Mineral nutrition of hyperprolific sows

W H Close. Close Consultancy, Wokingham, UK RG41 2 RS: e-mail: will@closeconsultancy.com

INTRODUCTION

One of the major achievements in pig production over the last few decades has been the improvement in sow reproductive performance and in several countries it is not uncommon for sows to wean 25-30 piglets per year. These achievements have been brought about by a better understanding of the biology of the pig, including the nutrient requirements of the sow and the provision of feeding strategies to meet these needs. This paper will discuss the mineral nutrition of the sow, with special focus on the trace minerals.

MINERAL REQUIREMENTS

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).

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

*Whittemore et al (2002)

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 and Table 2 shows the number of citations on which the various NRC recommendations for breeding sows have been made. Some estimates for sows do not have a single cited study, or are based on very few studies. Thus, the mineral requirements of sows are poorly defined and it is known that the body stores of both macro- and micro-minerals become depleted with advancing parity, and the higher the level of productivity, the greater the degree of depletion (Mahan and Newton, 1995).

Table 2. No. of references cited for trace minerals in NRC requirements for breeding sows

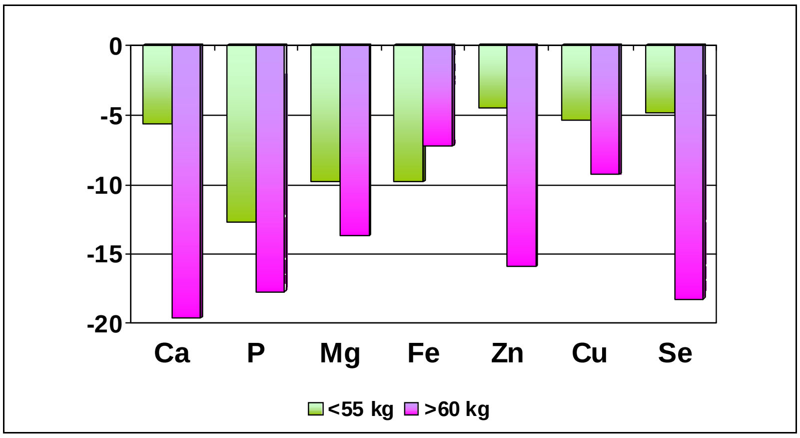
	Total	1950 – 1970's	1980's	1990's
Mineral				
Iron	10	7	3	-
Zinc	5	3	2	-
Copper	4	1	1	2
Manganese	7	4	2	1
Selenium	14	9	2	3
Iodine	0	0	0	0

(Lindemann and Kim, 2006)

CONSEQUENCES OF INADEQUATE MINERAL SUPPLY

If dietary mineral supply is inadequate, then performance is likely to be affected and mobilisation from body tissues and skeletal structures occurs in an 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.

Figure 1. Mineral losses (%) in sows after 3 parities relative to non-gravid sows (Mahan and Newton, 1995)



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).

Comparison of the daily mineral intake of a 1st 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 3). 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 3. Trace mineral intake in relation to body weight and parity

	Recom-mended[1] per kg diet	Parity 1 (160 kg) Intake[2]			Parity 3+ (240 kg) Intake[3]			Difference[4]	
		mg/day	mg/kg BW	mg/kg$^{0.75}$	mg/d	mg/kg BW	mg/kg$^{0.75}$	(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 kg$^{0.75}$

The most demanding period for minerals is during late gestation and lactation. For example, during the last 2 weeks of gestation some 50% of total minerals retained in developing foetal tissue were deposited (Mahan, 2007). Studies of foetal development have shown that a litter of 12 piglets requires approximately 73 and 44 g of Ca and P, respectively, during the last 2 weeks of gestation. Because of this large requirement it is likely that bone demineralisation occurs with a possible weakening of the skeleton during late gestation and just prior to lactation when the demands are even higher. Similar traits have been seen with the trace minerals.

The situation in lactation becomes even more exacerbated and studies have shown that sows suckling 11 compared with 8 piglets per litter need 85 and 68 g/day, respectively during the last 10 days of a 21-day lactation. The requirement for calcium was 19 g/day at the higher litter size and 13.3 g/day for the lower litter size. Thus, the demand for minerals increase with the stage of lactation as milk yield increases and as the demands increase with higher litter size. Similar traits have been shown with the trace minerals and it is interesting to note that the daily retention of iron (Fe) and copper (Cu) was greater in the first 11-day period: 20.3 and 11.5 g, respectively, than the last 10 days of a 21-day lactation, with 3.7 and 3.5 g, respectively (Mahan, 2007). These results suggest that sows suckling large litters of piglets may be unable to meet the trace mineral needs of nursing piglets with the levels of minerals normally provided in the diet. Thus, the performance, health, immunity and welfare of the sow and her piglets are dramatically affected.

However, increasing the mineral content of the diet may not necessarily be the answer, as high levels of inorganic minerals have been shown to reduce reproductive performance. A better understanding of the mineral needs of the sow, as well as providing minerals in specialised form may be key to improving the reproductive performance, as well as to protect sow longevity.

FORM OF MINERAL PROVISION

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 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. It is only possible to chelate transition elements; other minerals, such as selenium and chromium can be provided in yeast form.

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

STUDIES ON ORGANIC IRON AND SELENIUM

Iron (Fe)

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 Fe, Alltech Inc). 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 4). Mortality of suckling piglets was reduced from 10.8% (range 9.6-13.0) to 6.8% (range 4.4-9.0). 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 4).

Table 4. Organic Fe: Effects on sow and piglet performance (Close and Taylor-Pickard, 2005)

Study/Country	Sow feed intake (kg/day)	Piglet weaning wt (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)	5.84 -- 6.06	9.6 -- 5.0	24 -- 17	46 -- 50
	(150 ppm)	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*	-	-

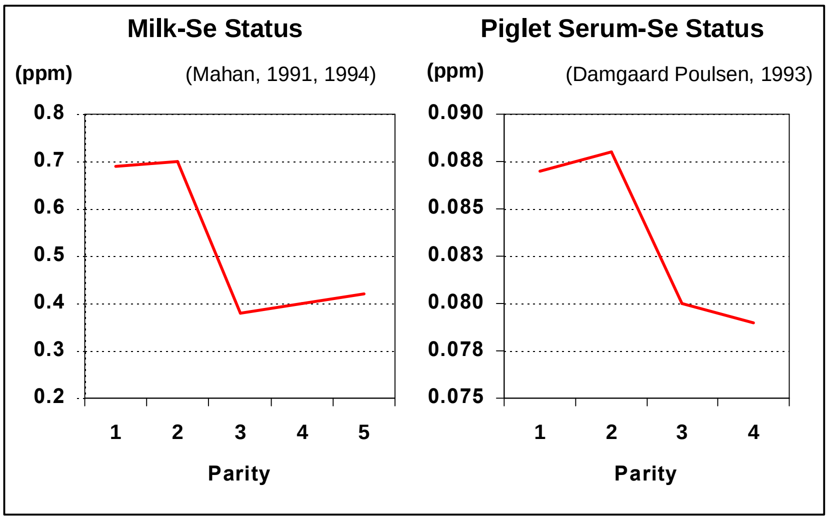
*includes stillborn piglets

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.

Selenium (Se)

Although selenium is present in plants and grain as organic Se, it has customarily been added to the diet in inorganic form, and especially as sodium selenite. Despite this, selenium deficiency is prevalent worldwide. The problem is especially noted in piglets born to older, highly prolific sows. This may be related to the depletion of the sow's trace mineral reserves with time. Mahan (1995) found that milk Se declined markedly after the 2nd parity in sows that had been reared and maintained on diets containing 0.3 ppm Se from sodium selenite (Figure 2). Damgaard Poulsen (1993) has shown that the Se concentration in the serum of newborn piglets from parity 3 and 4 sows was significantly reduced compared with those from parity 1 and 2 sows. This indicates that inorganic sources of Se cannot meet the Se requirements of the modern sow, and it is interesting to note that increasing problems with sows appear from parity 3 onwards (stillborn piglets, culling rate, wean-oestrus interval, etc.).

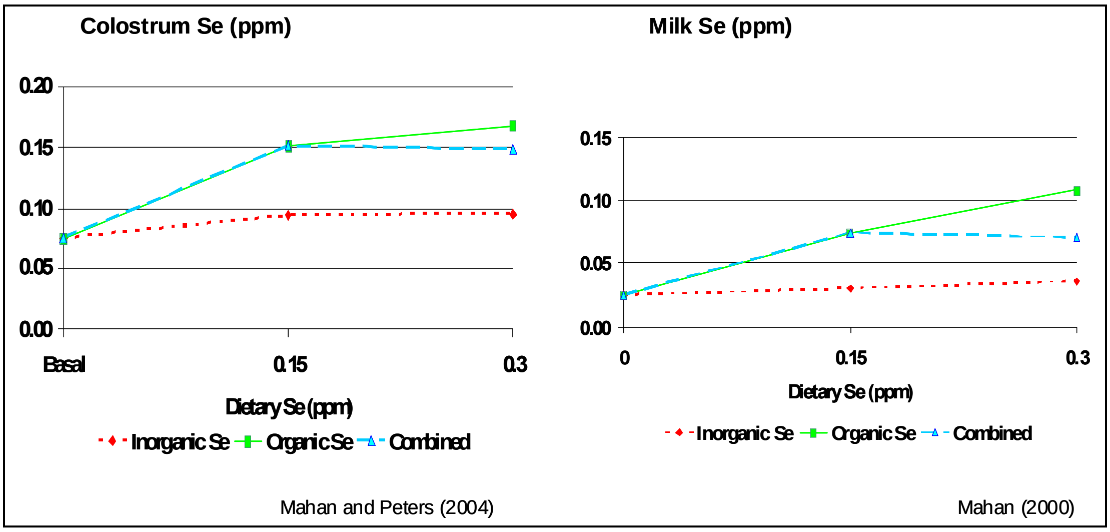
Figure 2. The effect of parity on the Se status of sows and piglets when fed sodium selenite



This has prompted the use of organic selenium from selenium yeast where the major source of Se is seleno-methionine. The seleno-aminoacid is better retained by the animal and results in higher levels in the body, with heightened immune status and increased productivity.

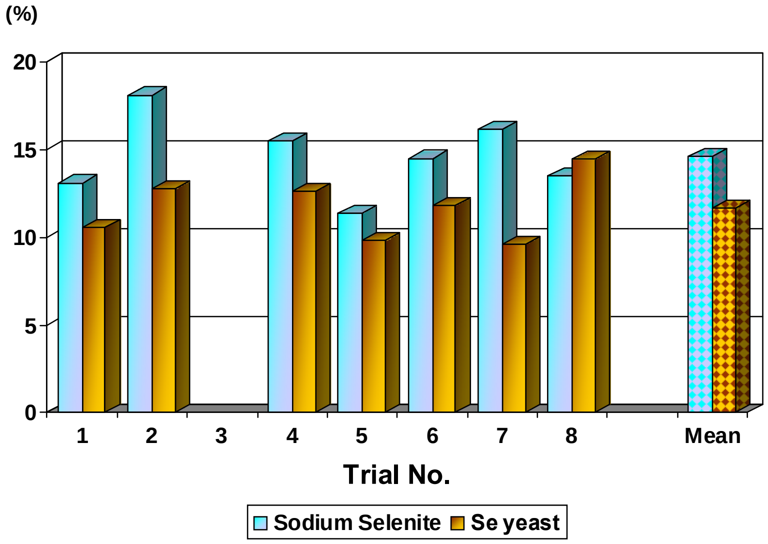
Compared to sodium selenite, the addition Se yeast to the diet of the sow during gestation and lactation enhanced both the placental and mammary transfer of Se. Thus, the Se content of the piglet at birth and the colostrum and milk Se content are increased Mahan (2000) and Yoon and McMillan (2006). Mahan and Peters (2004) further noted that only dietary organic Se is effectively transferred to colostrum and milk. Feeding the sow organic Se improves the Se Status of the young piglet at a very critical period when Se deficiency is most likely. The immune status of the piglet is enhanced, pre-weaning mortality is reduced and piglet performance improved. The number of stillborn piglets at parturition is also reduced. The milk Se content from sows fed Se yeast is maintained independent of parity, whereas it decreases with parity when they are fed similar levels of sodium selenite.

Figure 3. The effect of selenium level and source on colostrum and milk Se content



As a consequence of the higher Se status, an improvement in sow productivity has been reported in several studies when Se yeast (Sel-Plex™) was fed, compared with sodium selenite (Figure 4). Pre-weaning mortality was reduced by 20% from 14.5 6o 11.6%. As a consequence those sows fed the Se yeast weaned 0.27 more piglets per litter compared to those fed sodium selenite. Indeed, the return on investment, or ROI, when using Se yeast is calculated as 5:1, which is a very cost-effective response.

Figure 4. The pre-weaning mortality of piglets from sows fed Se yeast (Sel-Plex™) or sodium selenite (Taylor Pickard and Close, 2010)



Shipp *et al.* (2008), also reported that the weaning weight of piglets from sows fed 0.3 ppm Se from Se yeast was 0.48 kg heavier than that of piglets fed 0.3 ppm Se from sodium selenite at similar age at weaning. Similarly, when piglets weaned from sow fed either Sodium selenite or Se Yeast were fed either Sodium selenite or Se yeast at 0.3 ppm Se in their diets in the 4-week period post weaning, mortality was reduced from 6.0 to 2.8%. This reduction in mortality, together with the higher litter size at weaning, results in an extra 1.1 pigs sold per sow per year (assuming 2.3 litters per sow per year).

Table 6. Effect of Se source on piglet mortality post weaning (Lampe *et al.* 2005)

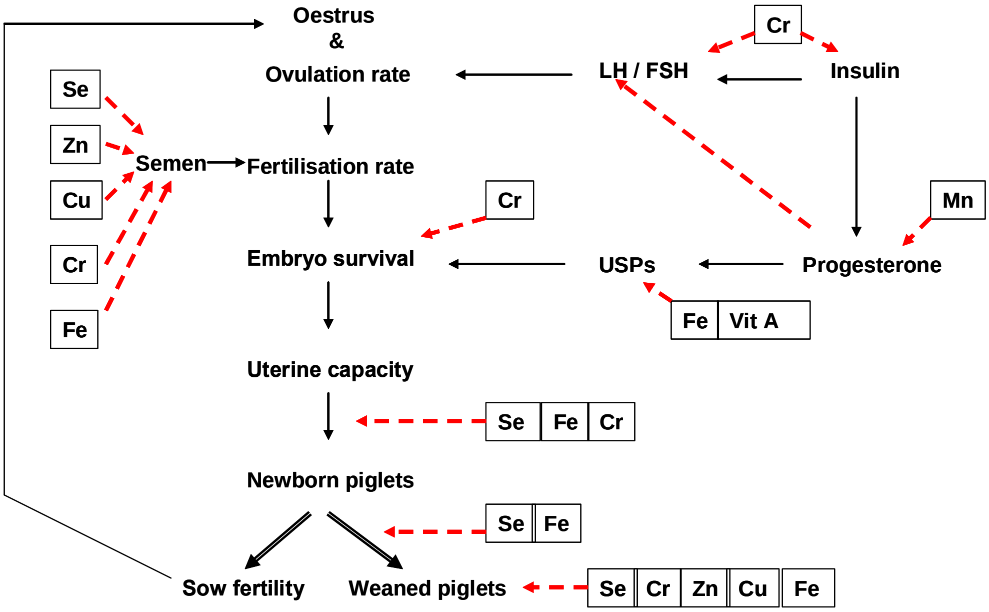
Sow diet	Sodium Selenite (Na Se)		Selenium Yeast (Se yeast)	
	/	\	/	\
Piglet diet	Na Se	Se yeast	Na Se	Se yeast
	|	|	|	|
Mortality (%)	6.0	4.8	3.6	2.8

These studies demonstrate the superiority of providing Se in Se yeast rather than the inorganic form, such as sodium selenite.

TRIALS ON COMBINATION OF MINERALS

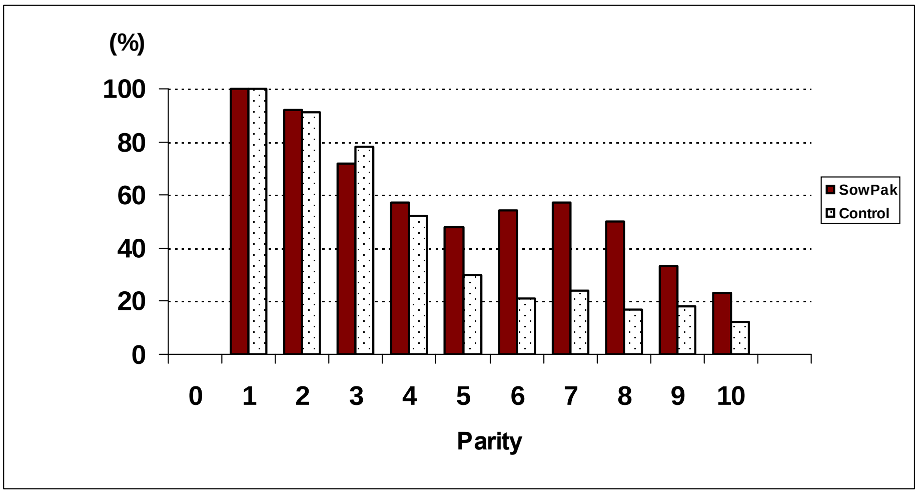
Different trace minerals impact at different periods of the reproductive life of the sow and it is likely that the greatest impact on sow productivity will be from combinations of minerals (Figure 5).

Figure 5. Role of minerals in sow reproduction (Close, 1999)



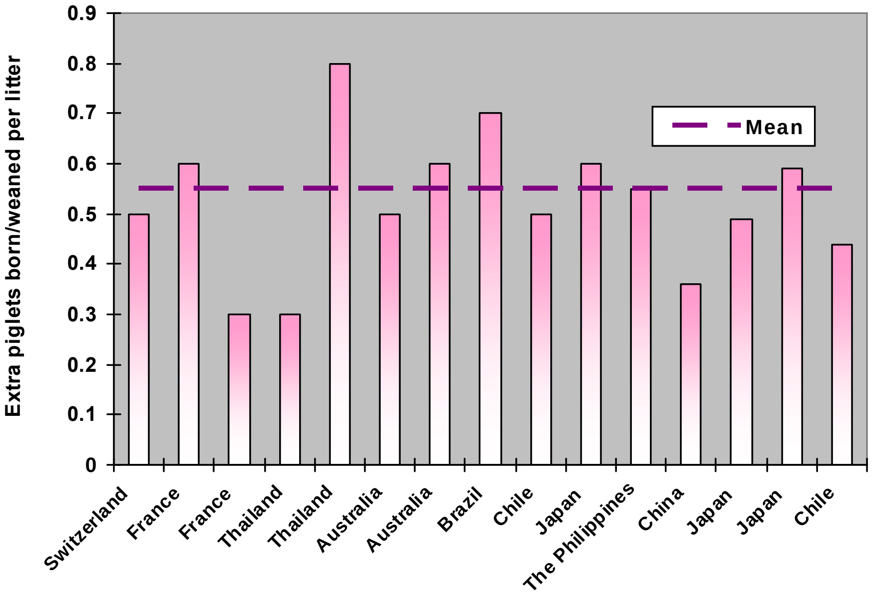
With this in mind, Fehse and Close (2000) supplemented the diet of sows with a special combination of organic minerals (Sow-Pak™: Se, Fe, Zn, Cu, Mn and Cr, Alltech Inc) and reported an extra 0.5 piglets weaned per litter for sows weaning 26.5 piglets per sow per year. Sow longevity was also increased as illustrated in Figure 6. The proportion of the sows fed Sow-Pak™ 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.

Figure 6. The proportion of sows in the different parities when the diet was supplemented with organic minerals, compared with inorganic mineral supplementation



Since this original trial, a number of commercial and field trials have been conducted in which Sow-Pak™ (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 7).

Figure 7. The effect of organic mineral supplementation (Sow-Pak™) on litter size (Close, 2007)



Supplementation of the diet with organic minerals increased the number of piglets weaned by 0.52 ±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 ROI value of 4.5:1.

An interesting study has recently been reported by Peters and Mahan (2008) in which they compared the performance of sows fed diets containing either inorganic or organic trace minerals at NRC or industry levels to sows over 6 parities. Sows fed organic trace minerals produced more piglets per litter ($p<0.05$) compared with sows fed inorganic minerals: 12.2 *vs* 11.3 total born and 11.3 *vs* 10.6 born alive, respectively. Performance was highest when the diets were supplemented with organic minerals at industry compared with NRC levels. Reduced reproductive performance appeared to be exacerbated when the gestation diet contained higher dietary levels of calcium (Ca) and phosphorus (P) than those recommended by NRC 1998). They concluded that feeding sows organic trace minerals may improve sow reproductive performance, but there were minimal effects on other reproductive measurements. This is in contrast to the recent study of Papadopoulos *et al.* (2009) which concluded that partial substitution of inorganic minerals with a chelated mineral source failed to exert significant effect on performance and total body mineral concentration. However, the minerals were only provided during late gestation and lactation.

CONCLUSIONS

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. In this respect, 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.

REFERENCES

Ashmead, H.D. and Graff, D.J. (1982). Placental transfer of chelated iron. *Proceedings of the International Pig Veterinary Congress;* Mexico: pp 207.

British Pig Executive / Meat and Livestock Commission (2004) Feed formulations for Pigs. *A guide and practical interpretation of the BSAS nutrient requirement standards for pigs*. BPEX/MLC, Milton Keynes, UK.

British Society of Animal Production (2003). Nutrient Requirements Standards for Pigs. Authors: C.T. Whittemore, M.J. Hazzledine and W.H. Close. BSAS, Penicuik.

Close, W.H. (1999). Organic minerals for pigs: an update. In: *'Biotechnology in the Feed Industry. Proceedings of the 15th Annual Symposium'* pp 51-60. Edited by T.P. Lyons and K.A. Jacques. Nottingham University Press, Nottingham.

Close, W.H. (2007). The effects of organic mineral supplementation on sow productivity: an overview. In *'Manipulating Pig Production'* **XI:** p 91. Edited by J.E. Paterson. APSA, Werribee, Victoria.

Close, W.H. and Taylor-Pickard,, J. (2005). The effects of maternal organic iron supplementation on piglet performance. *12th International Symposium on Trace Elements in Man and Animals.* Poster P8. Page 52. University of Ulster, Coleraine, N. Ireland.

Damgaard Poulsen, H. (1993). Minerals for sows. Significance of main effects and interactions on performance and biochemical traits. *PhD Thesis*, University of København, Denmark.

Fehse, R. and Close, W.H. (2000). The effect of the addition of organic trace elements on the performance of a hyperprolific sow herd. In: *'Biotechnology in the Feed Industry. Proceedings of the 16th Annual Symposium'* pp 309-325. Edited by T.P. Lyons and K.A. Jacques. Nottingham University Press, Nottingham.

GfE (2006) Empfehlungen zur Energie- und Nährstoffversorgung von Schweinen. DLG Verlag, Frankfurt am Rhein, pp 247.

Lampe, J., Gourley, G., Sparks, J. and Stumpf, T. (2005) Pre-wean piglet survivability: Sel-Plex™ *versus* sodium selenite as selenium. *Journal of Animal Science*, **83** (Supplement 2): Abstract 205.

Lindemann and Kim (2006) Recent advances in sow reproductive function. In: *Nutritional approaches to arresting the decline in fertility of pigs and poultry.* Edited by J A Taylor-Pickard and L. Nollet. Wageningen Academic Publishers. Wageningen, The Netherlands.

Mahan, D.C. (2000) Effect of organic and inorganic selenium sources and levels on sow colostrum and milk selenium content. *Journal of Animal Science*, **78**: 287-2879.

Mahan, D.C. (2007) Pressures on mineral reserves: What's the best way to meet the needs of highly prolific sows? In: *'Nutritional Biotechnology in the Feed and Food Industries. Proceedings of Alltech's 23rd Annual Symposium'* pp 71-80. Edited by T.P. Lyons and K.A. Jacques. Nottingham University Press, Nottingham.

Mahan, D. and Newton, C. A. (1995). Effect of initial breeding weight on macro- and micro-mineral composition over a three-parity period using a high-producing sow genotype. *Journal of Animal Science*, **73**: 151-158.

Mahan, D.C. and Peters, J.C. (2004) Long-term effects of dietary organic and inorganic selenium source and levels on reproducing sows and their progeny. *Journal of Animal Science*, **82**: 1343-1358.

Mahan, D.C. and Peters, J.C. (2006) Enhancing sow reproductive performance by organic trace mineral dietary inclusions. In*: Nutritional Biotechnology in the Feed and Food Industries*. Proceedings of Alltech's 22nd Annual Symposium, pp 103-108. Edited by T.P. Lyons, K.A. Jacques and J.M. Hower. Nottingham University Press, Nottingham.

NRC (1988). National Research Council. Nutrient Requirements of Domestic Animals, No. 2. *Nutrient Requirements of Swine. 10th Edition.* Natural Academy of Sciences, Washington. D.C.

Papadopoulos, G.A., Maes, D.G.D and Janssens, G.P.J. (2009). Mineral accretion in nursing piglets in relation to sow performance and mineral source. *Veterinaria Medicina*, **54**: 41-46.

Peters, J.C. and Mahan, D.C. (2008) Effects of dietary organic and inorganic trace mineral levels on sow reproductive performances and daily mineral intakes over six parities. *Journal of Animal Science*, **86**: 2247-2260.

Richards, M.P. (1999). Zinc, copper and iron metabolism during porcine fetal development. *Biological Trace Element Research* **69**, p 27-36.

Roberts, R.M., Raub, T.J. and Baer, F.W. (1986). Role of uteroferrin in transplacental iron transportation in the pig. *Federation Proceedings*, **45,** 2513-2518.

Shipp, T.E., Funderburke, D.W. and Funderburke, C.L. (2009). Effects of feed sodium selenite *vs* selenium yeast as the selenium sources for sows during late gestation and lactation. *Journal of Animal Science*, **87** (Supplement 2): Abstract 261.

Taylor-Pickard, J.A. and Close, W.H. (2010) The effects of Sel-Plex™ on sow performance: an overview. Poster presented *at Alltech's 26th Annual International Animal Health and Nutrition Symposium:* 16-19 May, Lexington, Kentucky, USA.

Whittemore C.T., Close, W.H. and Hazzledine, M.J. (2002). The need for nutrient requirement standards for pigs. *Pig News and Information* **23**, 67N-74N.

Yoon, I. and McMillan, E. (2006) Comparative effects of organic and inorganic selenium on selenium transfer from sows to nursing pigs. *Journal of Animal Science*, **84**: 1729-1733.