information relating to the nutrient requirements of newly weaned and young growing pigs.

10. Information from world science and from local experimentation is significant in the formulation of pig feeds in all countries surveyed. The larger feed compounders also develop their nutrient requirement standards from in-house research and development work. To this is added appropriate company interpretation of the scientific literature. All elements of the pig feed compounding, supplement supply, and specialist nutritional consultancy sector will tend to pull the available scientific and technical literature together to create 'in-house' recommendations of nutrient requirements for the various classes of pigs and various customer needs. A proportion of this information base will remain as in-house intellectual property, a proportion will be released to customers in the form of technical literature, and a proportion will be published in the public domain.

11. A National Standard laying down requirement may be appropriate where there is a lower level of scientific expertise available at the point at which the feed is compounded. In the nature of things, the quality of information impacting upon the formulation of diets for pigs fed by the smaller compounders and on-farm mill-and-mixers is variable. This sector has greater difficulty obtaining and interpreting contemporary information flows, depends more on published text sources or habitual practice, and may be considered to be the sector in greatest need of a National Standard for the nutrient requirements of pigs. In parts of Europe such standards are specifically prepared.

12. The European, Australian and North American feed compounding, supplement supply and technical consultant sector [with the exception of Denmark] makes rather wide use of nutrient requirement models. These tend to be based upon published algorithms, but are substantially adapted, supplemented with in-house information, and refined for industry use. These models help determine optimum nutrient supply for specific production and market circumstance. Success rates with models have been mixed, in part due to the difficulty of obtaining reliable input data. Practical models, of various degree of sophistication, are being developed in Europe for growing and finishing pigs and for sows that can predict requirements in individual circumstances.

13. Presently models are used more to inform diet formulation than to drive it. Nonetheless, there is general agreement that only by use of models can optimum solutions be determined for systems with diverse objectives, and models will be necessarily integral to nutrient budgeting (the simultaneous satisfaction of production and societal objectives).

14. In some of the European countries, excretion of N and P is of major concern and there are guidelines for the levels of nitrogen, crude protein and phosphorus in the diets. In

response to limits relating to the land application of nitrogen and phosphorus, 'nutrient budgeting' is becoming a significant element of feed formulation activity. But there is no specific inclusion in Quality Assurance schemes of 'Nutrient Standards', and no detailing of how any such nutritional standard might contribute directly to health, welfare, and the environment. Neither are there management plans for nutrient budgets, accommodating environmental as well as production aspects. These omissions might be usefully addressed.

15. All countries and all sectors emphasised a need for the collection of robust scientific information relating to the interaction between nutritional provision to pigs, and pig health, pig welfare, environmental protection [especially N and P], and the safety of pig meat for human food. The satisfaction of this need is a matter for scholarly review, the construction of models, and new research.

16. Despite an evident shortage of scientific information, environmental and health issues already form an important and influential background to feed formulation. There is concern that environmental and retail interests may, in expressing their view of societal needs, demand nutritional standards that have no basis in sound independent science.

17. The production sector sees conflicts of interests arising when it implements the demands of legislation and standards relating to welfare, environmental protection and food safety. There are serious conflicts with cost and efficiency of production. There are also conflicts amongst the various 'non-commercial' societal concerns themselves. Thus nutritional requirements for welfare may be in conflict with nutritional requirements for environmental protection. The production sector lacks the information needed to make informed decisions relating to the balance between animal welfare and environmental protection benefits, and between these and the necessity of economic production in a competitive market.

18. The information base for the setting of vitamin and mineral requirement is universally perceived as poor. There is general agreement throughout Europe that this shortcoming should be urgently addressed.

19. Useful work has been completed by mineral and vitamin supply companies, and this is the major source of information for feed compounders. It is considered that the NRC (1998) review may not be an adequate reference source to account for recent European research findings.

20. To gain insight into current practice for vitamin and mineral inclusions, a survey was conducted of feed manufacturing companies with a substantial national market share, or of agencies making recommendations to such feed manufacturers, in the following countries: Denmark, Germany, Netherlands, United Kingdom, United States, Spain and Australia. The range of inclusion levels used was wide.

21. The survey revealed practical international supplementation rates for vitamins considerably higher than ‘National Standards’. Calcium levels were similar to or lower than those of NRC, while phosphorus levels have reduced in response to environmental imperatives and the move to formulation on the basis of available phosphorus. The newly forming body of information relating to digestibility will be helpful in responding to the environmental imperative regarding the release of P. New environmental imperatives are arising with respect to excretions of dietary copper and zinc.

22. ARC (1981) is now an inappropriate guide to mineral and vitamin requirement. There has been significant change in the state of knowledge, the pig [genotype lean tissue growth, appetite, reproductive productivity], production circumstances [disease, housing, management, feed ingredients], and the need to improve pig health. The vitamin and mineral supply companies offer an effective service, but cannot be said to be independent. The contemporary alternative (NRC, 1998), appears to have been rejected by practitioners as not relevant to the European situation, whilst European practice itself shows wide variation in the case of some important vitamin and mineral elements.

23. It is likely to be unsafe [particularly in the light of recent research] to prioritise the need for attention to particular requirement amongst the various vitamins and minerals, or to separate their ‘performance’ from their ‘societal’ functions. Nevertheless it would appear that there is special contention relating to the vitamins retinol, cholecalciferol, alpha tocopherol, menapthone, folic acid, and biotin, and to the minerals phosphorus, zinc, selenium, iodine, manganese and sodium.

24. As present European practice may have reached its current position somewhat independently of [and is now substantially different from] the ‘Standard’, a review of vitamin and mineral requirement with a European dimension, would be useful.

Remit

The remit assigned to the working group is given in Appendix 1.

Broadly, the working group interprets the remit as a scoping exercise to determine if there may be justification for a deeper and wider-ranging review that would culminate in substantive and authoritative documentation presenting recommendations for optimal nutrient allowances to be offered to pigs. And if this were so, whether that documentation should prioritise its focus on any particular aspects.

It became apparent during the course of the exercise that energy and protein should be treated differently to vitamins and minerals. Recent scientific reviews addressing the energy and protein requirements of growing pigs and sows and boars [although not young weaned pigs] were found available in the public domain, but equivalent literature was not available for vitamins and minerals. Further, the ‘best numerical value’ approach is more appropriate for vitamins and minerals than for energy and protein. Tables of numerical values are therefore presented in this document for vitamins and minerals, but not for energy and protein.

The working group presumes 'required nutrients' to be defined within the conventional understanding of the dietary components of usable energy, protein and its constituent amino acids, available minerals and vitamins. The working group has not examined the requirement for feed additives included into diets for presumptive positive outcomes, or for feed additives included into diets for presumptive prevention of negative outcomes. Similarly, recommendations for fibre have not been examined because of the diverse nature of non-starch polysaccharide and the lack of understanding of requirement *per se* for NSP for any class of pig. Nor have we examined the requirement for water. In the case of water, there are the recent reviews of Frazer *et al*, (1993) [weaned pig], Brooks and Carpenter (1993) [growing pig], Brooks (2000) [sow and boar]. It is noted that the United States National Academy of Sciences National Research Council sub-committee on Swine Nutrition included in their review *Nutrient Requirements of Swine* (10th Edition) chapters on 'Water' and 'Nonnutritive Feed Additives' and 'Minimising Nutrient Excretion' (NRC, 1998).

The working group believes that the eating quality of the pig meat product is as important an attribute as the efficiency of its production. However, we have not incuded the interaction between nutrient supply and meat quality in our brief. This may be more a function of feed type than nutrient supply. Neither have we included the nutrient requirement for ovulation and conception *per se* (if any there be).

Introduction

Nutrient provision to the pig must optimise the nutritional welfare of the pig, and minimise environmental impact through polluting excretions and sub-optimal efficiency of nutrient resource use. There must also be assurance of the safety of animal feedstuffs to the animal, and of the safety of animal products for consumption by man. However, the working group takes it as given that the purpose of providing nutrients to pigs is to grow lean and fatty tissues and supporting skeletal and visceral organs, to initiate and maintain pregnancy, and to resource the synthesis of milk. The objective of these functions is the production of saleable pig-meat at a quality that commands an appropriate price.

Any statement of nutrient requirement for the pig assumes an equivalent statement of nutritional value of the feed offered. Methods used for the valuation of nutrient sources is contentious, varies amongst nations, and is often considered to be the intellectual property of businesses involved in the purchase and compounding of feedstuffs. The working group did not consider the valuation of feedingstuffs as within their brief. Published tables of nutrient value of feedstuffs are readily available internationally (for example, NRC, CVB, AMIpig), although these guide values are of limited use for precise diet formulation due to incomplete information and natural variation in the nutritional content of individual feed ingredients. It is explicit in nutritional science that nutrient requirement of the animal is defined conterminously with nutrient evaluation of feeds. This limits transferability of standards across boundaries in feed evaluation methodology.

The energy, amino acid, mineral and vitamin value of feeds is not only a function of the feed alone. The animal itself exerts a substantial influence upon feed nutritive value according to the metabolic state of the pig and the end-product intentions of the pig [and of its keeper] for the use of consumed nutrients (Whittemore and Manson, 1995; Whittemore, 1999). It is reasonable therefore that the determination of nutrient requirement will depend upon some level of modelling activity to synthesise the elements of input and output.

There can be no single definition either of the pig, the production environment, or the production purpose [due to the wide variations presently found in genotype, farm and market]. Nutrient requirement must therefore be established for a defined end product within a defined circumstance. This has been accepted by NRC (1998), who propose a modelling approach. Whilst the initiative was applauded, the published outcome was not without negative criticism (Whittemore, 2000). The present authors consider it unlikely that a Standard Model for the calculation of nutrient requirement would find universal acceptance. There is much yet to be understood in the matter of the construction and use of models (Whittemore *et al.* 2001(a), (b), (c), (d)). Further, models may often be considered part of the individual intellectual property of businesses compounding feeds and/or offering consultancy to customers on the nutritional requirement of pigs. It is possible therefore that nutritional standards may be best presented in the form of principles and algorithms describing the utilisation of nutrients by pigs, so that users can build models suitable to individual purpose. Such documentation would deal with the understanding of the animal's response to nutrients, and the definition of target output in terms of production of meat, protection of the environment, and pig and human health.

Information presently available to UK users on nutrient requirements of pigs

Information base

The scientific literature may be divided into five broad groups. 1. Scientific reports of nutritional experimentation germane to the establishment of requirements and published in scientific journals. 2. Independent peer-refereed scientific reviews published in scientific journals and drawing together published information with the general intention of enabling, or establishing requirements. 3. As for (2), but either lightly, or not at all peer-refereed, and not published in scientific journals but usually appearing in the form of books or proceedings. 4. Scientific reviews prepared by, or overseen by, a National Committee or similar group with the specific remit of establishing nutrient standards. Presently, nutritional specifications for UK pig feed formulations arise from all four sources. But additionally, knowledge also arises from; 5. Field experience, technical literature published in non-scientific journals and not peer-reviewed, in-house trials and experiments that are not subject to peer review nor published, and from customer demand. This fifth group of information sources is of increasing importance following the withdrawal of Government funding in many European countries from 'near-market' research and development work.

In UK, Nutritional Standards are perceived to emanate from scientific reviews prepared by, or overseen by, a National Committee. Classic examples presently in use would be those of ARC (1981), AFRC (1990, 1991), SCA (1987), NRC (1998). These may be considered variously to have been somewhat overtaken by events [especially changes in farming method, market requirement and pig performance potential], subjected to criticism (for example; Stranks *et al.,* 1988; Whittemore, 2000), or considered to make recommendations inappropriate to present UK national [and local] circumstance. However, even although its relevance to UK and its methodologies may be questioned, the NRC (1998) publication is of paramount importance in its contemporaneity and in the absence of any credible alternative. (However, many aspects of vitamin and mineral requirement are similar to those of ten, and some of more than 30 years, earlier). Significant usage of National Standards for nutrient requirement may be restricted to the provision of a base-line to minimum expected nutrient provision.

The NRC (1998) publication has feed tables dealing *inter alia* with the availability of energy, amino acids and minerals. Amino acid ileal digestibilities and proximate analysis of feedstuffs are also available from published tables and computer software (for example, AMIPig). Information on the [putative] availability of phosphorus from both vegetable and mineral sources is available from the supply trade and tables such as those of NRC, and CVB [see also www.tessenderlo.com]. As availability is the consequence of both level of supply and interaction with animal demand, such data, while welcome, can only be indicative.

Particularly valuable as sources of scientific information upon which to base legitimate determinations of nutrient requirement are independent peer-refereed reviews published in scientific journals and books or proceedings. This is especially the case where these collate and interpret the findings of reported experimentation. Recent authoritative publications falling into this category in relation to breeding pigs are *Nutrition of Sows and Boars* (Close and Cole, 2000), and *The Lactating Sow* (Verstegen *et al.,* 1998). The former of these, in addition to a comprehensive review of feed intake, energy, amino acid and water requirement, gives clear recommendations for the provision of minerals and vitamins. In relation to growing pigs, authoritative publications falling into this category have recently been commissioned by the journal *Animal Science.* These are in the form of three reviews: *Technical review of the energy and protein requirements of growing pigs; food intake* (Whittemore, *et al.,* 2001a). *Technical review of the energy and protein requirements of growing pigs; energy* (Whittemore, *et al.,* 2001b). And *Technical review of the energy and protein requirements of growing pigs; protein* (Whittemore, *et al.,* 2001c). These publications fulfill their brief, as titled, but importantly have nothing to say about requirements for vitamins and minerals. It is partly for this reason that a significant proportion of the text of this report relates to present practices for vitamin and mineral inclusions. Also, the reports of Close and Cole (2000) and Whittemore *et al.* (2001) do not adequately address the special nutrient requirements of the young pig from the point of weaning to 20kg live weight.

In both the case of the breeding and of the growing pig, these recent reviews offer a comprehensive analysis and bibliography of the scientific literature relating to energy and protein requirement for production output optimisation. Such will therefore not be repeated here. The presence of these reviews would suggest, *prima facie*, that a case for further review in these particular areas is not urgent.

Models

Models simulating the response of pigs to changes in nutrient supply are used to varying degree in UK. A significant proportion of the UK pig herd is fed by diets mixed 'on-farm'. Where consultants have access to models relating to nutrient requirement they will be intermittently used. The feed compounding sector uses models part-based on published algorithms, but substantially supplemented with in-house intellectual property. These models assist the formulation of nutrient provision in relation to requirement both (a) within-company for strategic decision-making, and (b) together with customers for tactical decision-making to optimise individual customer benefit. The scientific provenance of the elements of these models tends to be of mixed vintage (see Moughan *et al.,* 1995; Kyriazakis, 1999, Birkett and de Lange, 2001a), and/or confidential. Models are particularly adept at predicting the general magnitude and direction of response to change in energy supply [feeding level] and to change in the ratio of energy to balanced amino acids. The validity of quantitative conclusions from these models, particularly to specific farm circumstance remains contentious. A new round of model-building initiatives in UK, Europe, and Canada is presently active (for review, see Whittemore *et al.,* 2001(a), (b), (c)), and a new generation of models will probably be available within five years (Whittemore *et al.,* 2001(d), Birkett and de Lange, 2001(a), (b), (c)). These models will have the purpose of providing optimum nutrient provision within the context of Integrated Management Systems which will account also for the needs of Environmental protection.

Environment

Typical of Quality Assurance schemes, the England and Wales EFSIS-certified Quality Assurance Scheme, ASSURED BRITISH PIGS [and its direct QMS equivalent in Scotland], lays down Standards requiring compliance in relation to pig health, pig welfare, environmental protection and the safety of pig meat for human food. The conditions for feed and water supply are detailed, and the safety and wholesomeness of the diet is subjected to inspection. Compounded feeds, and feed ingredients for on-farm mixing, must come from Assured sources. For feed compounders there is the UKASTA UFAS assurance scheme, but this does not include by obligation small units and on-farm mill-and-mixers. There is, however, no specific inclusion in QA schemes of Nutrient Standards, and no detailing of how any such nutritional standard might contribute directly to standards relating to health, welfare, and the environment. This might be judged as an oversight.

Management plans for nutrient budgets, accommodating environmental as well as production aspects, are not yet explicit in QA schemes. If such be sought, then there would be a need for the collection of robust scientific information to enable the recommendation of appropriate nutritional provision to pigs in respect to pig health, pig welfare, environmental protection, and the safety of pig meat for human food. However, the satisfaction of this need is not a matter only for scholarly review, but also for the construction of models and the consensus of a scientific committee. As the fundamental information base on the interactions between nutrition of the pig and pig-health, pig-welfare and the environment is presently imperfect, it is also a matter for new research.

Information on nutrient requirements of pigs presently available internationally
The Netherlands
The livestock feed industry of the Netherlands is relatively closely controlled. National Standards exist with regard to usages of phosphorus and nitrogen. The scientific information base used in practice comprises; (a) reports from the scientific and technical literature, (b) experimental results from national research laboratories, and (c) information from feed-industry in-house R & D. Important are the published official standard recommendations available from the Dutch Centraal Veevoeder Bureau (CVB), covering mainly feed composition tables for energy, amino acids [with availabilities] and the major minerals, together with some scientific review background. Use is also made of ARC (1981), but more importantly NRC (1998); these especially for minerals and vitamins. It is evident that information from world science and local experimentation is significant in the formulation of pig feeds in the Netherlands. The suggestion is that the feed compounding companies create from the basic scientific information their own interpretations of requirements for nutrients as appropriate to circumstance. In the Netherlands, where compounding companies dominate pig feed formulation, there seems to be a sense that a National Standard laying down requirement may be more appropriate where there is a lower level of scientific expertise available at the point at which the feed is compounded. This view is of interest with regard to the Danish position, and that of UK where over half the pigs are fed by smaller compounders and from on-farm mill-and-mix units.

The Netherlands feed industry makes rather wide use of nutrient requirement models. These tend to be based upon published algorithms, but are substantially adapted, supplemented with in-house information, and refined for industry use. The quality of science is understood to be high. The 'National' TMV model (TMV, 1994), updated in 1998, is comprehensive in its presentation of nutrient requirement science, but tends to be used more as a reference rather than in front-line applications.

Quality Assurance Standards at farm and feed-compounder level are published, comprehensive and applied with rigor. The Dutch IKB Quality Assurance scheme (http://www.hollandmeat.nl/gb/index.htm) shares the same principles as the British Farm QA schemes. They aim to achieve standards above the (Dutch) National and EU legal base, and they have in place a directly analogous scheme to the UK for the setting of the standards, for inspection and for independent audit. The IKB scheme is part of an integrated chain control programme from feed manufacture through to retail. No effective difference is evident between the standards set, purposes, policies, achievements and aspirations of IKB and equivalent UK QA schemes. The main difference however is that, like the Danish Scheme, control appears to lie at the level of the slaughterhouse/packer. The Netherlands feed industry is sensitive to developing standards for nutritional provision to pigs in respect to pig health and welfare, environmental protection, and the safety of pig meat for human food. For example, pig health considerations figure strongly in the preparation of weaner diets, welfare in the bulk density of sow diets, and the environmental imperative in the setting of phosphorus and nitrogen levels in compounded diets for growing pigs. In response to limits to the land application of nitrogen and phosphorus, nutrient budgeting, aided by modelling techniques and involving production response and environmental protection requirements, is becoming a significant element of feed formulation activity. Food-borne pathogens are important to the assurance of the wholesomeness of feedstuffs.

In the Netherlands there is some confidence in the existing information base with regard to nutrient requirement. But there is less confidence in the scientific basis to the provision of nutrients to target requirements of pig health, pig welfare, environmental protection, and the safety of pig meat for human food.

Certain opinion suggests that improvement of nutrient requirement standards for the optimisation of performance would be of little benefit without first resolving the more pressing problem of the measurement of performance potentials and requirements for particular production circumstances of farm type, management level, genotype, and market outlet.

Denmark

There is in Denmark a culture of cooperation and compliance that exists within an integrated industry structure receiving societal support. Denmark has a National Standard for the nutrient requirements of pigs covering all nutrients to be provided to all the various classes of pigs. The documentation for this standard is reviewed and revised, on a semi-continuous basis by representatives of the National Committee for Pig Production together with the scientists of the Foulum research institute and field advisers. Information sources for the Danish standards include national research, national field trials, and the international scientific and technical literature. The standard will in future include review material providing background to the standards. The documentation is in the public domain [explicit and quantitative amino acid, vitamin and mineral requirements for all pig classes are available on the web at www.lu.dk], but much of the technology transfer is in the form of an information stream passing down a tightly coordinated chain, rather than a finite reference text. The Danish information base may also be of limited use elsewhere because of the inflexibility of the energy and protein provision recommended, differences in feed evaluation methodology and expression, and the particularly local and prescriptive nature of the Danish production sector.

The usage of the recommended standards is high, and closely followed by all Danish pig producers. However, the standards are not mandatory. There is some latitude for adjusting the standard in the case of abnormal feed intake, or disease, or production circumstance. There is a view that feed ingredient choice, feed processing and feed additives may have a role to play in the control of odours and of salmonella. Phytase is seen as helpful in reducing the rate of phosphorus input and excretion.

Models have no part in the calculation of nutrient requirement in Denmark. They are considered to be unnecessary in the light of the presentation of a clear nutritional prescription agreed between all the sectors involved in pig feeding. Further, the National

Committee remains to be persuaded that models are operationally effective in the optimisation of production.

Pig health and welfare, environmental protection and pig meat safety are taken into consideration when the standards are reviewed. Specific quality guidelines are in place for organic production and the production of pigs for export. Safety margins have been reduced/withdrawn in respect to provision of protein and digestible phosphorus in the light of environmental protection requirements. Although formulation of the nutrient requirement clearly has optimisation of performance as its target, there is seen to be a forthcoming need for nutrient [N and P] budgeting. But there is presently an inadequate scientific data base for such purposes, and conflicts of interest between various targets are already apparent. Particularly evident issues relate to; (a) nutrition x disease interactions, (b) pig welfare x environmental welfare conflict regarding N and P provision, (c) the definition of requirement for non-essential amino acids, and (d) the dietary requirement for weaned and young growing pigs.

The information base for the setting of vitamin and mineral requirement is perceived as poor. There is a lack of independent scientific judgement relating to insurance levels and the requirements for optimum animal health.

Australia

Australian nutritional standards are now historical; being SCA (1984) and ARC (1981). There is therefore no National recommendation and no good up-to-date information specifically developed and available for Australia. Most information on nutritional standards and feeding practice is obtained from company literature, scientific journals or from production-based information developed by the Pig Research and Development Corporation (PRDC) [now Australian Pork Ltd]. Current recommendations for sows have recently been published (Close and Cole, 2000). These are considered useful, but the long-term and seasonal effects of nutrition on productivity in sows remain under-explored. The equivalent information available till now for growing pigs was not relevant to modern pig genotypes. There is relatively high usage of technical literature relating to new products [growth promoters, minerals, prophylactics]. The information base relating to energy and protein is not good, while that for minerals and vitamins is distinctly poor and there is a need for a major review in this latter area.

The health and welfare aspects of nutrient provision are considered to have been accommodated by the monitoring of the production performance level. Environmental considerations do not figure largely; although there are developing concerns about odours, N and P excretion and also high mineral levels in composts. Many pigs are now kept in straw-based eco-shelters and the nutrient requirements for such pigs are based on ‘hit or miss’ principles.

With regard to the use of models, AUSPIG is theoretically available to everyone, but only used to establish requirements and responses by a few large companies and a hand-full of advisers/consultants.

France

The last official publication was the Institut National de la Recherche Agronomique [INRA] publication in 1984, which covered not only pigs, but also poultry and rabbits. Other reports have been published since then, but on net energy. The Institut Technique du Porc [ITP] and Institut Technique des Céréales et des Fourrages [ITCF] regularly publish information specifically targeted at producers, which provide some nutritional recommendation, such as the percentage of lysine required in the diet. Information on feed composition is also given.

INRA is unlikely to produce national tables of nutrient requirement recommendations, as these are not deemed to be appropriate. However, they are now working on simple models for growing and finishing pigs and for sows that can predict requirements in individual circumstances. There is great interest in models, but they are not yet widely used. INRA will produce simple practice-based models next year. Some companies have their own technical models. The Association Française de Zootechnie will also publish a new 'Composition of Feed Ingredients' book, covering some 130-140 ingredients. The information base in relation to energy and amino acid nutrition is considered good, and is well used. The nutritional value of dietary fibre from different feed ingredients would benefit from more investigation.

No specific nutritional recommendations relating to pig health and welfare are used; other than those indicated by performance. There is a demand for specific branded pork products that require specific nutritional treatments to be applied in the grower/finisher period. Information on systems of production may be provided by organisations such as ITP, but this is producer-orientated, there is no specific documentation, and the information is of a practical nature. In France, excretion of N and P is of major concern and there are guidelines for the levels of nitrogen, crude protein and phosphorus in the diets. Control of odours by nutritional means could be important. Salmonella and E-coli are of major concern, but there are no nutritionally related recommendations.

The information base for vitamin and mineral requirements is considered poor. This is viewed as a neglected area of pig science and INRA is now developing a program of research into minerals.

Spain

There are no National Standards for the Nutrient Requirements of Pigs in Spain. This is considered a shortcoming. The official standard most widely accepted is NRC (1998). The level of knowledge on NRC requirements in the Spanish industry is high. However, the level of usage is moderate to low. Genetics, feed intakes and growth parameters vary widely across the Spanish pig industry. Usable nutrient standards would need to take these variations and differences between farms into account. There are wide differences in vitamins and minerals inclusions levels in Spain.

Regarding composition of raw materials, the equations and values published by CVB in the Netherlands are widely used. Also, FEDNA [Spanish Foundation for the Development of Animal Nutrition; an animal nutrition foundation comprising Spanish research and industry members] has published tables of feedstuffs composition for the different species. However, it has not published any nutrient requirements.

Spanish Quality Assurance schemes have been developed by different companies. These programs are mainly focused on food safety and meat quality standards. In some instances, there are some differentiated products that require specific nutrient specifications. [For example, vegetable-fed pigs with a specified content of linoleic acid in backfat, and heavy castrate pigs for the dried cured ham industry that require specific nutritional provision]. The environmental regulations can affect protein and total phosphorus level in some high-density areas in Spain, however, there is no official nutritional standard to guide the satisfaction of these regulations.

Use of modelling is quite limited in Spain. A few companies have had experiences with different well-known scientific models in the market. Validation in practice is limited.

U S

The Nutrient Requirements of Swine (NRC, 1998) operates as the US standard. This is the reference used within the Unite States for establishing requirements and responses. Information on energy and amino acids is based on recent research publications. Information on minerals and vitamins is less up-to-date. However, it is the mineral and vitamin recommendations that have the widest usage. NRC (1998) does not actually provide an estimate of energy requirement, but only of intake. The recommendations for the amino acids are used to a moderate level. The NRC publication also provides information on the composition of feed ingredients and this is seen as a valuable source of information. Compared with other countries, the range of ingredients used in the feeding of pigs is small and mostly based on corn and soybean meal. There is an inadequate level of information relating to dietary fibre and to feed additives.

Models are provided in the NRC publication, but their use by the industry is neither wide nor overt. Some commercial models are available. [For example AUSPIG, which is controlled by one company]. Many systems are 'all in all out', so it is easy to get an estimate of weight gain, which along with the carcass weight and percentage lean, allows nutritional requirements to be calculated for each situation. On-farm data is fundamental. Nutrition is not specifically designed to enhance carcass quality per se; systems of production are considered only in terms of calculated lean accretion rate.

US Quality Assurance schemes, range from the simple to the sophisticated. There are no specific nutritional recommendations for pig health and welfare, other than indicated by pig performance.

Environmental protection and meat safety are presently widely discussed; especially in relation to N and P. Phytase enzymes are added to many diets. Odour control is becoming increasingly important. In future, balance between the needs of production and of the environment will need to be considered in the design and specification of rations.

Salmonella is a major concern at present, but nutrition is not considered to be related. On many production units animal protein is not provided in the pre-slaughter diet.

Identification of areas in which the current provision of information is inadequate to meet the functional needs of UK stakeholders – Feed Supply Sector

Information base

Since ARC (1981) has largely fallen into disuse, there is now no clear view of a 'National' requirement standard for the provision of nutrients to pigs. Nonetheless, those involved in the formulation of diets [both for compounding mills and on-farm mixers] are considered to have a clear view at any moment in time of their own current recommendations for nutrient requirement. Many of these are in the public domain [for example from breeding companies, feed compounders and supplement suppliers]. These standards will be derived from a combination of scientific published reports, technical literature from supply companies, in-house experimentation, and current perceptions of industry expectations for best practice. In UK there is a view that nutrient requirement is a flexible and not a determinant character, and one that should be varied according to specific farm, genotype, disease, environmental and market circumstance. How this might best be done is however less clear, as the view of the benefits of models is mixed.

Usage of ARC (1981), NRC (1998) and other such sources is low, especially amongst the larger feed compounders. Both the larger and the smaller organisations will refer more to NRC (1998), Stranks *et al.* (1988), Close and Cole (2000) and Whittemore (1998). The Documentation from the Dutch CVB has mixed credibility as a 'European National Standard', although it is accepted that this contains comprehensive information of feed value, and also expert scientific reviews in some areas.

The larger 'National' feed compounders obtain their nutrient requirement standards much from in-house research and development work. To this is added appropriate company interpretation of the scientific literature. All elements of the pig feed compounding, pig feed supplement supply, and specialist pig nutritional consultancy sectors will tend to pull the available scientific and technical literature together to create 'in-house' recommendations of nutrient requirements for the various classes of pigs. Of these a proportion will remain as in-house intellectual property, a proportion will be released to customers in the form of technical literature, and a proportion will be published in the public domain.

This information, together with that from the scientific literature, causes the UK feed formulation and manufacturing sector to appear to be satisfied with its level of access to information on nutrient requirement for the optimisation of diet energy and amino acids for production performance.

With regard to the need for Nutrient Standards, the opinion was forwarded that there were many factors that will influence the estimation of the proper requirement for energy and protein in any given production circumstance. The feed compounding, supplement supply and specialist nutritional consulting sector tended to be of the view that a National Standard for energy and amino acids would not be helpful. However, there was a need for the constant up-dating of scientific research in the form of reviews, so that those responsible for diet formulation have at their disposal the means to make informed choices, and to build appropriate models. Such reviews have been recently published.

An exception to the above is the nutrition of the weaned and young growing pig, which strongly influences all subsequent performance. In this case information is scarce, and much of what there is, is protected in-house by those manufacturers specialising in the area. There is a need for detailed review and for research, especially that based in the understanding of gut physiology.

In the nature of things, the quality of information impacting upon the formulation of diets for pigs fed by the smaller compounders and on-farm mill-and-mixers is variable. This sector has greater difficulty obtaining and interpreting contemporary information flows, depends more on published text sources or habitual practice, and may be considered to be in greatest need of a National Standard for the nutrient requirements of pigs.

In the case of vitamins and minerals, the present National Standards are perceived as having more to do with the prevention of deficiency than the security of health and welfare and the optimisation of performance. However, ARC (1981), Stranks *et al.* (1988), Whittemore (1998) and NRC (1998) may be used in the absence of alternative independent reference. CVB appears to support higher levels of calcium inclusion than favoured in UK, where there is some interest in the possibility of reducing both Ca and P levels. Useful work has been completed by mineral and vitamin supply companies, but the generally available database is not large. It is considered that the NRC (1998) review may not be an adequate reference source to account for recent European research findings. Further, the most available sources of information is from interested parties [the suppliers].

There is seen to be a need for an independent review of vitamin and mineral requirements. Particularly to account for the European dimension, the change in pig production circumstance [genetic composition, environment], the issues of potency and availability, and the need to consider provision for the optimisation of health and performance.

Models

Nutrient requirement models have been widely implemented by feed compounders, supplement suppliers, and nutritional consultants. These models help determine optimum nutrient supply for specific production and market circumstance. They are derived from published information, but substantially adapted to incorporate in-house knowledge and accommodate local adjustments and dimensions. Although invariably originating from a base of published research, in some cases in-company models may now comprise more than 75% of in-house intellectual property. Success rates with models have been mixed, which is in part due to the difficulty of obtaining reliable input data.

One authority was of the view that models with general availability and applicability [of which there are internationally now some six or so well known] were invariably a disappointment to users. This was often due to
(a) their inability to cope with, and iterate with, the complexity of specific production circumstances
(b) lack of validation data
(c) an inability to provide the comprehensive input data demanded.
Much improved value appears to be obtained by models when
(a) the user is also the constructor of the model
(b) the model can relate to specific production circumstance, and when
(c) the model has access to validation data sets which are both large and diverse.

Environment
The feed manufacturing industry Quality Assurance schemes influence feed formulation decisions in relation to ingredient wholesomeness, cross contamination, drug residues, microbiological security, and the safety of feedstuffs for the feed-consuming pig and the pig-consuming public. The manufacture of animal feed by larger compounders is regulated by the UKASTA UFAS guidelines. These however are not mandatory, nor do they necessarily cover the smaller compounders and on-farm mill-and-mixers. There is a perception of a shortcoming in this regard, which may have implications for the demonstration of compliance with nutrient requirements for pig health and welfare, environmental protection and the safety of pig meat for human consumption.

The feed supply sector is aware of a need to comply with QA requirements imposed by third parties upon their customers. The production sector is governed by the general quality assurance scheme of ABP, and also by specific QA requirements of individual purchasers of pig meat. These impinge directly upon diet formulation particularly in relation to feed ingredient choice [inclusion or exclusion lists]. These have more to do with the perceived wholesomeness and eating quality of the pig meat product than with the health and welfare of the pig itself.

There is concern that retail marketing managers and store hygiene managers may, in expressing their view of customer needs, demand nutritional standards that have no basis in sound independent science.

Despite an evident shortage of scientific information, environmental issues form an important and influential background to feed formulation. These however do not impinge to the same extent as in the Netherlands where there is legislative control on the provision to pigs of nitrogen and phosphorus in order to reduce excretion rates. For example, low N and low total P diets may be specifically formulated in response to an environmentally driven feed formulation request. In general, however, pig feeds are not compounded to environmental protection requirements, nor are the mechanisms evident by which this can be done. Nutrient management and budgeting systems are not in day to day use. Models are seen as likely to be useful in this regard.

It is accepted that there are substantive influences of pig health and welfare and the safety of pig meat upon the calculation of the proper nutrient provision to pig. In many cases it is field experience that enables improvements in these areas. However, these agendas are not driven by properly informed independent science. There is a need for information in these areas, particularly the interaction between nutrient supply and the strength of the immune system.

There are tensions between the reduction [marginalisation] of protein and phosphorus levels with a view to environmental protection on the one hand, and on the other the health and welfare of the pig with regard to its normal growth function, its immune system and the integrity and strength of the skeleton. The requirement for non-essential amino acids remains unresolved.

Identification of areas in which the current provision of information is inadequate to meet the functional needs of UK stakeholders – Production Sector

Areas in which the current provision of information is inadequate to meet the functional needs of pig producers

The production sector identifies as different, (a) the nutritional requirements for maximising economic return, and (b) nutritional requirements for maximising welfare, environmental protection or food safety.

Given the production target of optimisation of animal performance to maximise economic return it is presumed that nutrient standards are in place and delivered typically by least cost formulation through the medium of the compound feed sector and commercial nutritional consultants. It is further presumed that these nutritional standards could be refined, using models, to accommodate genetic improvement in slaughter pigs.

Nevertheless, there is a perception that the information base relating to the definition of achievable production goals for specific genotypes and farm production circumstances is inadequate. If this is the case, then it is difficult to deliver a nutrient requirement at farm level in the absence of a clear definition of what levels of what types of production the requirement is targeted to attain. In breeding pigs the effects of genetic improvement on nutritional requirements are difficult to predict, particularly for lifetime performance. Here, there is a current and on-going need for research on nutritional standards for modern sow genotypes. And there is an urgent need for a better understanding of the interaction between disease, immunity and nutrition. [Although this applies to all classes of pig, there is particular urgency in the case of newly weaned and young growing pigs].

The production sector is sensitive to the origins of new scientific information relating to pig nutrition. This now comes mainly from the commercial [rather than the independent] science sector. It is understood that large national and multinational operators will have their own confidential research programmes and are positioned to apply new nutritional information through their supply chains. However [amongst others] are the following four possible shortcomings;

(a) the information is not independent and carries a financial risk

(b) the ability of national compounders to fund in-house research on a scale that is scientifically robust has been eroded with the reduction in the size of the UK pig herd
(c) inadequacies and gaps in knowledge may develop where there are potential conflicts between commercial interests and societal concerns relating to livestock production
(d) research undertaken solely by the commercial sector [and subject to restricted release] risks unnecessary and costly duplication.

Current and future needs of producers for information in the context of genetic change and societal concerns relating to welfare, environmental protection and food safety
UK producers have suffered significant financial loss through the imposition of measures not imposed on others. It is important to ensure that additional burdens are not unilaterally imposed unless adequate compensatory safeguards are put in place. Such safeguards would be to directly compensate UK producers, or to exclude those who are non-compliant from the market place.

The production sector sees conflicts of interests in meeting current and future legislation and standards relating to welfare, environmental protection and food safety. These conflicts are not only with the interest of commercial drivers [cost of production], but also amongst the various 'non-commercial' societal concerns. Thus nutritional requirements for welfare may be in conflict with nutritional requirements for environmental protection. [Eg, feed bulk for adult animals, levels of mineral provision, use of prophylactic levels of minerals and vitamins, level of feeding (growth-rate) of slaughter pigs, level of protein provision, ingredient source of protein supply].

The production sector lacks the information needed to make informed decisions relating to the balance between nutritional requirements for cost-effective production and nutritional requirements for the satisfaction of third-party [societal] concerns. Also lacking is the information needed to balance nutrient requirements consistent with conflicting societal interests.

Producers need robust independent information on the benefits to the environment from changes in nutritional standards targeting greater environmental protection. It is possible that nutritional standards for environmental protection may increase the cost of production without due justification. There is seen to be a lack of sound review of existing scientific information, of expert modelling, and of newly commissioned research. There is also a need for independent cost/benefit analysis of new nutritional technologies intended to reduce the environmental impact of pig production, such as the use of 'non-nutritive' but nutritionally-related feed additives, and the use of low-protein diets to reduce the daily rate of N excretion into the environment.

It is felt that the research underpinning for the construction of management plans for nutrient budgeting is lacking. The wider industry and societal implications for setting tighter crude protein or phosphorus limits in pig diets for reduced N and P excretion require urgent scientific review and further investigation. [For example, such restrictions may limit the use of certain low-cost food industry co-products in pig feeds but there will be a cost to the environment from other methods of disposal].

Food safety presents a major challenge and there are inevitable negative consequences for cost of production, pig health and welfare, and environmental impact. Withdrawal of feed additives promoting pig health on the grounds of risks to food safety may, for example, both reduce pig welfare and increase pollution rate. Exclusion from pig diets of animal-derived products may have consequences for both pig health and pig performance. In the case of GM feed ingredients, there is a real problem in the classification of meat other than by [global] audit trail.

A conclusion may be drawn that the production sector will only be able to make informed decisions over changing nutritional requirements to meet societal concerns over welfare, environmental protection and food safety if it has access to independent and reliable information on the cost and benefits of such changes. There is a need therefore to focus on this area.

Minerals and Vitamins

It is rather difficult justify the term 'requirement' for minerals and vitamins in the same way as it is used for protein and energy; namely for purposes of eliciting an overt response. Recommendations for the dietary inclusion levels of vitamins and minerals to give guidance to the industry are more properly the province of pig health, pig welfare and of environmental protection. Therefore, in contrast to the case for energy and protein, the state of the art for vitamin and mineral nutrition is not such as to allow algorithms for the estimation of dose response relationships according to production targets. The presentation of deterministic tables of requirement and of supplementation practice is therefore considered justified.

A statement of the amount of mineral and vitamin required daily may be of more general applicability than a statement of required diet concentration, but it may be argued that for some nutrients the latter may indeed be proper. The minor nutrients are subject to complex interactions amongst themselves and response is highly variable and dependent often upon [unquantifiable] production circumstance. Requirement may be influenced by judgement and common best practice as well as by findings from scientific experimentation. Thus may the allowance for phosphorus be reduced in the light of environmental concerns; and vitamin E increased in the light of expected disease challenge. When determining supplementation level for vitamins and minerals, feed and raw material processing, ingredient inclusions [such as polyunsaturated fatty acids in relation to vitamin E and glucosinolates in relation to iodine] and feed storage must be taken into account.

The value of the ARC and NRC National Standards

The presumptive 'National Standard' reference sources for vitamin and mineral requirements in UK are ARC (1981) and NRC (1998). Their recommendations for requirements are given in Table 1. These include the contribution from raw materials [in contrast to later tables that [with the exception of Ca, P, and Na] give supplementation levels].

Table 1. Dietary requirements of minerals and vitamins [total, per kg dry matter (ARC) or per kg 0.90 dry matter (NRC) of final compounded diet], as may be suggested from the recommendations of ARC (1981) and NRC (1998).

	Weaned pigs up to 15 kg live weight		Growing pigs of 15 – 50 kg live weight		Growing pigs of 50 – 150 kg live weight		Breeding sows	
	ARC (1981)	NRC (1998)	ARC (1981)	NRC (1998)	ARC (1981)	NRC (1998)	ARC (1981)	NRC (1998)
Calcium (g)	11	7.0	9	6.0	8	4.5	9	7.5
Phosphorus (g)	9	6.0	7	5.0	6	4.0	7	6.0
Chlorine (g)	1.5	1.5	1.5	0.8		0.8		1.2-1.6
Sodium (g)	1.3	1.5	1.3	1.0		1.0		1.5-2.0
Potassium (g)	2.5	2.6	2.5	2.3		1.7		2.0
Magnesium (g)	0.4	0.4	0.4	0.4		0.4		0.4
Zinc (mg)	50	80	50	60	50	50		50
Manganese (mg)	16	3	16	2	16	2	10	20
Iron (mg)	60	80	60	60		40		80
Cobalt (mg)								
Iodine (mg)	0.16	0.14	0.16	0.14	0.16	0.14	0.50	0.14
Selenium (mg)	0.16	0.25	0.16	0.15	0.16	0.15		0.15
Copper (mg)	4	5.0	4	4.0	4	3.0		5.0
Fluorine								
Retinol (mg)	0.60	0.55	0.60	0.40	0.40	0.40	0.70	1.2-0.60
Cholecalciferol (mg)	0.0035	0.005	0.0030	0.0038		0.0038		0.005
DL alpha tocopherol acetate (mg)	13.6	11	8.5	11	8.5	11	10.2	44
Menaphthone/menadione (mg)	0.3	0.5	0.3	0.5		0.5		0.5
Thiamin (mg)	1.5	1.0	1.5	1.0	1.5	1.0		1.0
Riboflavin (mg)	2.5	3.0	2.5	2.5	2.5	2.0	3.0	3.75
Nicotinic acid /niacin(mg)	20	12.5	14	10	14	7		10
Pantothenic acid (mg)	10	9.0	10	8.0	10	7.0	10	12
Pyridoxine (mg)	2.5	1.5	2.5	1.0	2.5	1.0	1.5	1.0
Cyanocobalamin (mg)	0.018	0.015	0.010	0.010	0.010	0.010	0.015	0.015
Biotin (mg)		0.05		0.05		0.05		0.2
Folic acid/folacin (mg)		0.3		0.3		0.3		1.3
Choline (mg)	800	400	800	300	800	300	1900	1250
Ascorbic acid (mg)	None		None		None		None	

1 mg retinol is 3333 i.u. vitamin A
1 mg cholecalciferol is 40000 i.u. vitamin D3
1 mg DL alpha tocopherol acetate is 1 i.u. vitamin E

A note on the requirement for essential fatty acids. NRC (1998) suggest that the dietary requirement for essential fatty acids for all classes of pigs will be met from a dietary inclusion level of 1.0 g linoleic acid / kg diet. This is very much less than the 7 g linoleic acid / kg and 5 g arachidonic acid / kg diet recommended by Close and Cole (2000) for reproductive function. Whittemore (1998) suggests 5 – 50 g linoleic acid / kg, and ARC (1981) 5 – 15 g linoleic acid / kg.

ARC (1981) is little used for practical contemporary diet formulation. Seventy percent of the information base in that document was from experiments completed more than 30 years ago. Some seven years later, the review of Stranks *et al.* (1988) suggested similar allowances to the ARC (1981) recommendations for minerals, but also suggested iron and zinc levels be approximately tripled where copper is included at growth promoting levels. In the case of the vitamins, Stranks *et al.* (1988) suggested multiple increases for specific vitamins broadly as follows: retinol, x 4; cholecalciferol, x 10; DL alpha tocopherol acetate, x 2; menapthone, x 3. An allowance of 0.3 mg / kg was suggested for biotin.

Average levels of addition of trace elements and vitamins by the UK feed compounding trade as found in the survey of UKASTA (1985), only four years after ARC (1981) was published and quoted by Stranks *et al.* (1988), are shown in Table 2. Marked elevations were already apparent for *all but* selenium, thiamin, nicotinic acid, pantothenic acid, pyridoxine, cyanocobalamin, biotin and folic acid.

Table 2. Average levels of additions of trace elements and vitamins in UK compounded growing pig feeds (UKASTA, 1985).

	Weaned pigs up to 15 kg live weight	Growing pigs of 15 – 50 kg live weight	Growing pigs of 50 – 150 kg live weight
Zinc (mg)	112	103	97
Manganese (mg)	48	41	38
Iron (mg)	164	146	142
Cobalt (mg)	0.7	0.7	0.7
Iodine (mg)	1.4	1.2	1.1
Selenium (mg)	0.18	0.17	0.16
Copper (mg)	156	134	101
Retinol (mg)	4.5	3.5	3.0
Cholecalciferol (mg)	0.05	0.05	0.04
DL alpha tocopherol acetate (mg)	85	50	40
Menaphthone (mg)	2.8	2.1	1.8
Thiamin (mg)	1.7	0.8	0.6
Riboflavin (mg)	4.6	3.9	3.5
Nicotinic acid (mg)	23	16	14
Pantothenic acid (mg)	13	11	10
Pyridoxine (mg)	2.3	1.3	1.1
Cyanocobalamin (mg)	0.02	0.014	0.013
Biotin (mg)	0.05	0.03	0.02
Folic acid (mg)	0.5	0.2	0.1
Choline (mg)	87	42	33
Ascorbic acid (mg)			

1 mg retinol is 3333 i.u. vitamin A
1 mg cholecalciferol is 40000 i.u. vitamin D3
1 mg DL alpha tocopherol acetate is 1 i.u. vitamin E

In the case of breeding pigs, the review of Close and Cole (2000) suggests similar mineral inclusion levels as might be realised from ARC (1981) and NRC (1998) above, but with an increase (x 2) in the inclusion rates of zinc and selenium. With regard to vitamins, Close and Cole (2000) recommend broadly similar dietary levels to those of NRC (1998) with the exception of the following, for which the allowances are substantially higher: retinol (x 2), 2.7 mg / kg; cholecalciferol (x 5), 0.025 mg / kg; DL alpha tocopherol acetate (x 2), 50 – 75 mg / kg; menaphthone/menadione (x 3), 1 – 2 mg / kg; biotin (x 2), 0.3 – 1.0 mg / kg, folic acid (x 3), 3 – 4 mg / kg.

The NRC (1998) review is the seminal reference document presently available, and its importance [even if by default due to the absence of any European equivalent] should not be underestimated. However, it is not without shortcoming. Those using the NRC (or any other) mineral and vitamin recommendations for purposes of feed formulation should be alert to:

(a) the relationship between diet concentration and feeding level
(b) the need to make appropriate adjustments for field circumstances [disease, genetic potential, conditions of management]
(c) the need for pragmatic and qualitative judgements based on field outcomes as well as published research findings
(d) prevailing local industry practice
(e) ingredient type, and feed and raw material processing (not only do different ingredients themselves carry differing levels of available vitamins and minerals, but withdrawal of potentially 'protective' feed ingredients such as meat & bone meal and fishmeal also increases the need for more critical assessment of the requirement for supplemetation)

In the US some groups use NRC (1998) as a base requirement, and for practical dietary allowances then apply a multiplier such as x 3 for pigs up to 30 kg, x 2.5 up to 70 kg, x 1.5 for finishing pigs, and x 2.5 for sows. Whilst apparently arbitrary, such practice has some support from work such as that of Stahly and Cook (1996) which suggested that for young weaned pigs experiencing some immune challenge, B vitamins at x 4 the NRC (1998) level were required. Similarly, Lutz and Stahly (1998) suggested riboflavin requirement to be x 3-4 that of NRC (1998). [Coelho (2001) has reported cost-effective responses to a combination of riboflavin, pantothenic acid, niacin, cyanocobalamin and folic acid of up to x 16 the NRC (1998) recommendation].

The presentation by NRC (1998) of mineral and vitamin requirements for growing pigs to 120 kg W in the form of curvilinear regressions of diet concentration on W might be considered an advance [especially for modellers] on tables with step changes for given phases of growth. Unfortunately perhaps, the form of the equation chosen by NRC is unjustifiably complex, taking the form; Requirement (concentration in the diet) = $e^{a+b(\ln W)+c(\ln W)(\ln W)}$. This ascribes to the requirement an aura of both accuracy and respectability unmerited in view of errors and variations associated with the source data. Neither are the parameter values enlightening. If some equation form is sought [albeit unjustified at this time], the general representation of the decline in recommended mineral and vitamin allowance as the pig grows and consumes increasing quantities of feed may be suggested by the more simple and perhaps meaningful descriptor of the NRC data set; Requirement (concentration in the diet) = a + b . lnW.

Survey of current International practice for vitamin and mineral supplementation
To gain insight into current practice, a survey was conducted of feed manufacturing companies with a substantial national market share, or of agencies making

recommendations to such feed manufacturers, in the following countries: Denmark, Germany, Netherlands, United Kingdom, United States, Spain and Australia. The range of inclusion levels used by feed manufacturers are shown in Table 3, presented as dietary additions per kg of air dry compounded complete feed, with the exception of calcium, phosphorus, digestible phosphorus and sodium which are given as the final levels in the compounded feed. Vitamin supplementation in Spain is typified by wide variation in inclusion level, and the presence of some particularly low levels thought to relate to the less well integrated sector. Some of the lower levels presented in Table 3 may be considered exceptional rather than typical.

Table 3. Range of dietary additions of minerals and vitamins found in the countries surveyed [added, per kg final compounded feed, with the exception of calcium, phosphorus, digestible phosphorus and sodium which are given as the final feed levels].

	Weaned pigs up to 15 kg live weight	Growing pigs of 15 – 50 kg live weight	Growing pigs of 50 – 150 kg live weight	Gestating sows	Lactating sows
Calcium (g)	7.5-9.2	6.0-8.2	5.5-7.2	7.0-9.0	7.0-9.0
Phosphorus (g)	7.0	5.0-6.4	5.0-6.0	5.5-7.5	5.5-7.5
Digestible phosphorus (g)	3.4	2.4-2.7	2.0-2.1	2.1-2.2	2.8-3.0
Sodium (g)	1.5-2.5	1.5-1.7	1.4-2.2	1.5-1.9	1.5-2.0
Zinc (mg)	100-200	100-200	70-150	80-125	80-125
Manganese (mg)	40-50	30-50	25-45	40-60	40-60
Iron (mg)	80-175	80-150	65-112	80-150	80-150
Cobalt (mg)	0-1	0-0.5	0-0.5	0-0.6	0-0.6
Iodine (mg)	0.2-1	0.2-1.5	0.2-1.5	0.2-2.0	0.2-2.0
Selenium (mg)	0.2-0.3	0.15-0.3	0.2-0.3	0.2-0.4	0.2-0.4
Copper (mg)	6-18	6-12	6-8	6-20	6-20
Retinol (mg)	1.5-4.8	1.2-4.1	1.2-3.0	2.1-6.0	2.1-6.0
Cholecalciferol (mg)	0.02-0.05	0.0125-0.05	0.01-0.05	0.02-0.075	0.02-0.075
DL alpha tocopherol acetate (mg)	30-100	10-80	10-80	25-80	25-100
Menaphthone (mg)	2-5	1-4	1-2	1-5	1-5
Thiamin (mg)	1.5-3	1-2	1-2	1-2	1-2
Riboflavin (mg)	4-10	4-6	2-4	3-8	3-8
Nicotinic acid (mg)	14-40	12-25	9-25	15-35	18-35
Pantothenic acid (mg)	8-20	10-15	8-15	7-15	5-15
Pyridoxine (mg)	2.5-5	1-3	1-3	2-5	2-5
Cyanocobalamin (mg)	0.03-0.05	0.02-0.025	0.015-0.022	0.015-0.030	0.015-0.045
Biotin (mg)	0.1-0.2	0-0.2	0-0.15	0.1-0.3	0.1-0.3
Folic acid (mg)	0-1.5	0-1	0-1	1-3	1-3
Choline (mg)	0-450	0-350	0-300	0-1000	0-1000
Ascorbic acid (mg)	0	0	0		0

1 mg retinol is 3333 i.u. vitamin A
1 mg cholecalciferol is 40000 i.u. vitamin D3
1 mg DL alpha tocopherol acetate is 1 i.u. vitamin E

These additions are the result *inter alia* of a combination of:
(a) referral to published recommendations for nutrient allowances
(b) accumulated wisdom

(c) internal publications from the manufacturers and suppliers of the components of vitamin and mineral supplements
(d) published papers in the scientific literature
(e) understood common practice in the trade
(f) requirements of customers [including considerations of liability in the event of product under performance].

Inevitably those minerals and vitamins that have the highest cost implications for the diet as a whole (eg Ca, P, biotin, alpha tocopherol) attract the greatest level of scrutiny.

Across the countries surveyed there is some general agreement as to mineral and vitamin supplementation required, despite variation in raw material composition, feed processing and pig performance.

[For the information of the reader, an Appendix Table [Appendix 2] is presented which recasts Table 3 by the removal of atypically high and atypically low values. The range presented therefore covers that in which the various values most frequently appear.]

There is substantial divergence between present European practice [Table 3] and the available National Standards [Table 1].

It is evident that the Dutch CVB recommendations for digestible phosphorus are now generally followed. In the case of digestible P there are now comprehensive tables of feedstuffs values and pig requirements available from the mineral supply trade. This newly forming body of information will be helpful in responding to the environmental imperative regarding the release of P.

Notable divergences in practice amongst the countries surveyed (Table 3) include:

(a) in some cases calcium supply to growing pigs may be limited to reduce the acid binding capacity of the feed
(b) there appears to be difference of opinion regarding zinc requirement
(c) retinol and cholecalciferol supplementation both vary rather widely
(d) alpha tocopherol supplementation is subject to local variation in the perception of need, and in addition will be individually adjusted for dietary level of polyunsaturated fatty acids and for the stimulation of the immune system
(e) biotin inclusions range widely; UK having a perception that higher levels may reduce foot problems in sows
(f) there is disagreement as to the need for choline supplementation; choline may also be added independently of the vitamin supplement.

Feed compounders use as a major source of published information the literature of the vitamin supply companies themselves [for example Roche (2001), Rhone-Poulenc (2000)]. Table 4 gives the range of additions to the feed suggested by these sources [expressed as addition per kg air dry compounded complete feed]. In commerce, most feed manufacturers ignore the vitamin contribution made from the raw materials. This customary practice has arisen as a result of variability in vitamin content and vitamin availability in raw materials, losses on processing, the relatively low cost of supplementation and the high cost of raw material vitamin analysis. Comparison of Tables 3 and 4 would suggest that feed compounders are cognisant of vitamin supplier's recommendations, but may be more sparing where costs are high and data showing benefit are sparse [for example, retinol, cholecalciferol, biotin, folic acid].

Table 4. Range of dietary additions of vitamins [total, per kg final compounded diet], as suggested by Roche (2001) and Rhone-Poulenc (2000).

	Weaned pigs up to 15 kg live weight	Growing pigs of 15 – 50 kg live weight	Growing pigs of 50 – 150 kg live weight	Breeding sows
Retinol (mg)	3.0-6.0	2.1-3.6	1.5-2.4	3.0-4.5
Cholecalciferol (mg)	0.038-0.075	0.025-0.05	0.025-0.038	0.038-0.05
DL alpha tocopherol acetate (mg)	40-100	30-60	30-50	40-80
Menaphthone (mg)	2-4	1-3	1-2	1-2
Thiamin (mg)	2-4	1-2	0.5-1.5	1-2
Riboflavin (mg)	5-10	4-6	3-5	5-9
Nicotinic acid (mg)	30-50	15-30	15-30	20-45
Pantothenic acid (mg)	10-30	8-20	8-18	10-25
Pyridoxine (mg)	3-6	2-4	1.5-3	3-5
Cyanocobalamin (mg)	0.03-0.06	0.02-0.03	0.015-0.025	0.02-0.03
Biotin (mg)	0.15-0.3	0.10-0.25	0.10-0.20	0.25-0.35
Folic acid (mg)	0.8-2.5	0.5-1.0	0.5-1.0	2-5
Choline (mg)	0-800	0-300	0-200	0-800
Ascorbic acid (mg)	0-200	0-100	0-200	200-500

1 mg retinol is 3333 i.u. vitamin A
1 mg cholecalciferol is 40000 i.u. vitamin D3
1 mg DL alpha tocopherol acetate is 1 i.u. vitamin E

Conclusion [vitamin and mineral]

ARC (1981) is now an inappropriate guide to mineral and vitamin requirement. The state of knowledge, the pig [genotype lean tissue growth, appetite, reproductive productivity], and production circumstance [disease, housing, feed ingredients] have changed significantly. The vitamin and mineral supply companies offer an effective service, but cannot be said to be independent. The contemporary alternative (NRC, 1998), appears to have been rejected by practitioners as not relevant to the European situation, whilst European practice itself shows wide variation in the case of some important vitamin and mineral elements.

The survey revealed supplementation rates considerably higher than 'National Standards'. For the 'B' vitamins rates were around x 3 of NRC (1998), biotin x 4, menaphthone x 6, retinol x 8, cholecalciferol x 10. Supplemental iron and iodine were x 1.5 NRC, zinc x 2, and manganese x 20. Calcium levels were similar to or lower than those of NRC, while phosphorus levels have reduced in response to environmental imperatives and the move to formulation on the basis of available phosphorus.

There are substantial differences between the NRC (1998) 'National Standard' and international usages. Some recent work appears to support the higher commonly used levels. In the light of the possibility that present European practice may have reached its current position somewhat independently of much of the published research, a review of vitamin and mineral research reports since 1998, and with a European dimension, would appear to be useful.

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Appendix 1. Remit and composition of working group

British Society of Animal Science nutritional standards working group :pigs

1. **To form a species working group** [Dr W Close and Dr M. Hazzledine] **with, in addition to the academic sub-contractor** [Professor Colin Whittemore]**, a representative of the feed supply industry** [Dr Brian Vernon, BOCMPauls] **and the species production sector** [Richard Campbell Esq, BPEX and MLC Commissioner] **who will act as assistant reviewers.**
2. **To review for their livestock species** [Pigs] **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 viability of conclusions.
   - Assess the extent to which the scientific basis of the information makes it relevant to extrapolate to current UK circumstances (eg 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.

Appendix 2. Table of commonly practiced dietary additions of minerals and vitamins

Appendix Table. Adjusted range of dietary additions of minerals and vitamins found in Denmark, Germany, Netherlands, United Kingdom, United States, Spain and Australia [added, per kg final compounded feed, with the exception of calcium, phosphorus, digestible phosphorus and sodium which are given as the final feed levels]. The particular adjustment made has been the removal from the data set (overall countries) used in Table 3 of atypically low and atypically high values. The values therefore approximate the range within which the various values most frequently appear. The statistical determination of a mode was not attempted due to the limited nature of the data set. These data may be considered as representing 'usual practice' over the group of countries surveyed.

	Weaned pigs up to 15 kg live weight	Growing pigs of 15 – 50 kg live weight	Growing pigs of 50 – 150 kg live weight	Gestating sows	Lactating sows
Calcium (g)	7.5-9.2	6.0-8.2	5.5-7.2	7.0-9.0	7.0-9.0
Phosphorus (g)	7.0	5.0-6.4	5.0-6.0	5.5-7.5	5.5-7.5
Digestible phosphorus (g)	3.4	2.4-2.7	2.0-2.1	2.1-2.2	2.8-3.0
Sodium (g)	1.5-2.5	1.5-1.7	1.4-2.2	1.5-1.9	1.5-2.0
Zinc (mg)	100-200	100-200	70-150	80-125	80-125
Manganese (mg)	40-50	30-50	25-45	40-60	40-60
Iron (mg)	80-175	80-150	65-112	80-150	80-150
Cobalt (mg)	0.4-0.5	0.2-0.5	0.2-0.5	0.4-0.6	0.4-0.6
Iodine (mg)	0.5-1.0	0.4-1.0	0.4-1.0	0.5-1.0	0.5-1.0
Selenium (mg)	0.2-0.3	0.15-0.3	0.2-0.3	0.2-0.4	0.2-0.4
Copper (mg)	6-20	6-15	6-15	6-20	6-20
Retinol (mg)	1.5-4.8	1.2-3.6	1.2-2.7	3-4.5	3-4.5
Cholecalciferol (mg)	0.03-0.05	0.03-0.05	0.015-0.037	0.025-0.05	0.025-0.05
DL alpha tocopherol acetate (mg)	40-100	35-60	20-60	35-80	35-80
Menaphthone (mg)	2-5	2-4	1-2	1-3	1-3
Thiamin (mg)	1.5-3	1-2	1-2	1-2	1-2
Riboflavin (mg)	4-10	4-6	2-4	3-8	3-8
Nicotinic acid (mg)	20-40	15-25	10-25	20-35	20-35
Pantothenic acid (mg)	8-20	10-15	8-15	7-15	5-15
Pyridoxine (mg)	2.5-5	1-3	1-3	2-5	2-5
Cyanocobalamin (mg)	0.03-0.05	0.02-0.025	0.015-0.022	0.015-0.030	0.015-0.045
Biotin (mg)	0.125-0.20	0-0.15	0-0.05	0.175-0.25	0.175-0.20
Folic acid (mg)	0.5-1.5	0-1	0-1	1-3	1-3
Choline (mg)	200-500	100-300	0-200	300-950	300-950
Ascorbic acid (mg)	0	0	0	0	0

1 mg retinol is 3333 i.u. vitamin A
1 mg cholecalciferol is 40000 i.u. vitamin D3
1 mg DL alpha tocopherol acetate is 1 i.u. vitamin E

A note on the requirement for essential fatty acids. NRC (1998) suggest that the dietary requirement for essential fatty acids for all classes of pigs will be met from a dietary inclusion level of 1.0 g linoleic acid / kg diet. This is very much less than the 7 g linoleic acid / kg and 5 g arachidonic acid / kg diet recommended by Close and Cole (2000) for reproductive function. Whittemore (1998) suggests 5 – 50 g linoleic acid / kg, and ARC (1981) 5 – 15 g linoleic acid / kg.