Trace mineral nutrition of pigs revisited: meeting production and environmental objectives

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Summary

Trace mineral nutrition has been a neglected area of pig nutrition. There is little recent information on the trace mineral requirements of modern pig genotypes and it has become customary to provide levels in the diet much higher than those recommended. Some minerals, such as copper and zinc, are added at 'pharmacological' levels to increase growth, to enhance immunity and to reduce diarrhoea in piglets. There is, however, concern about the large quantities of undigested elements being excreted and causing environmental pollution.

Although inorganic sources of trace minerals have been widely used, there are questions about their availability to the animal and this has created interest in proteinated or chelated (organic) trace elements. These are better absorbed and are more available to the animal. As a consequence, inclusion levels can be reduced while maintaining, or even enhancing performance. The results of studies comparing inorganic and organic sources of copper, zinc, iron, and selenium, and combinations of these, are discussed. Indeed, providing a balance of inorganic and organic minerals may be the most effective way to meet the animal's need and studies with sows have shown improvements in reproductive performance.

In the future, the source of mineral may therefore be of increasing importance in attempting to satisfy both production and environmental demands.

Keywords: pig nutrition, trace minerals, organic/ inorganic sources, bio–availability, reproductive performance, environment

Introduction

Trace minerals are a commonly forgotten source of nutrients in animal feedstuffs. Their physiological role is often underestimated and their presence in the feed in adequate quantities taken for granted. However, they are necessary to maintain body function, to optimise growth and reproduction and to stimulate immune response and therefore determine health status. Indeed, it is difficult to realise the impact of insufficient trace minerals as symptoms of deficiency may not be evident. However, a deficiency of trace elements can cause a considerable reduction in performance.

Mineral requirements

It is rather difficult to justify the term 'requirements' for minerals in the same way as it is for energy, protein or amino acids. Requirements for minerals are hard to establish and most estimates are based on the minimum level required to overcome a deficiency symptom and not necessarily to promote productivity or, indeed, to enhance immunity. Most of the work relating to mineral requirements has been carried out in the 1960s and 1970s and may not be relevant to the modern animal. This is reflected in the review of NRC (1998) which, with few exceptions, shows only minor differences in the requirements of several minerals proposed by NRC (1988) or ARC (1981) (Table 1). The differences in nutrient requirements are the result of different production targets and the differing physiological status of the animal.

Indeed, there is a paucity of information on mineral requirements for current pig genotypes and Van Lunen and Cole (1998) have suggested that the mineral needs for growth in the modern fast–growing pig hybrids are about twice the level required by the slower growing pigs of some 20–30 years ago.

The consequences of an inadequate supply of dietary minerals have been reported on by Mahan and Newton (1995) for the high–producing lactating sow. They have shown that the body mineral content of sows at the end of their third parity was considerably lower when mean litter weaning weight at 21 days was above 60 kg rather than below 55 kg, and for both groups it was significantly less, by as much as 20%, than for unbred control animals of similar age. This suggests that considerable demineralisation of the sows' skeletal structures occurred to meet the needs at the higher level

of production. Thus, the higher the level of production, the greater the mineral needs of the animal. Interestingly, the levels of minerals in the diets used by Mahan and Newton (1995) were those proposed by NRC (1988).

These results raise questions about the amounts of minerals to be provided in the diet, the availability of these to the animal and the effects of mineral status of the animal on productivity. This is especially pertinent to the breeding sow and Richards (1999) has shown that already in late gestation, the sow has to rely on her liver iron reserves to meet the foetal demands for minerals and this loss of minerals from the body is further exacerbated during lactation. If dietary intake during late pregnancy and lactation is insufficient to meet metabolic demands and the sow has to rely on her body stores, this continuous drain on body reserves results in a reduced mineral status, as shown by Damgaard Poulsen (1993). This reduced mineral status is likely to result in poorer performance.

Mineral allowances

Because of these concerns, minerals are often provided in the diet at levels well above the 'recommended requirements'. These are called 'allowances' and should take account of the class of the animal, its level of performance, as well as the source and bio–availability

of the mineral. A survey of the allowances commonly provided in diets in several European countries has recently been carried out by Whittemore *et al.* (2002) (Table 2). This shows the wide variation in inclusion levels, with some as high as 3–4 times those recommended in Table 1. These are provided to ensure good rates of performance and to meet the animal's needs under the different systems of production and management, as well as to enhance its immune and health status.

When determining mineral supplementation, consideration must be given to the quantity and type of raw ingredients, the processing of the diet, the storage and environmental conditions, as well as the inclusion and content of other minerals. Minerals do interact and this must be taken into account. A well known example is the interaction between copper, zinc and iron, and if high levels of copper are used for growth–promoting purposes, then the requirements for both zinc and iron increase. Stranks *et al.* (1988) proposed that in diets containing 175 mg Cu/kg, the level of iron should be increased to 200 mg/kg diet, whereas that for zinc should be increased to 150 mg/kg diet. These values are higher than those recommended in many national standards and explain the high allowances in commercial practice. Thus, the provision of minerals is not straightforward.

Table 1   Dietary requirements for trace elements (per kg diet)*.

	Piglet		Growing pig		Finishing pig		Breeding sow	
Body weight (kg)	**< 20**		**20 – 50**		**50 – 120**			
Source	**ARC[1]**	**NRC[2]**	**ARC[1]**	**NRC[2]**	**ARC[1]**	**NRC[2]**	**AFRC[3]**	**NRC[2]**
Zinc (mg)	50	100	50	60	50	50	50	50
Manganese (mg)	16	4	16	2	16	2	15	20
Iron (mg)	60	100	–	60	–	50	60	80
Copper (mg)	4	6	4	4	4	3.5	5	5
Iodine (mg)	0.16	0.14	0.16	0.14	0.16	0.14	0.5	0.14
Selenium (mg)	0.16	0.3	0.16	0.15	0.16	0.15	0.15	0.15

* Values represent the highest concentrations quoted
[1] ARC (1981) per kg dry matter
[2] NRC (1998) 90% dry matter
[3] AFRC (1991) 90% dry matter

Table 2   Range of dietary mineral additions in several EU countries (per kg feed) (Whittemore *et al.* 2002).

	Piglet			Growing Pig			Finishing Pig			Breeding Sow		
Body weight (kg)	**< 20**			**20 – 50**			**50 – 120**					
Zinc (mg)	100	–	200	100	–	200	70	–	150	80	–	125
Manganese (mg)	40	–	50	30	–	50	25	–	45	40	–	60
Iron (mg)	80	–	175	80	–	150	65	–	110	80	–	150
Copper (mg)	6	–	18	6	–	12	6	–	8	6	–	20
Iodine (mg)	0.2	–	1	0.2	–	1.5	0.2	–	1.5	0.2	–	2.0
Selenium (mg)	0.2	–	0.3	0.15	–	0.3	0.2	–	0.3	0.2	–	0.4

Sources and bio–availability of minerals

Customarily, inorganic salts such as sulphates, carbonates, chlorides and oxides are added to the diet to provide the correct levels to meet the animals' needs. These salts are broken down in the digestive tract to form free ions and are then absorbed. However, free ions are very reactive and can form complexes with other dietary molecules, which are difficult to absorb. The availability of the trace mineral to the animal therefore varies considerably and under extreme conditions it may be unavailable for absorption and therefore of little benefit to the animal. Large quantities of undigested minerals are then excreted and cause environmental pollution.

Bio–availability is normally defined as the degree to which an ingested nutrient in a particular source is absorbed in a form that can be utilised or metabolised by the animal. This therefore reflects the absorption and utilisation of the nutrient ingested . Even under similar conditions, there can be quite large differences in availability. For example, in chicks, Sandoval *et al.* (1997) measured the bio–availability of zinc from carbonate, oxide or metal as 78, 77 and 46%, respectively, relative to that of zinc sulphate. Edwards and Baker (1999) compared the bio–availability of three sources of zinc oxide, all containing between 69 and 80% zinc, against that of zinc sulphate. Relative to that of zinc sulphate, the bio–availability of the oxide sources varied between 22 and 91%, when assessed as tibia zinc content. They concluded that such differences have implications for animal nutrition, not only because of the higher costs per unit of available zinc, but also because unabsorbed zinc could contribute to the build–up of zinc in the soil, causing environmental pollution.

In more recent studies with piglets, Damgaard Poulsen and Carlson (2001) evaluated the bio–availability of several zinc sources by regressing the rate of zinc retention and net absorption against the rate of zinc intake provided from zinc oxide, zinc sulphate or zinc acetate. Surprisingly, the difference in utilisation between the different sources was small: 22% for zinc oxide, 23% for zinc sulphate and 19% for zinc acetate. It was anticipated that the bio–availability of zinc from the sulphate and acetate sources would have been considerably higher than that from the oxide source.

Relative to zinc sulphate, the bio–availability of zinc from the oxide and acetate sources was 95 and 85%, respectively. These compare with values of 67–87% determined by Wedekind *et al.* (1994) and based on metacarpal, coccyginal and plasma zinc content. Thus, the estimate of bio–availability may depend on the response trait measured. Nevertheless, the bio–availability values in the studies of Damgaard Poulsen and Carlson (2001) show that uptake of zinc from the different inorganic sources was low, implying that 75–80% of the ingested zinc is excreted by the animals.

For this reason, there is growing interest in organic, that is proteinated or chelated trace 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 bio–active and provides the animal with a metabolic advantage that often results in improved performance. They can therefore be included at much lower levels without compromising performance, thus minimising nutrient excretion and environmental impact.

Relative values for the availability of selected sources of copper, zinc and iron for pigs are presented in Table 3.

Environmental implications

Copper and zinc are of particular concern, since inorganic sources of copper sulphate and zinc oxide are often fed at pharmacological levels that are well above the physiological requirements of the animals in order to promote growth rate and to prevent scouring and diarrhoea. Their excretion contributes to soil and water pollution and may well be toxic to plants and

Table 3   Relative bioavailability values of selected sources of copper, zinc and iron (Ammerman *et al.* 1995).

	Copper	**Zinc**	**Iron**
Sulphate	100		100
Carbonate	85 (2)		19–95 (3)
Oxide	30 (4)	50 (1)	10 (1)
Chloride		100	
Citrate			150 (4)
Lysine		100 (1)	
Methionine	110 (1)	100 (2)	185 (1)
Proteinate			125 (1)

Bioavailabilities are relative to those of sulphate (= 100)
Values in brackets indicate the number of observations

animals. They are also the most likely to be toxic to the microflora in the soil. It is for this reason that the Animal Feed Committee of the European Union has proposed maximum inclusion levels that are well below current authorised levels (Table 4). These values refer to the total content in the feed, including that present in the raw ingredients.

Copper

Copper (Cu) is required for the proper functioning of the central nervous–, the immune– and the cardiovascular systems, as well as for pigmentation of the skin. It is required for the synthesis of haemoglobin, has a basic role in iron metabolism and it functions as an enzyme activator and enzyme constituent. Although the minimum requirement is only 5–10 ppm, higher levels stimulate growth. Copper, and copper sulphate in particular, has therefore been added at 100–250 ppm to pig diets as a growth enhancer. However, recent studies suggest that organic sources of Cu may be more effective in promoting growth than copper sulphate, as well as minimising nutrient excretion.

A 5.0% improvement in daily feed intake and a 4.8% improvement in growth rate were observed in piglets when organic copper was given at the same level as the traditional copper sulphate (Coffey *et al*. 1994). Zhou *et al.* (1994) reported a 29% increase in feed utilisation and a 19% improvement in growth rate in post–weaned piglets when Cu–lysine was added to the diet, compared with Cu–sulphate. Serum Cu levels and cell mitogenic activity of the piglets fed the Cu–lysine was also higher. Similar results have also been reported by Apgar and Kornegay (1996), although earlier studies (Stansbury *et al.* 1990, Apgar *et al.* 1995) did not show any difference in performance between sources of copper.

Studies by Carlson (2001) and Wu *et al.* (2001), also reported that piglets in the post–weaning period were able to maintain growth performance when 50–100 ppm Cu was provided from organic Cu, compared with the customary level of 250 ppm Cu from $CuSO_4$. Additionally, they measured the rates of absorption and retention and reported that organic sources of copper did not interfere with zinc or iron metabolism, unlike the inorganic copper sources (Table 5). Field studies, such as those reported by Close (1998), also support the findings that a partial or total replacement of copper sulphate by organic copper improves piglet performance.

Smits and Henman (2000) evaluated the performance of grower and finisher pigs fed diets supplemented with either copper sulphate (150 ppm Cu) or organic copper (40 ppm Cu). Those pigs fed the diets with the organic Cu at 40 ppm achieved similar levels

Table 4 Current and proposed maximum levels of dietary copper and zinc in the EU.

Class of pig	Copper (ppm)			Zinc (ppm)	
	Current	Proposed		Current	Proposed
< 10 weeks	175	30		250	100
10 – 16 weeks	175	20		250	100
> 16 weeks	35	20		250	100
Breeding sows	35	20		250	100

Table 5 Absorption and retention of Cu, Zn and Fe in pigs fed different Cu sources (Carlson 2001).

Cu (ppm)	Control	Organic Cu		CuSO$_4$
	0	50	100	250
Copper				
Faecal Cu (mg/day)	27.3	72.9	123.6	325.5
Absorption (%)	3.7	8.9	8.8	17.6
Retention (%)	0.6	6.2	5.8	16.4
Zinc				
Absorption (%)	13.7	19.6	22.0	14.5
Retention (%)	12.2	18.2	20.6	13.5
Iron				
Absorption (%)	23.4	21.1	22.0	20.6
Retention (%)	22.6	20.2	21.0	20.1

of performance ($P>0.05$) to those fed 150 ppm Cu from $CuSO_4$. However, there was a significant reduction ($P<0.05$) in the quantity of copper excreted in the faeces; it was some 3 to 4 times lower in the pigs fed 40 ppm organic Cu than in those fed $CuSO_4$ (Table 6).

In a subsequent study, they further confirmed the significant reduction in faecal Cu when organic Cu (50 ppm Cu) was compared with copper sulphate (160 ppm Cu). They concluded that by replacing high levels of $CuSO_4$ with lower levels of organic Cu, it is possible to maintain the growth–enhancing effect of the diet, but since the excretion of Cu was dramatically reduced, it will be achieved in an eco–friendly and responsible way.

Work in rats (Du *et al.* 1996) has also shown a considerably higher utilisation of Cu from organic sources compared with $CuSO_4$, resulting in significantly higher levels in body tissue. Cell mitogenic activity is also increased and this leads to higher hormonal and, therefore, metabolic status. This study also suggested that complexed Cu ions are absorbed differently than those from inorganic sources in a way that does not interfere with Zn or Fe metabolism. It is suggested that metal complexes are absorbed in a dipeptide–like amino acid complex and then transported across the intestinal mucosa.

Zinc

Zinc (Zn) is involved in many metabolic functions and plays a vital role in hormone secretion, especially those relating to growth, reproduction, immuno–competence and stress. It is a component of many metalloenzymes, is implicated in carbohydrate, fat and protein metabolism and influences vitamin A and E transport and utilisation. It is involved in the process of keratin generation and in collagen and skin nucleic acid synthesis. Zinc is also essential for male reproduction. Zinc requirements have been established as 50–100 mg per kg (Table 1).

The natural content of Zn in cereals is about 20–40 ppm. Oil seed co–products, fish meal and meat and bone meal all have higher content and may contain up to 100 ppm. However zinc interacts with other minerals and zinc deficiency has been observed in animals fed on high calcium diets. Phytic acid will reduce the availability, but this can be partly redressed by the use of phytase enzymes. A supplement of zinc is therefore required under most practical conditions.

Marked differences in the bioavailability of zinc from different sources have been documented. In poultry, Wedekind *et al.* (1992) indicated that the bioavailability of a Zn–methionine complex was 206%, relative to that of zinc sulphate (taken as 100%) and 61% for zinc oxide. In a subsequent study (Wedekind *et al*. 1994), they showed that even at high levels of dietary calcium content, the availability was not reduced. Similar responses have been reported in dogs (Lowe *et al.* 1994). In several studies with ruminants, there have been improvements in the growth of hair, horn, hoof and skin, as well as a reduction in the somatic cell count of milk and a reduction in the incidence of clinical mastitis when organic forms of zinc have been compared with inorganic sources (Boland *et al.* 1996).

Zinc has a positive effect on both the immune response to pathogens and the prevention of disease by maintaining healthy epithelial tissue. In this respect, zinc oxide (ZnO) is usually added at high inclusion levels (2–3 kg/tonne) to piglet diets because of its known pharmacological effects, increasing growth rate and reducing the incidence of scouring. Carlson *et al.* (1998) also reported that high levels of zinc oxide altered duodenal morphology (deeper crypts and greater total thickness) and increased intestinal metallothionein concentration, which indicated that high amounts of zinc may also have an enteric effect on the pig. However, the availability of zinc oxide, compared with zinc sulphate ($ZnSO_4$) and organic zinc, is low and there is increasing concern about the high content of zinc in

Table 6 The growth performance and faecal Cu excretion of pigs fed different Cu sources (Smits and Henman 2000).

Diet	Control (no added Cu)	$CuSO_4$ (150 ppm Cu)	Organic Cu (40 ppm Cu)
Growers (30–60 kg)			
Feed intake (kg/d)	1.94	2.05	2.08
Growth rate (kg/d)	0.90	0.95	0.96
Feed : Gain (kg/kg)	2.15	2.16	2.21
Faecal Cu (mg/kg DM)	130	853	275
Finishers (60–90 kg)			
Feed intake (kg/d)	2.35	2.59	2.65
Growth rate (kg/d)	0.85	0.87	0.84
Feed : Gain (kg/kg)	2.84	2.98	3.02
Faecal Cu (mg/kg DM)	108	776	198

slurry and the ensuing environmental impact. As a consequence, producers are more and more looking at alternative sources of zinc.

Cheng *et al.* (1998) compared the response of piglets fed zinc sulphate and zinc lysine in lysine–deficient (0.8% lysine) and lysine–adequate (1.1% lysine) diets. There was little difference in performance between the two sources of zinc, but for the piglets fed the lysine–adequate diet, the feed:gain value was lower with the zinc lysine complex than with the zinc sulphate in the diets, but not significantly so ($P>0.05$).

Spears *et al.* (1999) fed piglets diets containing either 50 or 150 ppm supplemental zinc, provided as either 100% zinc sulphate, 75% $ZnSO_4$ and 25% zinc proteinate, or 50% $ZnSO_4$ and 50% zinc proteinate. Zinc levels did not affect feed intake, growth rate or feed:gain ratio over the period of the study (Table 7). However, in piglets fed 50 ppm zinc, replacing a portion of the $ZnSO_4$ with Zn proteinate tended to improve both feed intake and growth rate. In the 150 ppm zinc treatments, piglet that received 50% of their supplemental zinc from zinc proteinate had a higher gain and feed:gain ratio ($P<0.05$) than those fed 25% of proteinated zinc over the entire study period. Interestingly, there were no major effects of zinc source on plasma zinc or on cellular immune response, but piglets receiving organic zinc tended to have a greater skinfold thickness response to PHA administration than those receiving only $ZnSO_4$.

Carlson *et al.* (2000) compared the performance of piglets for a 4–week period post weaning when fed 0–800 ppm of an organic source of zinc or 2000 ppm Zn as zinc oxide. Dietary zinc had no effect on growth rate, feed intake or feed efficiency, but piglets fed either 50 or 100 ppm of the organic zinc had the highest growth rates compared to all other treatments.

Mullan *et al.* (2002) have recently shown that piglets fed 100 ppm Zn from a proteinated zinc source had the same growth rate as those fed 1500–2250 ppm Zn from zinc oxide, but those piglets fed 250 ppm Zn from proteinated Zn had superior growth rate ($P<0.01$) (Table 8). Piglets fed the diets containing both levels of proteinated Zn had significantly ($p<0.05$) reduced levels of zinc in their faeces compared with those fed zinc oxide; indeed it was no higher than that in the faeces of the control piglets fed no supplemental zinc. Wu *et al.* (2001), on the other hand, reported that piglets fed 2000 ppm Zn from zinc oxide had higher growth rates than those fed 200 or 400 ppm proteinated zinc. However, the piglets fed the zinc oxide also excreted more than four times as much zinc as those receiving organic zinc.

Iron

Iron (Fe) plays a key role in many biochemical reactions. It is present in several enzymes responsible for electron transport and is essential for the activation of oxygen and for oxygen transportation. It is a component of haemoglobin, is vital to cellular and whole body energy and protein metabolism and is essential for good health and the prevention of anaemia.

Table 7   Effect of zinc source on piglet performance (Spears *et al.* 1999).

Zn (ppm):	50			150		
$ZnSO_4$ (%)	100	75	50	100	75	50
Organic Zn (%)	–	25	50	–	25	50
Feed intake (g/d)	697[a]	775[b]	756[ab]	716[ab]	711[a]	725[ab]
Growth rate (g/d)	408[ab]	437[a]	416[ab]	411[ab]	385[b]	429[a]
Feed : Gain (g/g)	1.71[ab]	1.77[ab]	1.82[ab]	1.74[ab]	1.85[a]	1.69[b]

[ab]Means in a row without a common superscript differ ($P<0.05$)

Table 8   The performance of piglets fed diets containing different sources of supplemental zinc in the post–weaning period (Mullan *et al.* 2002).

	Diet	Control	Zinc oxide	Organic zinc		*P* value
Zinc (ppm)	Stage 1	–	2250	100	250	
	Stage 2	–		1500	100	250
Feed intake (g/d)		552	525	556	575	0.681
Growth rate (g/d)		367[a]	389[b]	405[b]	427[c]	0.001
Feed:Gain (g/g)		1.58	1.38	1.36	1.27	0.057
Faecal zinc content (ppm DM)		2290	8910	1960	1830	0.001

[abc]Means in a row without a common superscript differ ($P<0.05$)

Except for the new–born piglet, the requirement for iron can generally be met through the diet. However, the content and availability of Fe varies considerably between the different inorganic sources, with availability values ranging between 10 and 100% (Ammerman *et al.* 1995). On the other hand, the availability of chelated or proteinated relative to inorganic sources of Fe was reported as 125 to 185% (Henry and Miller 1995) and this has prompted interest in their inclusion and use, especially in sow and piglet diets.

Recent studies have shown that providing organic iron in the diet can improve animal performance. Iron linked to amino acids has been shown to increase the transfer of iron across the placenta and into the embryo (Ashmead and Graff 1982). When provided at 200 ppm in the gestation diet, significant quantities crossed the placenta and were incorporated into the foetuses. This resulted in a significantly reduced mortality and heavier piglets at birth and at weaning (Ashmead 1996). When fed continuously over eight parities, there were fewer still–born piglets and more piglets weaned in each parity, as well as a shorter interval between weaning and oestrus.

Field studies using organic iron in the diet of the gestating and lactating sow have shown similar responses (Close 1999). There was a positive effect on the feed intake of the sow and on the weight gain of the piglets, which resulted in a heavier body weight at weaning. Pre–weaning mortality was also reduced and the blood haemoglobin levels in piglets were increased.

These phenomena may be explained on the basis that chelated iron is absorbed into the blood in a form that is more readily transferred across the placenta and into the developing embryo. The availability and absorptive efficiency is also increased and liver iron content is higher (Egeli *et al*. 1998). The iron status of the piglet is therefore higher at birth and throughout lactation, resulting in better performance. In addition, a progesterone–dependent protein, uteroferrin, which is secreted in the uterus in early pregnancy, is also proposed to play a role in the transfer of iron to the foetal piglet, as well as being implicated in embryo survival; the latter phenomenon is consistent with the higher litter size reported in several trials.

Selenium

Selenium (Se) is an important component of the glutathione peroxidase (GSH–Px) enzyme system. It acts as an antioxidant and is involved in thyroid metabolism. Deficiency symptoms in pigs include: mulberry heart disease, reduced immune function, lower reproductive performance, white muscle disease, MMA and reduced glutathione peroxidase activity. Selenium is particularly important in the diet of the sow; inadequate selenium will result in problems at farrowing, increased rate of stillborn piglets, low Se levels in milk which leads to higher piglet mortality and lethargic and weak piglets, as well as mulberry heart disease. Indeed, the role of Se is similar to that of vitamin E, as both are anti–oxidants.

Usually an inorganic source of selenium, such as sodium selenite, is added to the diet. However, recent trials conducted by Mahan (2000) have shown that when a seleno–methionine yeast was provided in the diet of sows at the same level as the normal inorganic sodium selenite, the Se content of the newborn piglet and of milk increased threefold (Figure 1). Similar results were also obtained by Janyk *et al*. (1998) who reported that piglet growth rate was 10 g/day higher and piglet mortality during lactation was considerably reduced on the organic selenium compared with the sodium selenite treatment. This suggests that the organic form of selenium was readily transferred across the placenta and mammary tissue, indicating that it was superior to the inorganic form.

When organic Se was fed to growing/finishing pigs there was a linear and significant increase in the Se content of muscle tissue, unlike that for inorganic
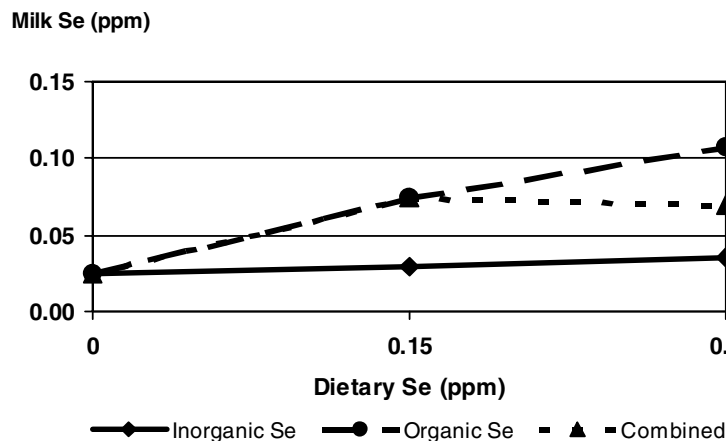

Figure 1 Effect of Se source on Se content of sow milk (Mahan 2000).

selenium where there was only a minimal increase (Mahan *et al*. 1999). There were also improvements in the colour of the pork and a reduction in drip–loss. The improved nutritional quality of pork could be an excellent way to enhance the Se intake of humans.

More detailed accounts of the role of selenium in animal nutrition, and selenium yeast in particular, are discussed by Mahan (1999).

Other trace minerals that have a major impact on performance are manganese and chromium and these have recently been reviewed by Close (1998) and Lindemann (1996).

Minerals and reproduction

It is clear that changing the source of trace minerals from inorganic to organic, either partially or totally, can influence pig performance and the efficiency of feed utilisation. Most studies have been carried out on the post–weaned or growing–finishing pig. However, reproductive performance may also be enhanced. In dairy cows, Boland *et al.* (1996) showed that cows treated with organic minerals had a non–significant reduction in days to emergence of the first dominant follicle (7.8 *vs* 9.3) and to first ovulation (20.3 *vs* 25.3). Conception rate to first service was also higher (65 *vs* 58 %). Indeed, adding a combination of minerals may be a more effective way of improving performance than single minerals.

In pigs, Fehse and Close (2000) supplemented the normal level of inorganic minerals in the diet with a special pack of organic minerals and recorded 0.4 more piglets weaned per litter between parities 3 and 6. Pre–weaning mortality of the piglets was also reduced. Interestingly, more of the 'supplemented' sows remained in the herd, especially after parity 4, with fewer sows being culled, suggesting that these animals were better able to maintain productivity.

It may well be that the modern hyper–prolific sow becomes depleted of her mineral reserves after only 3–4 parities and has a higher need than hitherto assumed if high levels of performance are to be continuously achieved. The provision of the additional organic minerals may better meet the needs of the animal, enhancing its metabolic, physiological and endocrine status and thus optimising sow productivity.

Similar improvements in productivity have been reported by Smits and Henman (2000) and Acda and Chae (2002). The latter concluded that organic trace element supplementation, even at low levels, improved the reproductive performance of sows and the quality of the piglet up to 2 weeks post weaning when compared with high levels of inorganic minerals.

The role of minerals in reproduction is often under–estimated and their involvement in the different components that determine litter size and sow productivity has been suggested (Figure 2).

Conclusions

Trace mineral nutrition has been a particularly neglected area of pig science and modern genotypes, with higher levels of productivity may require higher levels than are currently recommended. However, it is not just a question of quantity, but very much a question of source and bio–availability. The benefits of including trace minerals at the level required by the modern animal and in the most readily absorbed form are measurable in increased performance, better health and welfare. In this respect it is likely that organic minerals will play an increasing role in pig nutrition, not only for meeting the true requirements of the animal for optimal performance, but also for minimising their excretion and hence better meeting environmental standards, as well as providing healthy meat for the consumer.
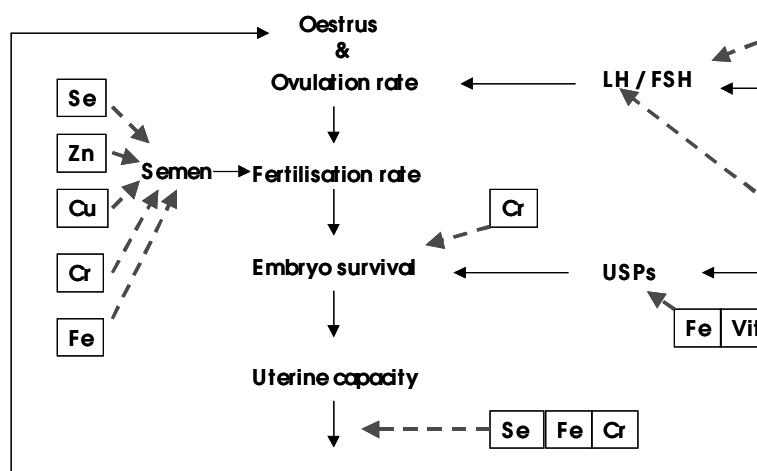

Figure 2 The potential role of trace elements in sow reproduction (Close 1999).

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