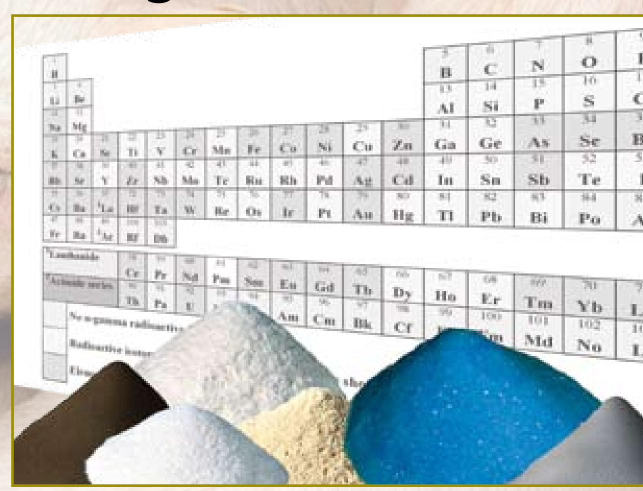
PIG PROGRESS

THE INTERNATIONAL MAGAZINE ON PIG PRODUCTION SPECIAL 2009

Trace minerals in pig nutrition

Trends and implications of EU legislation

Setting the NRC standards for minerals



The catalyst for sow lifetime performance

A balancing act: mineral requirements versus environmental pollution

The big three issues from weaning to slaughter: production, health and environment

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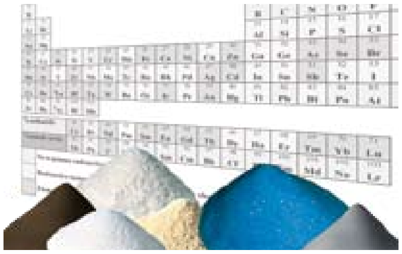
Trace minerals in pig nutrition

Organic trace minerals should be ragarded - especially in weaned pigs - as economical and natural growth promoters or, in short AGPAs (antibiotic growth promoter alternatives). In this series, more attention will be paid to the new role trace minerals can play in pig nutrition.



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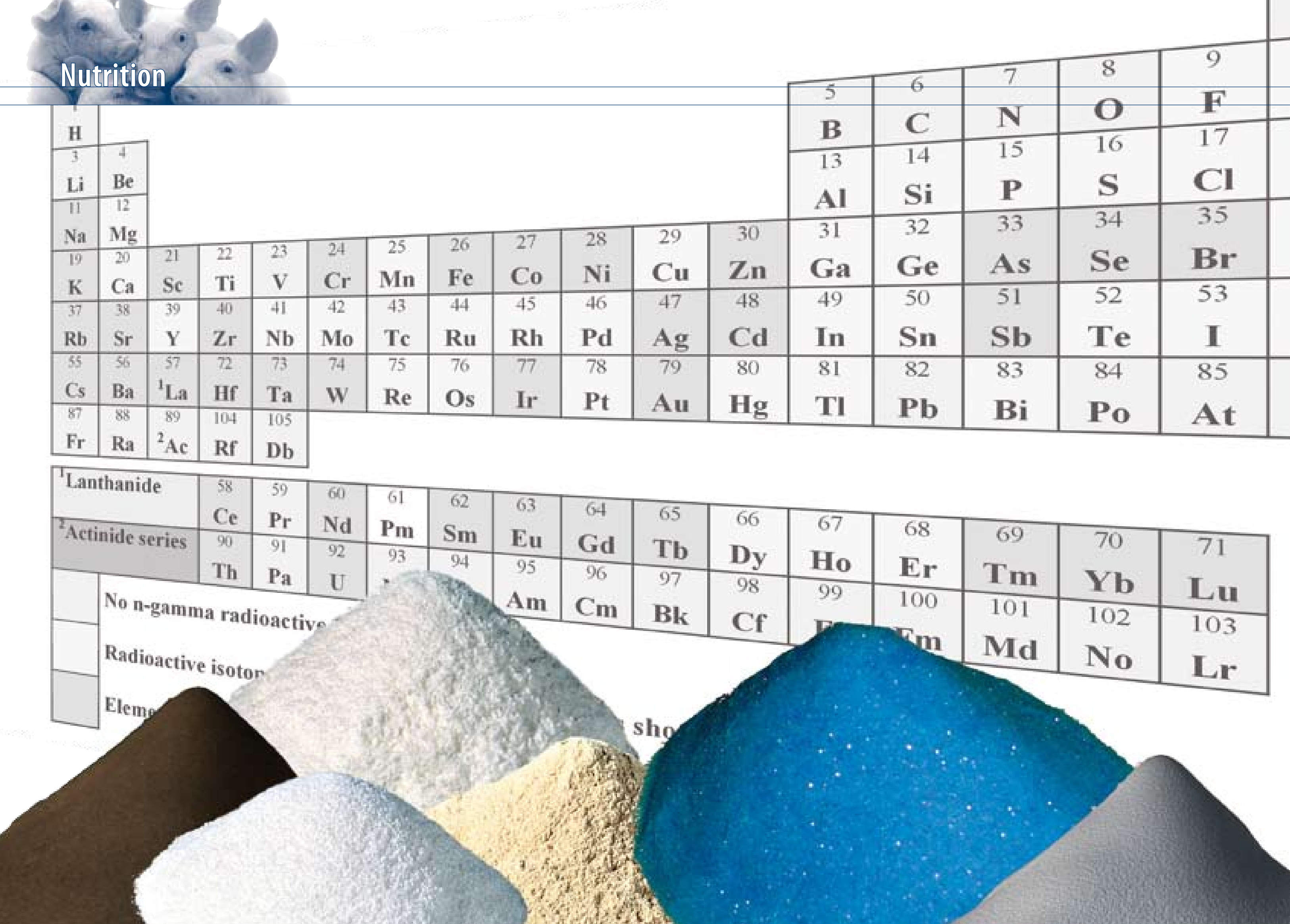


Trends and implications of EU legislation

In the first of this series 'Trace minerals in pig nutrition', recent events in the regulatory arena will be reviewed and resulting challenges will be discussed. What does the future of trace mineral supplementation look like?

By Elinor McCartney, Pen & Tec Consulting, Barcelona, Spain

In 1970, the EU published the first list of approved feed additives, including the trace elements cobalt (Co) copper (Cu), iron (Fe), iodine (I), manganese (Mn), molybdenum (Mo), selenium (Se) and zinc (Zn). Most of these were added to feeds as inorganic salts. Since 1970, research in trace element nutrition has led to the development of more bioavailable organic minerals, several of which have been approved for use in Europe. These include trace metals derived from chelates (Cu, Fe, Mn and Zn) and organic Se from strain-specific yeasts. *Table 1* summarises permitted forms and maximum concentrations of trace elements used as feed additives in pigs in the EU.

Application rates

The changes in trace mineral supplementation rates over time initially reflected technological progress. As production of pigs intensified in the 1970s and 1980s and genetic potential for growth and yields improved, commercial tendencies were to increase trace element supplementation rates, in order to allow for the greater mineral requirements of superior stock reared under industrial conditions. Cu was also added to pig feeds as a growth promoter, at much higher concentrations than essential for nutrition. In addition, EU prohibitions of certain antibiotic growth promoters (AGPs) in the late 1990s, culminating in the 2006 ban on all remaining AGPs, resulted in increased Zn usage in feeds, mainly to control post-weaning diarrhoea in piglets.

The use of high copper in swine and poultry nutrition has caused accidental copper poisoning in more sensitive animals, such as sheep grazing on pasture

Elinor McCartney, Pen & Tec Consulting: "The EU is concerned about adverse environmental and health effects of excess supplementation with trace minerals, especially Cu and Zn."

fertilised with pig or poultry manure. The widespread application of veterinary preparations to supply up to 3,000 ppm Zn in weaned piglet feeds is viewed with concern by consumers, environmentalists, scientists and legislators.

Environmental concerns arising during the 1980s and 1990s, resulted in a scientific review and general reduction in permitted feed concentrations of several trace metals in 2003 (Co, Cu, Fe, Mn and Zn). The EU SCAN (Scientific Committee on Animal Nutrition) concluded that Cu was only useful as a growth promoter in piglets up to a maximum of 175 ppm and that the reported performance enhancing effects of Zn were an indirect effect of control of post-weaning diarrhoea.

In summary, despite commercial trends towards higher feed inclusion rates of essential trace elements, the legislative response is likely to limit supplementation in most cases to strictly nutritional requirements.

Contamination risk

Inorganic minerals are derived mainly from mining operations or heavy industries and are subjected to minimum further processing prior to entering the food chain, generally as part of vitamin and mineral premixtures for animal feeds. Inorganic minerals are frequently contaminated with undesirable substances such as heavy metals (arsenic, cadmium and lead) or dioxins/PCBs (*Figure 1*). Such contamination may not be detected until the inorganic mineral is incorporated into premixtures, mineral feeds or complete feeds for animals and then picked up by the EU's RASFF (Rapid Alert System for Food and Feed). Since RASFF was extended to feeds in 2002, detection of such contaminants in inorganic minerals, usually of Chinese origin, has resulted in several costly product recalls.

Cadmium in Chinese Zn sulphate, imported via France in 2004, caused contamination of 4,000 French and Belgian farms and resulted in the blocking of many feed businesses. Control measures included the condemnation of livers and kidneys from affected food animals at slaughter.

A similar incident in Norway in 2005 was estimated to cost €10-12 million and resulted in criminal prosecution and financial penalties. In both cases, food chain operators had failed to take adequate precautions, particularly with respect to testing raw materials and quality control. In several such situations the problems were compounded by late detection and associated with dubious practices in relation to importation and certification of the inorganic minerals involved.

On the other hand, when inorganic minerals are used as raw materials to produce chelates, manufacturers generally introduce additional quality control procedures and audit suppliers carefully. The reasons for the extra quality control procedures are that chelates are value-added, high technology branded products, so producers want to protect their investment and their brand from the problems and costs associated with undesirable substances entering the manufacturing process. The extra care on chelates provides additional security to users.

Animal health

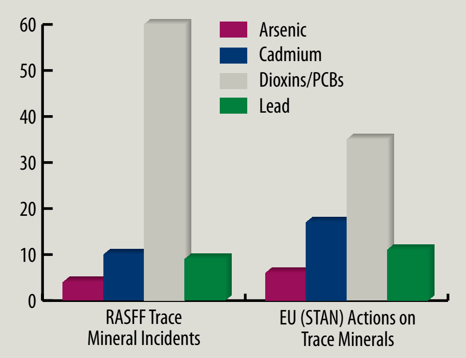
The basic advantage of true organic minerals is improved bioavailability. This is most clearly shown with organic Se from yeast, since the yeast transforms inorganic Se to organic seleni-

Table 1. Approved forms & maximum permitted concentrations of trace elements used as feed additives in the EU (January 2008).

Trace element	Approved forms	Maximum (ppm in feed)
Cobalt	Inorganic salts (Co carbonate, Co chloride, Co nitrate, Co sulphate)	2[a]
	Organic salts (Co acetate)	
Copper	Inorganic salts (Cu carbonate, Cu chloride, Cu oxide, Cu sulphate)	Piglets – 170[b]
	Organic salts & chelates (Cu acetate; Cu chelates of methionine, glycine or soy-derived amino acids)	Pigs – 25[b]
Iron	Inorganic (Fe carbonate, Fe chloride, Fe oxide, Fe sulphate)	Suckling piglets – 250 mg/day[c]
	Organic salts & chelates (Fe citrate, Fe lactate, Fe fumarate; Fe chelates of glycine or soy-derived amino acids)	Piglets & pigs – 750[c]
Iodine	Inorganic salts (calcium iodate, potassium iodide, sodium iodide)	10
Manganese	Inorganic salts (Mn carbonate, Mn chloride, Mn oxide, Mn hydrogen phosphate, Mn sulphate)	150[d]
	Organic chelates (Mn chelates of glycine or soy-derived amino acids)	
Molybdenum	Inorganic salts (ammonium molybdate, sodium molybdate)	2.5
Selenium	Inorganic salts (sodium selenite, sodium selenate)	0.5
	Selenium yeast (*Saccharomyces cerevisiae* CNCM I-3060)[f]	
	Selenium yeast (*Saccharomyces cerevisiae* NCYC R397)[g]	
Zinc	Inorganic (Zn carbonate, Zn chloride, Zn oxide, Zn sulphate)	150[e]
	Organic salts & chelates (Zn acetate, Zn lactate; Zn chelates of glycine or soy-derived amino acids)	

Notes:
[a] – Cobalt reduced in 2003 from 10 ppm.
[b] – Copper reduced in 2003 from 175 ppm in piglets, 100 ppm in pigs to six months (low-density populations), & 35 ppm in other pigs.
[c] – Iron reduced in 2003 from 1,250 ppm.
[d] – Manganese reduced in 2003 from 250 ppm.
[e] – Zinc reduced in 2003 from 250 ppm.
[f] – Available as Sel-Plex®
[g] – Available as Alkosel®

Figure 1. Detection of organic minerals in feed. RASFF/EU Summary 2002-2007.



um, mainly selenomethionine, which is absorbed and stored in pig tissue proteins. The improved selenium status of pig herds supplemented with Se yeast is exhibited as improved piglet viability, health and growth, as well as better meat quality (reduced drip loss, richer colour, and improved 'freshness').

True chelates of Cu, Fe, Mn and Zn offer benefits at lower supplementation rates than inorganic minerals and have the additional advantage of reduced interference with gut absorptive functions. Researchers around the world have indicated that using organic minerals in pig production leads to improved performance, notably a higher number of piglets born and weaned per sow per year and enhanced sow longevity. Some of the benefits observed are thought to be related to better maintenance of body mineral reserves in the sow.

False chelates

There are several reports in the literature of false chelates and fraudulent Se yeasts. Buyers should be suspicious of so-called Se 'chelates' or 'complexes', since the most economical true organic Se in animal nutrition comes from Se yeast. Similarly, chelates of Cu, Fe, Mn and Zn can be faked, by mixing inorganic minerals with amino acids or soybean derivatives. In the past it has been difficult for buyers to confirm the quality of purchased organic minerals, mainly due to difficulties with analytical methods. The easiest solution is to buy from a reputable supplier and exercise caution when offered an improbable product at a 'bargain' price.

Future trends

The future of trace element nutrition looks organic. The first EU Se yeast feed additive application (Sel-Plex® from Alltech, based on a specific strain of *Saccharomyces cervevisiae* CNCM I-3060) was approved in November 2006. New trace mineral products under evaluation by EFSA include chelates of Cu, Mn and Zn linked to the hydroxy analogue of methionine (HMTBa), polysaccharide 'complexes' of Cu, Fe, Mn, and Zn, and a chromium-methionine 'complex'. Whereas it is uncertain whether the EU will accept chromium as an essential trace mineral requiring supplementation, the EU approval process, which evaluates safety, quality and efficacy of each feed additive submitted, offers further confidence to buyers of approved products.

Improved user experience with organic minerals, more sophisticated quality control procedures and published, independently-validated analytical methods – a requirement of all approved feed additives in the EU – will help users select the appropriate organic minerals for their business.

Further research and innovation in trace element products may help to bridge the gap between the restrictions imposed by regulators on feed content of key minerals, and pig producers' objectives to maximise animal performance, health and longevity.

The following articles in this series will provide updates on chelate technology and will illustrate the benefits of chelated minerals in relation to pig performance and product quality. **PP**

References available on request

Setting the NRC standards for minerals

It is important to understand the process of how nutrient requirements for pigs are estimated, in order to appreciate the fact that they are the best estimates of nutrient needs at the time of publication. Requirements will obviously change as genetic improvements are made and as more research becomes available, clarifying the animal's nutrient needs under different conditions.

By Gary L. Cromwell, University of Kentucky and Charlotte Kirk Baer, Board on Agriculture and Natural Resources, National Research Council

Deficiencies of even a single nutrient in pig diets can limit the animal's performance and well being. (Photos courtesy of Linda Chant)

Energy and essential nutrients such as amino acids, minerals, and vitamins are required by animals for the various processes of life, including maintenance, growth, reproduction, lactation, and work. Having accurate estimates of dietary nutrient requirements of animals is important. Deficiencies of even a single nutrient in a diet will limit an animal's performance and well being, and diets with excessive nutrients are expensive and contribute to environmental pollution.

The National Research Council (NRC) plays an important role in establishing nutrient requirements for animals (see box 'Background of the National Research Council' on page 8). Whether the nutrient requirements are accurate or not is often a subject of debate among nutritionists in academia and the feed industry.

Gary Cromwell: "The NRC plays an important role in establishing nutrient requirements for animals."

A new approach to estimating

Several subcommittees have used a modelling approach to precisely estimate nutrient requirements. Models (a series of integrated mathematical equations) were needed for the new edition to account for the many factors that are now known to influence nutrient requirements.

A growth model was needed that would more accurately estimate nutrient requirements taking into consideration not only the pig's body weight, but also its accretion rate of lean (protein) tissue, gender, and various environmental factors. Gestating and lactating sow models were needed that would, along with body weight, consider weight gain during gestation, weight loss during lactation, number of pigs in the litter, weight gain of the litter (a reflection of milk yield), and certain environmental factors.

Three independent models were developed: a growth model, a gestation model, and a lactation model. The growth model estimates amino acid requirements of pigs from weaning to market weight, and the gestation and lactation models estimate energy and amino acid requirements of gestating and lactating sows. Along with energy and amino acid requirements, the software also allows the user to estimate mineral and vitamin requirements.

Estimating mineral requirements

The subcommittee did not use a modelling approach to estimate the mineral requirements due mainly to the fact that it was felt that there was not sufficient data available in the literature to develop an accurate model.

As a result, all of the estimates were based on empirical data from research studies. Estimates were made for six weight classes of pigs (*Table 1*) and for sows during gestation and lactation (*Table 2*). In every case, the estimates were made on the basis of dietary concentration of minerals.

The daily requirements were determined by multiplying the dietary concentration by the daily amount of feed consumed. Feed consumption, in turn, was estimated from the model-predicted energy consumption divided by the energy concentration of the diet.

Very little information is available as to what are the main mineral requirements for pigs.

Table 1. Mineral requirements of weanling, growing, and finishing pigs allowed feed *ad libitum* (90% dry matter)[b] NRC (1998).

Bodyweight, kg						
Item	**3-5**	**5-10**	**10-20**	**20-50**	**50-80**	**80-120**
Average weight in range, kg	4	7.5	15	35	65	100
Estimated DE intake, kcal/kg	855	1,690	3,400	6,305	8,760	10,450
Estimated feed intake, g/day[c]	250	500	1,000	1,855	2,575	3,075
Requirements of major minerals (%)						
Calcium[d]	0.90	0.80	0.70	0.60	0.50	0.45
Phosphorus[d]	0.70	0.65	0.60	0.50	0.45	0.40
Phosphorus, available[d]	0.55	0.40	0.32	0.23	0.19	0.15
Sodium	0.25	0.20	0.15	0.10	0.10	0.10
Chlorine	0.25	0.20	0.15	0.08	0.08	0.08
Magnesium	0.04	0.04	0.04	0.04	0.04	0.04
Potassium	0.30	0.28	0.26	0.23	0.19	0.17
Requirements of trace minerals[e] (ppm)						
Copper	6.0	6.0	5.0	4.0	3.5	3.0
Iodine	0.14	0.14	0.14	0.14	0.14	0.14
Iron	100	100	80	60	50	40
Manganese	4.0	4.0	3.0	2.0	2.0	2.0
Selenium	0.30	0.30	0.25	0.15	0.15	0.15
Zinc	100	100	80	60	50	50

[b] Pigs of mixed gender (1:1 ratio of barrows to gilts). The requirements of certain minerals may be slightly higher for pigs having high lean growth rates (>325 g/day of carcass fat-free lean), but no distinction is made.

[c] Assumes the diet contains 3,400 kcal of DE/kg.

[d] The percentages of calcium, phosphorus, and available phosphorus should be increased by 0.05 to 0.10 percentage points for developing boars and replacement gilts from 50 to 120 kg body weight.

[e] Chromium is recognised as an essential nutrient, but a requirement has not been established.

Modelling mineral requirements

Very little research information is presently available that would allow one to model the requirements for the various minerals such as the NRC swine subcommittee did for amino acids and energy.

Recently, the Swine NRC Committee conducted several studies at the University of Kentucky to generate data that would allow us to model the phosphorus requirements of growing-finishing pigs. Several balance studies were conducted to estimate the maintenance requirements for phosphorus. Another series of experiments were conducted to assess the accretion rates of whole-body phosphorus.

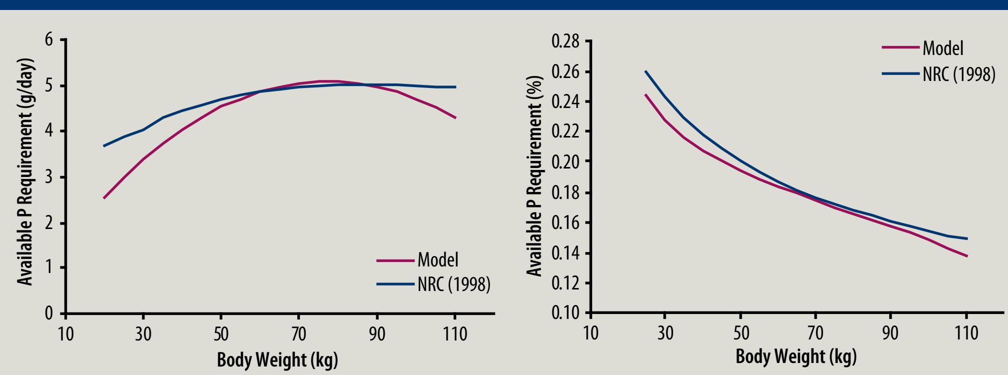
Figure 1 shows the results of these studies. The data indicate that our estimates of the phosphorus requirements, based on the sum of the requirements for maintenance and for deposition of phosphorus in body tissues, were similar to the bioavailable phosphorus requirements of NRC (1998), especially in the mid-weight range.

The two sets of estimates differed some in the lighter- and heavier-weight pigs, in which case the committee's estimates were less than those of NRC (1998). This study was done with a single genotype, and additional work of this type needs to be done with other genotypes of pigs to determine the effects, if any, that lean growth rate or perhaps other factors may influence phosphorus requirements.

Accuracy

In some ways, the question as to whether these figures are accurate is easy to answer as the subcommittee spent many laborious hours to producing an extensive review of the literature. On the other hand, a better answer is that the estimates are only as accurate as the amount and scientific quality of the research data upon which they are based. Unfortunately, for some minerals, requirement studies were scarce or non-existent. In some of those studies, the results may have been confusing and interpretation may have been diffi-

Figure 1. Model-predicted phosphorus requirement (g/day on left, % of diet on right) of pigs from 20 to 110 kg bodyweight.



The model is based on the phosphorus required for maintenance and whole-body phosphorus accretion compared with the available phosphorus requirement of NRC (1998). Pettey *et al.* (2004a; c), University of Kentucky.

Table 2. Mineral requirements of gestating and lactating sows (90% dry matter)[b] NRC (1998).

	Dietary requirements		Daily requirements	
	Gestation	Lactation	Gestation	Lactation
Estimated DE intake, Mcal/kg	6.29	17.85	6.29	17.85
Estimated feed intake, kg/day[c]	1.85	5.25	1.85	5.25
Requirements of major minerals	%		g/day	
Calcium	0.75	0.75	13.9	39.4
Phosphorus	0.60	0.60	11.1	31.5
Phosphorus, available	0.35	0.35	6.5	18.4
Sodium	0.15	0.20	2.8	10.5
Chlorine	0.12	0.16	2.2	8.4
Magnesium	0.04	0.04	0.7	2.1
Potassium	0.20	0.20	3.7	10.5
Requirements of trace minerals[d]	ppm		mg/day	
Copper	5.00	5.00	9.3	26.3
Iodine	0.14	0.14	0.3	0.7
Iron	80	80	148	420
Manganese	20	20	37	105
Selenium	0.15	0.15	0.3	0.8
Zinc	50	50	93	263

[b] The requirements are based on the daily consumption of 1.85 and 5.25 kg of feed for gestation and lactation, respectively. If lower amounts of feed are consumed, the dietary percentages of some minerals, particularly calcium and phosphorus, may need to be increased.

[c] Assumes the diet contains 3.40 Mcal of DE/kg.

[d] Chromium is recognised as an essential nutrient, but a requirement has not been established.

Background of the National Research Council

Contrary to what some people believe, the NRC is not part of the US Federal Government. Instead, the NRC is a private, non-profit organisation with a long history. The NRC was established in 1916 to provide advice to the US Federal Government on issues of science and technology. The first of the nutrient requirement publications, Recommended Nutrient Allowances for Swine and Recommended Nutrient Allowances for Poultry were published in 1944. These were concise documents (the swine publication was ten pages) that identified the nutrients known at that time to be essential for pigs and poultry and that listed dietary requirements for some of these nutrients. The following year, similar publications were released for beef cattle, dairy cattle, and sheep. The first publication of this type for horses was published four years later. Since 1953, NRC requirements have been considered as the minimal dietary concentration of a nutrient required to support normal performance for the most demanding function.

cult. For sows, the data for some minerals were even sparser. In some cases (e.g. iodine), the estimates for sows were based on data from growing pigs.

Things to remember

Some important points that should be remembered as one deliberates an answer for this question are as follows:

- Remember that the NRC requirements are estimates of **minimal nutrient requirements** required to support normal performance. They are simply guidelines that nutritionists in industry and academia can use as a starting point to establish recommended allowances for animals. This is true, not only for minerals, but also for other nutrients.
- In most cases, the requirements are based on the amount of a nutrient that will result in **optimal growth and efficiency** of feed utilisation or **optimal reproductive and lactational performance**. While it is well recognised that higher than NRC levels of calcium and phosphorus will increase bone mineralisation and strength (which may improve long-term productivity), this was not included in the requirement estimates for Ca and P.
- **Animals do change** (genetics, health, etc.), so mineral requirements of pigs 20 years ago may be different from those of pigs today or of pigs 20 years in the future. What was accurate then might not be accurate now.
- Estimates of requirements change as **new data** become available.
- The NRC mineral requirements are based on **dietary concentrations**, not daily amounts of minerals. Daily requirements are calculated amounts based on estimated feed intakes.
- Very high levels of certain minerals such as copper (100-250 ppm copper as copper sulphate or copper chloride) and zinc (1,500-3,000 ppm zinc as zinc oxide) will consistently produce a significant growth response in young pigs, but these responses are considered to be a **pharmaceutical effect** and are not included in the estimates of the copper and zinc requirements.
- The NRC mineral requirements, for the most part, do not take into consideration the **bioavailability** of minerals. The only exception is phosphorus. For other minerals, the estimates are for total mineral levels. It is generally recognised that organic forms of minerals are more bioavailable than inorganic forms, such as Sel-Plex® organic selenium produced by *Saccharomyces cerevisiae* CNCM I-3060 (Alltech) versus sodium selenite. A higher bioavailability of organic forms of several other minerals is also recognised such as Bioplex® organic trace minerals (Alltech).
- Finally, we are recognising more and more that certain minerals have an impact on the **immune function** in animals. Recently, scientists have found that certain trace minerals such as copper, zinc, selenium, and chromium, bolster the immune status in pigs and other animals when fed at high levels and perhaps in a more bioavailable (organic) form. This type of response was recognised but not considered in the establishment of the mineral requirements.

Answers

So, are the NRC mineral requirements really accurate? The answer likely will depend on who is answering the question. While some of the requirements may not be totally accurate, they were established based on the scientific knowledge at the time of publication and the best judgment of a distinguished group of swine nutritionists.

Will some of the requirements change in the next publication? Probably so, because present and future research will generate new information in some areas that will allow the next subcommittee to better estimate the requirements of certain nutrients.

Should the requirements be followed by every nutritionist in every situation? Probably not. They will require adjustment based on the understanding and experience of the nutritionist for the particular situation. PP

The catalyst for sow lifetime performance

Trace mineral nutrition has been a neglected area of pig science and modern hyper-prolific sows have different requirements than those currently recommended. However, it is not just a question of quantity, but very much a question of the source and bio-availability of the mineral.

By Dr William Close, Close Consultancy, Wokingham, UK

Dr Bill Close: "Minerals being in an organic form provide animals with a metabolic advantage that often results in improved performance."

Compared with the requirements for energy and amino acids, those for minerals, and indeed vitamins, are poorly defined despite their importance to overall herd health and productivity. Requirements for minerals are hard to establish and most estimates are based on the minimum level required to overcome a deficiency and not necessarily to optimise productivity, or indeed enhance immunity. It is for this reason that industry levels of inclusion for sows are several times greater than those published requirements (*Table 1*) and recent studies have shown that at these higher levels of minerals, reproductive performance may be impaired (Mahan and Peters, 2006).

Most of the work carried out to establish mineral requirements, and trace minerals in particular, has been carried out pre-1980, and may not therefore be appropriate to the modern hyper-prolific sow. Indeed, for several micro-minerals there is an extreme lack of information. Some estimates for sows do not have a single cited study, or are based on very few studies.

If dietary mineral supply is inadequate, then performance is likely to be affected and there is every possibility that mobilisation from body tissues and skeletal structures will occur to attempt to meet metabolic needs. This has been elegantly demonstrated by the work of Mahan and Newton (1995), which showed that the body mineral content of sows at the end of their third parity was considerably lower than that of non-bred litter sisters of similar age when fed diets of similar mineral content. In addition, the higher the level of productivity, that is litter weaning weight at 21 days of age, the greater the degree of depletion of minerals from the body.

Mineral requirements are based on a per kg of feed basis and take no account of the body weight of the animal, its level of production, changing metabolic needs during both gestation and lactation or indeed parity. Richards (1999) has shown that already in late gestation, the sow has to rely on her liver iron reserves to meet foetal demands and this depletion of minerals from the body is further exacerbated during lactation. This continuous drain on body reserves results in reduced mineral status, as shown by Damgaard Poulsen (1993).

Calculation of the daily mineral intake of a first parity sow with that of a mature sow in its 3rd or 4th parity, shows that there is a reduction in mineral intake of between 15 and 23%, based on a body weight or metabolic body weight basis, respectively (*Table 2*). This may help to explain why the average sow lifetime in many countries is only 3–4 parities instead of the anticipated 5–6 parities.

Table 1. Recent estimates of trace mineral requirements of breeding sows, compared with the levels currently used in practice (mg/kg).

	NRC (1998)	BSAS (2003)	GfE (2006)	Industry*
Mineral				
Iron	80	80	80-90	80-150
Zinc	50	80	50	80-125
Copper	5	6	8-10	6-20
Manganese	20	20	20-25	40-60
Selenium	0.15	0.20-0.25	0.15-0.20	0.2-0.4
Iodine	0.14	0.20	0.6	0.5-1.0

NRC = National Research Council
BSAS = British Society of Animal Science
GfE = German society for nutrition physiology
** Whittemore et al (2002)*

Form follows function

Customarily, inorganic salts - such as sulphates, carbonates, chlorides and oxides - are added to the diet to provide the correct levels to meet the animal's need. These salts are then broken down in the digestive tract to form free ions and are absorbed. However, free ions are very reactive and can form complexes with other dietary molecules which are then difficult to absorb. The availability of the trace mineral to the animal therefore varies considerably - and under extreme conditions may be unavailable for absorption - and so are of little benefit to the animal. Large quantities of undigested minerals are then excreted causing environmental pollution. It is also known that minerals in inorganic form interfere with each other, and excesses of one can result in the reduced absorption of others.

For this reason there is growing interest in organic, that is proteinated or

Table 2. Trace mineral intake in relation to body weight and parity.

	Recom-mended[1]	Parity 1 (160 kg) intake[2]			Parity 3+ (240 kg) intake[3]			Difference[4]	
	per kg diet	mg/day	mg/kg BW	mg/kg0.75	mg/day	mg/kg BW	mg/kg0.75	(1)	(2)
Fe (mg)	100	272	1.70	6.04	312	1.30	5.11	23	15
Zn (mg)	100	272	1.70	6.04	312	1.30	5.11	23	15
Cu (mg)	15	41	0.25	0.91	47	0.19	0.77	23	15
Mn (mg)	40	108	0.68	2.40	125	0.52	2.05	23	15
Se (mg)	0.25	0.68	0.0043	0.015	0.78	0.0033	0.0125	23	16

[1] BPEX: 2004

[2] Feed 2.3 kg/day in gestation and 5.0 kg/day over a 21 day lactation

[3] Feed 2.6 kg/day in gestation and 6.0 kg/day over a 21 day lactation

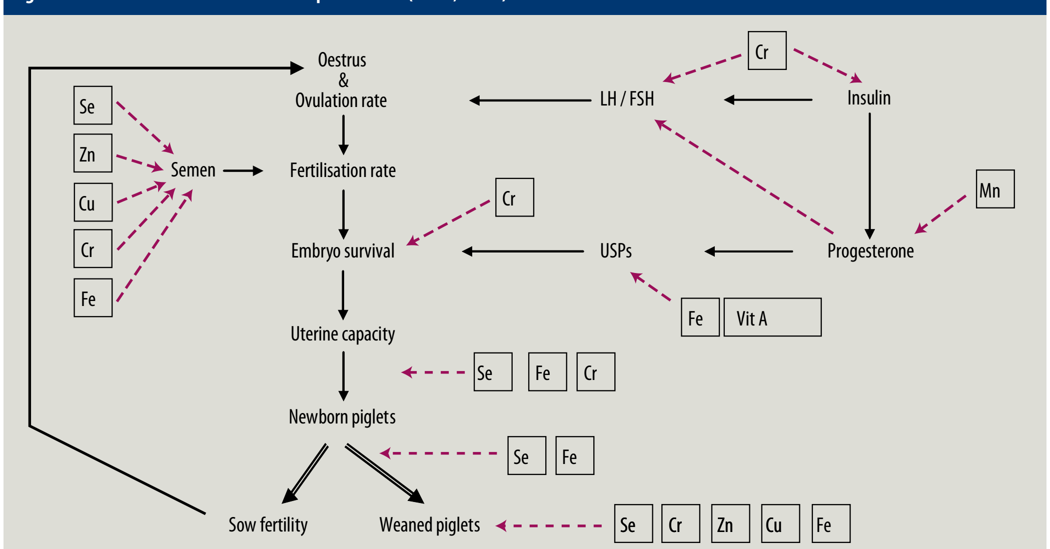
[4] (1) per kg BW (2) per kg0.75

Table 3. Organic Fe: Effects on sow and piglet performance (Close and Taylor-Pickard, 2005).

Study/Country	Sow feed intake (kg/day)	Piglet weaning weight (kg)	Piglet mortality (%)	% small piglets	% heavy piglets
Ireland	4.69 → 4.84	7.86 → 8.15	-	-	-
UK (1)	-	-	11.0 → 9.5	13 → 5	55 → 65
UK (2)	-	6.47 → 7.04	-	-	-
Australia	-	6.24 → 6.51	-	21 → 6	34 → 41
Vietnam	4.76 → 4.86	4.72 → 4.93	13.0 → 8.4	-	-
Chile (90 ppm Fe)	-	5.84 → 6.06	9.6 → 5.0	24 → 17	46 → 50
Chile (150 ppm Fe)	-	5.84 → 6.49	9.6 → 4.4	24 → 9	46 → 65
USA	4.59 → 4.66	6.22 → 6.22	23.1 → 13.4*	-	-

*includes stillborn piglets; figures at the left-hand side of each column relate to inorganic mineral treatments; figures at the right-hand side of each column relate to organic mineral treatments.

Figure 1. The role of minerals in sow reproduction (Close, 1999).



chelated minerals. In this form, the trace elements are chemically bound to a chelating agent or ligand, usually a mixture of amino acids or small peptides. This makes them more bio-available and bioactive and provides the animal with a metabolic advantage that often results in improved performance.

The response to organic iron, or a combination of organic trace minerals, will serve well to illustrate the effects that organic minerals have on sow productivity.

Improving sow mineral status

The piglet is born with limited iron reserves and needs supplemental iron after birth to prevent anaemia. Uteroferrin, an iron-binding protein, is the major mechanism by which the transfer of iron from the sow to the developing foetus occurs (Roberts *et al*, 1986).

However, increased dietary inorganic iron has minimal effect on foetal iron uptake by the uteroferrin pathway. In contrast, organic iron has been shown to increase iron transfer across the placenta to the developing foetus (Ashmead and Graff, 1982).

A series of commercial trials were therefore carried out in which sows were fed either a control diet containing 60-80 mg/kg inorganic iron or a test diet providing an additional 90 mg Fe/kg from an organic source (Bioplex® Iron, Alltech). The organic Fe was provided some 2-3 weeks before farrowing and throughout the 16-28 day lactation period.

The results showed that there was no difference in feed intake during lactation or the birth weight of the piglets. However, across all trials, the weaning weight of the piglets was increased from 6.17 (± 0.9) to 6.48 (± 0.9) kg (*Table 3*). Mortality of suckling piglets was reduced from 10.8% (range 9.6-13.0) to 6.8% (range 4.4-9.5). There was also a reduction in the proportion of lightweight piglets at weaning from 25.5 to 9.2% and an increase in the proportion of heavy-weight piglets from 45.2 to 55.3% (*Table 3*).

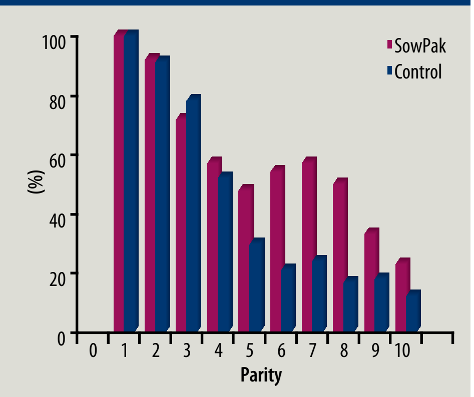
These results suggest that piglets from sows fed additional organic Fe had an improved neo-natal Fe status, possibly through an increased placental transfer of uteroferrin. This makes for a more active and stronger piglet at birth, with greater viability and suckling stimulus.

It is hypothesised that colostrum and milk intake is increased, resulting in reduced pre-weaning mortality and enhanced growth rate. Weaning weight is therefore increased and this has a lasting effect on subsequent growth rate and development of the pig through to slaughter.

Sow longevity and trace minerals

Different trace minerals impact at dif-

Figure 2. The proportion of sows in trial.



ferent periods of the reproductive life of the sow and it is likely that the greatest impact on sow productivity will be from combinations of minerals (*Figure 1*).

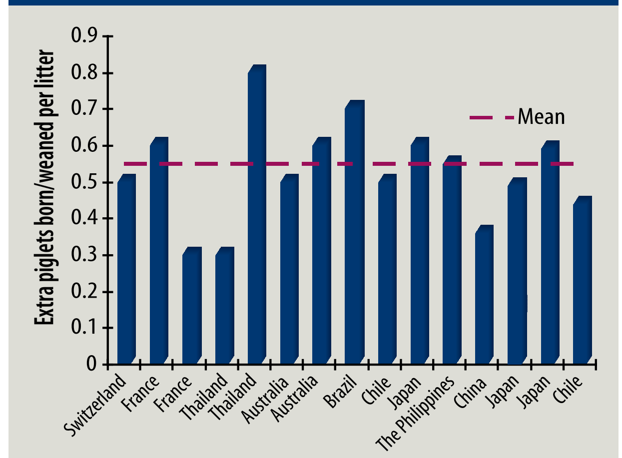
With this in mind, Fehse and Close (2000) supplemented the diet of sows with a special combination of organic minerals (Bioplex® Sow-Pak: Se, Fe, Zn, Cu, Mn and Cr, Alltech) and reported an extra 0.5 piglets weaned per litter for sows weaning 26.5 piglets per sow per year.

Sow longevity was also increased as illustrated in *Figure 2*. The proportion of the sows fed this supplement was maintained at 50-57% through parities 4 to 8, relative to 100% in parity 1, whereas for the control sows, it decreased from 52% in parity 4 to approximately 20% in parity 6.

Since this original trial, a number of commercial and field trials have been conducted in which the supplement (with or without Cr) partially replaced or was added on top of the standard inorganic mineral supplement in the diet of the sow during gestation and lactation. Performance was measured over a single or multiple parities for sows of different breeds in several countries throughout the world (*Figure 3*).

Supplementation of the diet with this product increased the number of piglets weaned by 0.55 ±0.14 (n=15), with the response varying between 0.3 and 0.8 extra piglets per litter. Assuming 2.3 litters per sow per year this equates to an extra 1.2 weaned piglets per sow per year. It was interesting to observe that the size of the litter had no effect on the number of additional piglets weaned. The response was very cost-effective with a calculated return on investment value of 4.5:1.

Figure 3. Effect of Bioplex® Sow-Pak on litter size (Close, 2008).



In short, organic minerals may play an increasing role in sow reproduction, since they have been shown to increase sow productivity, not only in terms of piglets weaned per litter, but also in prolonging lifetime performance. Ongoing research will better define the optimum organic mineral provision to meet the metabolic needs of the modern hyperprolific sow. **PP**

A balancing act: mineral requiremen

As pig barns have become larger and amassed several thousands of pigs per operation, there is a growing concern about the millions of tonnes of waste effluent from nitrogen, phosphorus, potassium, and high trace mineral concentrations that are produced each year. Requests to the swine industry are increasing to take responsible action in order to reduce this source of pollution.

By Bruce Mullan, senior research scientist, Department of Agriculture and Food, Western Australia and David Henman, innovations manager, QAF Meat Industries, Australia

The solution to this complex problem might start with formulating pig diets from a different and pro-active approach. Rather than use the traditional method of formulating pig diets to achieve maximum growth rates at minimal cost, with little attention as to what the majority of the animals excrete; the concept of 'environmental nutrition' gains respect. Its central idea focuses upon what the animals' true nutrients for performance are and increases feed efficiency by improving how these essential nutrients are metabolised in the animal's body, with the net result of minimising respective nutrient excretion.

Replacing inorganic trace minerals with corresponding organic minerals in pig diets is a good example of environmental nutrition. Less organic minerals can maintain or even improve pig performance with significant lower dietary levels and because they are more efficiently utilised by animals, reduce mineral output.

To understand this new process of balancing pig diets with minimum trace mineral concentrations and yet achieving acceptable performance, reproduction, desirable carcass quality and with minimum waste of dietary minerals, it is good to review how mineral requirements for pigs were first discovered: namely feed enough of a particular trace mineral in the diet until all related mineral deficiency symptoms cease.

Dietary zinc

That was the general scientific thinking back in 1955, when Tucker and Salmon discovered that parakeratosis, a common disease in pigs at the time, characterised by specific skin lesions, retarded growth and poor feed utilisation, was due to inadequate dietary zinc. Their findings also showed the disease appeared when diets had exces-

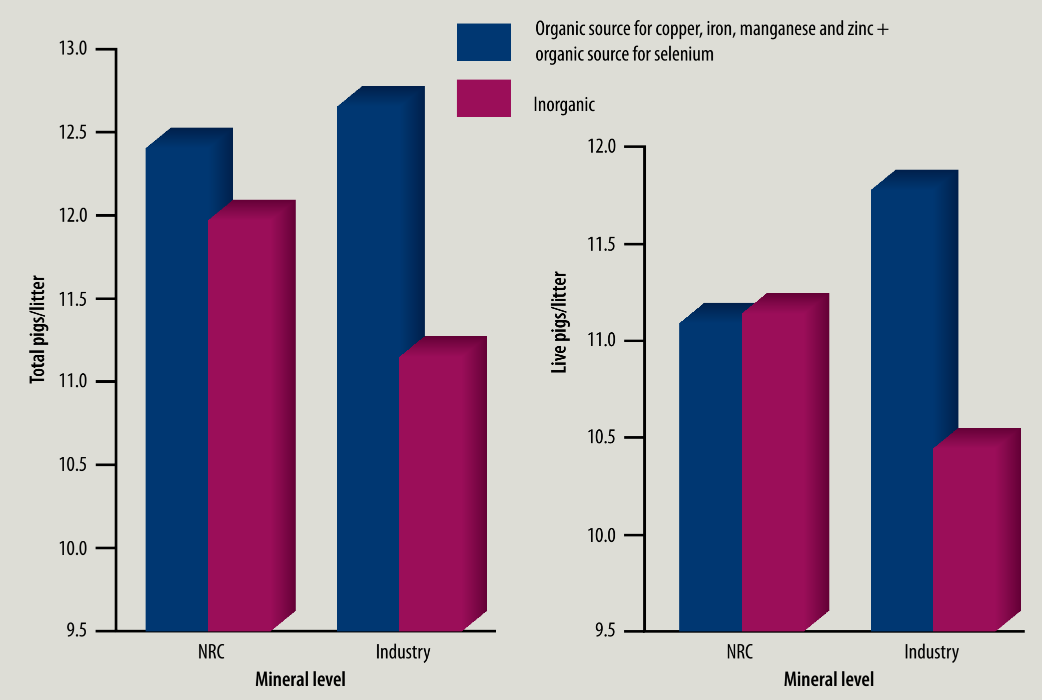
ts versus environmental pollution

Table 1. NRC (1998) mineral levels (ppm) and those recommended by industry and university nutritionists for the breeding sow.

Mineral	NRC (1998)	Industry and university[1]
Copper	5	10-20
Iodine	0.14	0.15-0.20
Iron	80	100-200
Manganese	20	40-80
Selenium	0.15	0.2-0.5
Zinc	50	100-150

[1]Mahan, 1995

Figure 1. Reproductive performance of sows over six parities.



sive calcium levels and in the presence of high phytate levels. The latter elements were thought to reduce zinc bioavailability, and thus precipitate a secondary zinc deficiency. Both conditions were prevented when 'enough' dietary zinc was added to the pig's diet.

Since then, researchers have learned much about trace mineral nutrition and recommend that we should acknowledge a variety of factors in determining the absolute mineral requirements of pigs as well as identifying any interactions amongst nutrients and other elements. Consequently, many present pig diets may have become over-formulated with higher trace mineral concentrations compared to those set forth by the National Research Council (NRC). The general conscience in the pig nutrition community is that higher than required trace mineral levels in swine diets accounts for such mitigating factors and also such mineral requirements need to be adjusted upward for the advancements in pig performance achieved over the last 50 years. This point is illustrated in *Table 1* (Mahan, 1995) which compares NRC (1998) trace mineral requirements for breeding sows and those mineral levels commonly used as swine industry standards.

Mineral levels

In a following study conducted by Peters and Mahan (2004), the same NRC (1998) mineral levels and those of industry were fed to sows over six parities utilising both inorganic and organic sources for copper, iron, manganese, zinc (Bioplex®, Alltech) and selenium (Sel-Plex® organic selenium produced by *Saccharomyces cerevisiae* CNCM I-3060, Alltech). They recorded that organic minerals produced approximately one more piglet born per litter when both NRC and recommended higher industrial levels of both sources were fed. Interestingly, the best performance from inorganic minerals was seen with the lower NRC recommendations, suggesting that the higher inorganic levels typically used by the industry are actually having a negative impact on breeding performance. The results of this study are illustrated in *Figure 1*.

This research study proves that organic trace minerals as mentioned can meet the higher mineral requirements of breeding sows and even illicit a positive response over inorganic trace minerals. If one links this favourable data with the understanding (Power, 2003) of the mechanisms that defines organic trace minerals' greater bioavailability, then the next logical step can be taken: we should be able to replace inorganic minerals at corresponding lower levels without a loss of performance. In turn, we reduce the amount of minerals to the pig diet, and it would make common sense that we reduce the level of minerals in the waste effluent. Thus a smaller environmental footprint is made when raising pigs in any capacity.

Reduced amounts of copper

Henman (2001) developed on this concept and revealed in a progression of experiments that copper, a major trace mineral formulated in pig diets, both as a nutrient and for its non-antibiotic growth promotion properties can be reduced in pig waste effluent by utilising an organic source for copper.

In the first experiment cited: two levels of copper sulphate (20 ppm and 220 ppm) or organic copper (100 ppm) were fed in grower-finisher diets to male pigs from 28 kg to slaughter. The performance data showed that the

Table 2. Faecal copper content of growing pigs fed diets containing different levels and sources of copper.

Copper level/source	Faecal copper content (ppm)	
	Males	Females
Basal diet (B)	159	187
B + 160 ppm $CuSO_4$	373	372
B + 50 ppm organic copper	198	200

Source: Henman, 2001

Table 3. Performance of male and female pigs from 10-23 weeks of age fed diets containing commercial levels of inorganic or organic minerals or a diet containing 25% of the commercial levels.

	Commercial mineral levels		25% levels	SED	P values		
	Inorganic	Organic	Organic		Trt	Sex	Trt x Sex
Start weight, kg	26.7	26.8	26.7	0.130	0.980	0.042	0.995
Final weight, kg	94.2	92.4	93.2	0.479	0.641	0.000	0.979
Daily gain, g	0.752	0.729	0.740	0.005	0.502	0.000	0.963
FCR	2.42	2.48	2.42	0.017	0.448	0.000	0.942
Feed intake, g/day	1.817	1.807	1.790	0.010	0.771	0.919	0.829

addition of copper sulphate or organic copper improved growth rates by 5% and feed conversion by 3%. There was no significant difference in performance between diets containing organic copper and the higher level of copper sulphate, as well as no differences in carcass characteristics (re: weight, P2 fat thickness, and dressing percentages), although the organic copper fed pigs were numerically superior. The researchers said that their results only confirmed that alternative forms of copper can be utilised to maintain performance whilst minimising copper excretion.

In a similar second experiment, organic copper was shown to reduce the amount of copper excreted by pigs. This time, a basal diet was set up, followed by the addition of 160 ppm Cu (copper sulphate) or 50 ppm organic copper). *Table 2* shows, there was an approximate 47% reduction in the fecal copper content excreted by both male and female groups fed the diets containing organic sources of copper.

It was concluded that the reduction in these final copper effluent levels indicates that organic minerals can be added at much lower dietary levels than inorganic copper without adversely affect growth parameters, but can significantly decrease trace mineral excretion. There was also some speculation that further study could record similar results with other trace minerals commonly formulated in pig rations.

Replacements

The results in these latter two experiments and the former sow trial, clearly lays the pathway in which other inorganic trace minerals can be replaced by their organic counterparts. With this confidence, Henman and co-workers designed a new experiment in which 600 ten week-old grower pigs were selected, segregated, and fed three different trace mineral treatments over a 13-week period. Faecal samples were collected during the seventh week of the experiment and analysed for specific trace minerals formulated (with the exception of selenium) in the treatment diets.

All dietary treatments contained selenium, copper, iron, manganese, and zinc supplements but differed in their inclusion and/or mineral source. The treatments were set up as follows: (I) inorganic minerals at industry levels, (II) organic minerals at industry levels, and (III) organic minerals at 25% of commercial levels formulated in treatments (I) and (II). The remainder of the diet was a typical grower-finisher diet fed to commercial pigs.

As *Table 3* illustrates, pig growth parameters, namely daily gain and feed efficiency were not affected by treatment. The researchers are quick to point out that when organic mineral levels were fed at just 25%, pig performance matched inorganic and organic mineral treatments fed at higher industrial levels. Of most interest, the 25% organic mineral diet yielded significant reductions in all trace minerals excretion levels over the inorganic mineral treatment: Cu – 50%, Fe – 25%, Mn – 21%, and Zn – 52%.

Lower use

It was concluded that organic minerals can successfully replace inorganic trace minerals at significantly lower use without a loss of pig performance. The opportunity to use this technology to meet environmental targets prevalent in the Australian pig industry is both practical and economical.

As the above research demonstrates, trace minerals must be added to diets in order to meet specific requirements of pigs. They must be fed at specific levels and have a certain degree of bioavailability in which the animal can efficiently metabolise them in their bodies in order to maintain health and productivity. Formulating pig diets with these parameters in mind should be relatively straightforward.

However, many pig diets have significantly higher trace mineral concentrations compared to those outlined by the NRC. Many nutritionists formulate with an additional ‘insurance factor’ in the hope that all the pigs’ trace mineral requirements are met. Unfortunately, this supplementation practice fails to meet the animals’ requirements due to trace mineral antagonisms and mineral precipitation in the small intestine. Also, because higher amounts of minerals are supplemented, increased concentrations of trace minerals are excreted in the manure.

In summary, implementing environmental nutrition procedures; such as replacing these inorganic trace minerals with corresponding organic minerals is a better method for formulating pig diets. It is a plausible solution to our current environmental concerns:

- Organic minerals can meet pig trace mineral requirements at levels significantly lower than current industry standards
- Such application will not only maintain performance, but has been shown to enhance performance in both sow and grower-finisher pigs.
- Organic minerals can be used as a sole trace mineral source to significantly reduce the levels fed, and thus directly result in significant reductions in trace minerals excreted in the manure. **PP**

The big three issues from weaning to slaug

As opposed to using inorganic minerals, the inclusion of organic minerals in pig and sow diets brings productive and environmental advantages to all stages of production. Performance is maintained and net margin is increased because of better nutrient utilisation.

By W.H. Close, Close Consultancy, Wokingham, UK and James L. Pierce, Nutrition Research Coordinator, Alltech, Lexington, KY, USA

It is rather difficult to define the term 'requirement for minerals' for pigs in the same way as it is for energy, protein and amino acids. Requirements for minerals are hard to establish and most estimates are based on the minimum levels needed to overcome a deficiency and not necessarily to promote productivity, or indeed to enhance immunity and health. It is for this reason that diets are formulated with an additional 'insurance factor', in the hope that all trace mineral requirements are met, regardless of circumstances.

However, higher levels of minerals do not necessarily meet the animal's needs, especially if provided in inorganic form; interactions and antagonisms between trace minerals, as well as minerals precipitation in the small intestine leads to reduced absorption. Higher amounts are excreted, leading to environmental pollution. Indeed, the importance of organic minerals in enhancing sow productivity has been presented in a previous article in this series (*Pig Progress* 24, 2-4). The mineral status of the sow is higher at both farrowing and at weaning and this positively affects the mineral status of the piglet and its quality and subsequent performance. When designing diets for the modern pig one needs to consider not only the level of mineral in the diet to meet production objectives, but also minimising the excretion of excessive minerals into the environment.

Table 1. Comparison of the performance of weaned and grow-finish pigs fed $CuSO_4$ or organic copper.

Source	Body weight (kg)	$CuSO_4$ (ppm)		Organic copper (ppm)			
Close (1998)	**10-30**	**160**		**100***			
	Growth rate (g/d)	592		656			
	Feed:Gain (g/g)	2.15		2.04			
Smits & Henman (2000)	**28-63**	**150**		**50**			
	Growth rate (g/d)	773		744			
	Feed:Gain (g/g)	2.24		2.26			
	Faecal Cu (mg/kg DM)	372		199			
Smits & Henman (2000)	**30-60**	**150**		**40**			
	Growth rate (g/d)	957		942			
	Feed:Gain (g/g)	2.05		2.08			
	Faecal Cu (mg/kg DM)	853		275			
Smits & Henman (2000)	**60-79**	**150**		**40**			
	Growth rate (g/d)	871		836			
	Feed:Gain (g/g)	2.98		3.02			
	Faecal Cu (mg/kg DM)	776		199			
Henman (2001)	**28-95**	**200**		**100**			
	Growth rate (g/d)	731		766			
	Feed:Gain (g/g)	2.44		2.43			
	P2 (mm)	9.6		9.7			
Wu *et al.* (2001)	**11-27**	**250**		**50**	**100**		
	Growth rate (g/d)	562		518	565		
	Feed:Gain (g/g)	1.69		1.78	1.77		
	Faecal Cu (mg/kg DM)	325		73	124		
Fremaut (2003)	**24-105**	**20**	**40**	**7**	**20**	**40**	
	Growth rate (g/d)	694	721	727	710	712	
	Feed:Gain (g/g)	2.78	2.75	2.84	2.85	2.94	
	Lean (%)	58.3	58.6	57.7	58.1	58.0	
Veum *et al.* (2004)	**6-16**	**250**		**25**	**50**	**100**	**200**
	Growth rate (g/d)	382		409	425	419	391
	Feed:Gain (g/g)	1.46		1.47	1.43	1.44	1.45

* additionally contained 60 mg Cu from $CuSO_4$

Minerals in the diet of the modern pig must therefore meet the following objectives:

- They must meet the needs of the animal to optimise productivity and enhance health
- They must be highly available and efficiently absorbed
- They must not interact with other minerals
- They must provide the animal with a metabolic advantage
- They must not cause environmental pollution and therefore must be included in the diets at the lowest possible levels without jeopardising the above objectives.

It is for these reasons that there is considerable interest in the inclusion of organic minerals in the diet of the sensitive, highly productive pig. In this form the trace minerals are chemically bound to a chelating agent or ligand, usually a mixture of amino acids or small peptides. The response to organic minerals is illustrated by considering Copper (Cu) and Zinc (Zn) in the diet of the piglet post-weaning and in the growing-finishing period, as well as the response to a combination of organic minerals and their effects on productivity.

ghter: production, health and environment

In order to make pigs grow optimally and with respect for the environment, minerals supplied have to meet a series of production objectives.

Response to copper

Although the requirements for copper to prevent a deficiency may only be 5–10 mg/kg, much higher quantities are added to the diet of the weaner and grow-finish pig because of its growth-promoting effects. In many countries it has been customary to add copper – and copper sulphate ($CuSO_4$) in particular – at 100–250 mg/kg as a growth enhancer. Large quantities of Cu are excreted in faeces and urine. There is therefore a strong case for evaluating the use of organic forms of Cu, as well as Zn, as replacements for inorganic forms.

A summary of several studies in which organic Cu (Bioplex®, Alltech) was compared to $CuSO_4$ is presented in *Table 1*. For the weaned piglet providing 50-100 ppm Cu from organic Cu gave similar or better performance than 160-250 ppm Cu from $CuSO_4$. Similarly, in studies with the grow-finish pig, growth performance at 40–100 ppm Cu from organic Cu was comparable with that of pigs fed 150–200 ppm Cu from $CuSO_4$.

A major consequence of providing organic copper at lower levels is the considerable reduction in faecal Cu excretion. In the studies of Smits and Henman (2000) and Wu and others (2001), there was a 3- to 4-fold reduction in faecal Cu excretion. In the studies of Veum and others (2004), 50 ppm Cu in the form of organic Cu decreased Cu excretion by 77% compared with feeding 250 ppm Cu as $CuSO_4$ for growth promotion. Thus the efficiency of Cu absorption from organic Cu was significantly higher compared with $CuSO_4$. The high level of $CuSO_4$ also influenced the absorption rate of Zn. At 50 and 100 ppm Cu from the organic source, the absorption of Zn was 19.6 and 18.5%, respectively, compared with only 12.5% when 250 ppm Cu from $CuSO_4$ was provided.

In the studies of Fremaut (2003), similar levels of growth were achieved when 7 ppm Cu from organic Cu replaced 40 ppm Cu from $CuSO_4$ in the diet. Over the grower - finisher period, this reduced total Cu excretion from 4.7 g to 1.5 g/pig. For a 500-sow unit selling 24 pigs per sow per year this resulted in an annual reduction of Cu excretion of 38.4 kg. In many countries the reduction is likely to be greater than this, since levels higher than 40 ppm Cu from $CuSO_4$ are commonly used.

Response to zinc

The Zn requirements of pigs have been established as 50-100 mg Zn/kg for all classes of pigs. However, higher levels of Zn, and zinc oxide (ZnO) in particular, are added to piglet diets to enhance growth and to prevent scouring and diarrhoea in the sensitive post-weaning period. Thus it is common in many countries to add 2-3 kg ZnO/tonne feed. On the other hand there is concern about the long-term feeding of ZnO to piglets and its environmental impact.

ZnO is poorly absorbed and large quantities are excreted, leading to environmental pollution. Meyer and others (2002) reported that 80% of Zn was excreted by piglets when 3000 ppm Zn from ZnO was provided in their diets. There was also a negative effect on the absorption of other trace minerals, especially Cu and Fe, which may lead to an imbalanced body mineral status. For these reasons these pharmacological levels of ZnO are banned in many countries.

In the EU the permitted Zn content in the complete feed for all classes of pigs is 150 mg/kg. This has prompted interest in alternative sources of zinc and organic Zn in particular.

In piglets, Mullan and others (2002) demonstrated that piglets fed 100 ppm Zn from organic Zn (Bioplex, Alltech) had similar growth rate to those fed 1500-2250 Zn from ZnO, but those piglets fed 250 ppm Zn from organic Zn had superior performance. There was a five-fold reduction in faecal Zn concentration; from 8910 mg/kg DM to 1830-1960 mg/kg DM.

Carlson and others (2004) compared the performance of piglets fed 2000 ppm Zn from ZnO with different levels of organic Zn and concluded that 50-

Table 2. Effect of supplementing the diets of piglets with ZnO or organic zinc on performance in the four-week period post weaning (Carlson *et al.*, 2004).

Source	ZnO	Organic zinc					
Zn ppm	**2000**	**0**	**50**	**100**	**200**	**400**	**800**
Feed intake (g/d)	559	500	518	554	476	511	484
Growth rate (g/d)	378	348	354	369	319	348	332
Feed:Gain (g/g)	1.47	1.44	1.46	1.50	1.49	1.47	1.46

100 ppm Zn from organic Zn gave the same level of performance as those fed 2000 ppm Zn from ZnO (*Table 2*). Similar to other studies, the excretion of Zn was significantly reduced when the lower levels of organic Zn were provided compared to the higher levels of ZnO. However, the effect of organic minerals in controlling scouring and diarrhoea is unclear.

These studies on piglets suggest that organic forms of Cu and Zn can give similar levels of performance compared with pharmacological levels of inorganic sources.

High levels of inorganic Cu and Zn may also reduce the availability and absorption efficiency of other trace minerals leading to an imbalanced minerals status, which may in fact reduce performance. If these high levels are used, in particular ZnO, it is suggested that organic forms of the other trace minerals are added to the diet to avoid these interactions.

Fremaut (2003) compared the performance of grow-finish pigs fed either organic or inorganic sources of zinc. At the common inclusion of 120 mg Zn/kg, the performance of the pigs fed organic Zn was 736 compared with 695 g/day. However, reducing the organic inclusion level to 36 mg Zn reduced zinc excretion to 27-30% while maintaining performance when compared to those pigs receiving 120 mg ZnO (696 vs. 695 g/day).

Hernandez and others (2005) investigated different levels of organic sources of Cu and Zn when compared with higher levels of inorganic sources. There was no difference in performance across the different treatments. More recently, and based on production traits and blood mineral concentrations, Hernandez and others (2007) recommended that diets be supplemented with 10 ppm Cu and 40 ppm Zn from organic sources.

Total replacement project

Although most research on mineral proteinates has been carried out on individual elements, it is likely that the greatest effect can be achieved when a combination of minerals are added to the diet. Several trace minerals act synergistically and therefore their combined effect may be greater than when provided individually.

Fremaut (2003) investigated the replacement of 100 or 200% of inorganic Cu and Zn with a combination of 30% organic minerals. The combination contained 36 mg Zn, 7 mg Cu, 40 mg Fe and 18 mg Mn/kg feed. The performance of the pigs was either similar or better compared with normal (20 mg Cu and 120 mg Zn/kg) or double (40 mg Cu and 240 mg Zn/kg) the levels of inorganic minerals.

Since these initial studies, several other studies have been conducted in the growing and finishing pig in which different levels and combinations of organic minerals were compared with normal industrial levels of inorganic minerals.

Table 3 summarises two of the most recent studies and shows the lowest inclusion of organic minerals, which gave similar performance to the normal industry levels of inorganic minerals. The trials of Geers and others (2008) show that the inclusion of the lower levels of organic minerals promoted a better feed conversion efficiency and, as a consequence, the margin per pig was increased, indicating a more cost-effective response.

Table 3. The effect of the total replacement of inorganic by organic minerals in performance of grow-finish pigs.

	Geers* *et al.*, 2008				Burkett** *et al.*, 2006	
	Trial 1		Trial 2			
	Control	Treatment	Control	Treatment	Control	Treatment
Feed intake (kg/d)	2.30	2.22	2.35	2.30	2.34	2.41
Growth rate (g/d)	811	803	751	765	910	930
Feed:Gain (kg/kg)	2.84	2.77	3.13	3.01	2.57	2.59
P2 (mm)	13.5	12.2	12.0	12.1	-	-
% Lean	60.0	60.7	62.4	62.7	50.9	50.6

Mineral levels in diets:

* Geers	mg	Zn	mg	Fe	mg	Cu	mg	Mn	mg	Se
Control	100	ZnO	100	$FeSO_4$	15	$CuSO_4$	40	MnO	0.3	Na Selenite
Treatment	40	*	40	*	15	*	20	*	0.3	Organic selenium

* all from organic trace minerals

** Burkett	mg	Zn	mg	Fe	mg	Cu
Control	16	25% ZnO	16	FeS		
	3	75% $ZnSO_4$	9	O_4	85	$CuSO_4$
Treatment	10	*	66	*	46	*

* all from organic trace minerals

Lower levels

These results show that the mineral requirements of the modern pig can be met with lower levels of organic minerals than common commercial industry levels of inorganic minerals. Performance is maintained and net margin is increased because of better nutrient utilisation. In addition, at these lower levels there is less mineral excretion, therefore minimising their environmental impact.

Thus the inclusion of organic minerals in pig and sow diets bring productive and environmental advantages to all stages of production and are cost effective. There are also improvements in both carcass and meat quality and this will be the subject of a subsequent article. **PP**

References available on request

Trace mineral supplementation is going through a global revolution. Concerns over inorganic mineral contamination and environmental pollution from over supplementation combined with latest application technology for organic minerals is changing long held beliefs on how minerals should be fed.

Over the last 20 years Alltech has committed significant resources into the area of trace mineral nutrition on a number of fronts, including production, quality assurance, research into application and customer education. With the proven success of brands such as the Bioplex® Trace Mineral range and Sel-Plex® organic selenium, Alltech is recognised as a global leader in trace mineral nutrition.

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