Mineral Supplementation in Modern Pork Production Systems for Optimum Health and Efficiency – The Need for Renewed Focus

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Introduction

Significant improvements in the efficiency of pork production have been seen in the past 10 years as a result of enhanced growth and feed conversion in the progeny and reproductive performance in the breeding herd. As a result of demands for food security, minimal environmental impacts, enhanced animal welfare and optimum health of consumers, the next 10 years will again see dramatic changes in pork production based around the need for further enhancements in efficiency and the nutritional qualities of pork whilst reducing the use of sow confinement during gestation and lactation.

Considering the magnitude of production efficiency changes between 2000 and 2010, it is reasonable to assume that the basic genetics, management and nutrition of most pig herds have also changed. Why then do we accept that the requirements for key minerals such as calcium, zinc, copper and manganese have remained static and that research conducted predominantly in the 1950's and 60's has any relevance to the modern pig. Using zinc as an example, the National Research Council (1979) and the Agricultural Research Council (1981) suggested that estimation of a zinc requirement was difficult given the number of interacting factors. These include the dietary calcium and phosphorus level, the presence of phytic acid or plant phytates, copper, cadmium, cobalt, vitamin D and protein level and source. The recommended dietary zinc level of 50 ppm (assuming dietary calcium content of no more than 0.75%) was proposed to prevent deficiency and avoid hyperkeratinisation or parakeratosis. The Standing Committee on Agriculture (1987) reviewed zinc recommendations and proposed a dietary level of zinc for growing pigs and sows of 45 mg/kg. Finally, the National Research Council (1998) reiterated 50 ppm as the dietary zinc requirement for all classes of pigs, but the latest data used to underpin this recommendation was from research undertaken in 1970. As a consequence, in 2010 we are using a dietary zinc recommendation based on 40-60 year old research with parakeratosis as a zinc deficiency being the primary basis for this recommendation. The same situation exists for calcium, phosphorus, manganese and copper and in the 20 years between 1979 and 1998 the recommended daily allowances for these minerals and projected feed intakes for different classes of pigs also remained the same (NRC, 1979; 1998).

If we compare the NRC (1998) recommendations for zinc, copper and manganese with commercial vitamin and mineral premixes used in pig diets (Table 1) we can see that these premixes make significant allowances above and beyond the NRC (1998) recommendations. In young pigs, the zinc content of the premix makes no allowances and equates to the requirement due to the routine use of 3000 ppm of zinc oxide in addition to the premix for the control of *E.coli* scours.

Table 1. *Comparison of NRC (1998) recommendations for zinc, copper and manganese with commercial vitamin and mineral premixes (mg/kg of diet).*

	Starter (5-20 kg)		Grower (20-110kg)		Breeder	
Mineral	Premix	NRC	Premix	NRC	Premix	NRC
Zinc	100	100	100	50	120	50
Manganese	40	4	40	2	50	20
Copper	20	6	15	4	15	5

Accounting for the fact that calcium, phosphorus, zinc, copper and manganese are all integral to the structural development and physiological functions of growing and breeding pigs, the aim of this paper is to discuss some of the changes that have or are likely to occur in modern pig production to prompt a rethink of how these minerals are applied in commercial practice and assess the adequacy of current commercial premixes.

Genetic Changes

Growing pigs

The primary driver behind the establishment of any nutrient requirement is feed intake. In the past 10 years genetic selection has favoured an increase in leanness and mature body size of the progeny pig as well as improved growth rate and feed conversion efficiency. A comparison of research undertaken by Campbell *et al.* (1988) and Moore *et al.* (2009) examining the response of growing pigs to increasing levels of total dietary lysine clearly demonstrates the genetic gains that have been made and the change in growth potential (Figures 1 and 2). The dramatic changes in average daily gain will accommodate most of the improvement observed in feed conversion efficiency as opposed to a reduction in feed intake, but we are now producing far more pig per unit of feed consumed than ever before. This alone should drive an overall increase in the dietary concentration of vitamins and minerals. In addition, the rapid growth rates require the pig to develop a robust structural conformity in a much shorter period of time which will also place greater demands on the mineral composition of the diet.

One way to extrapolate the possible increased demands on the modern progeny pig and the changing requirements for key minerals is to examine research on the metabolic responses of pigs to the exogenous administration of porcine somatotropin (pST). Goodband *et al.* (1993) reported that pST and dietary lysine increase rate, efficiency and composition of gain in pigs, but that bone growth was affected. Bones were weaker, more elastic and less mineralized. Subsequent research by Carter *et al.* (1999) showed that pST increases the absorption and retention of Ca and P independent of dietary Ca and P level, however, serum measures associated with Ca, P and bone metabolism were dependent on the Ca and P content of the diet suggesting an effect of increased growth hormone on the homeostatic control of Ca, P and bone metabolism.

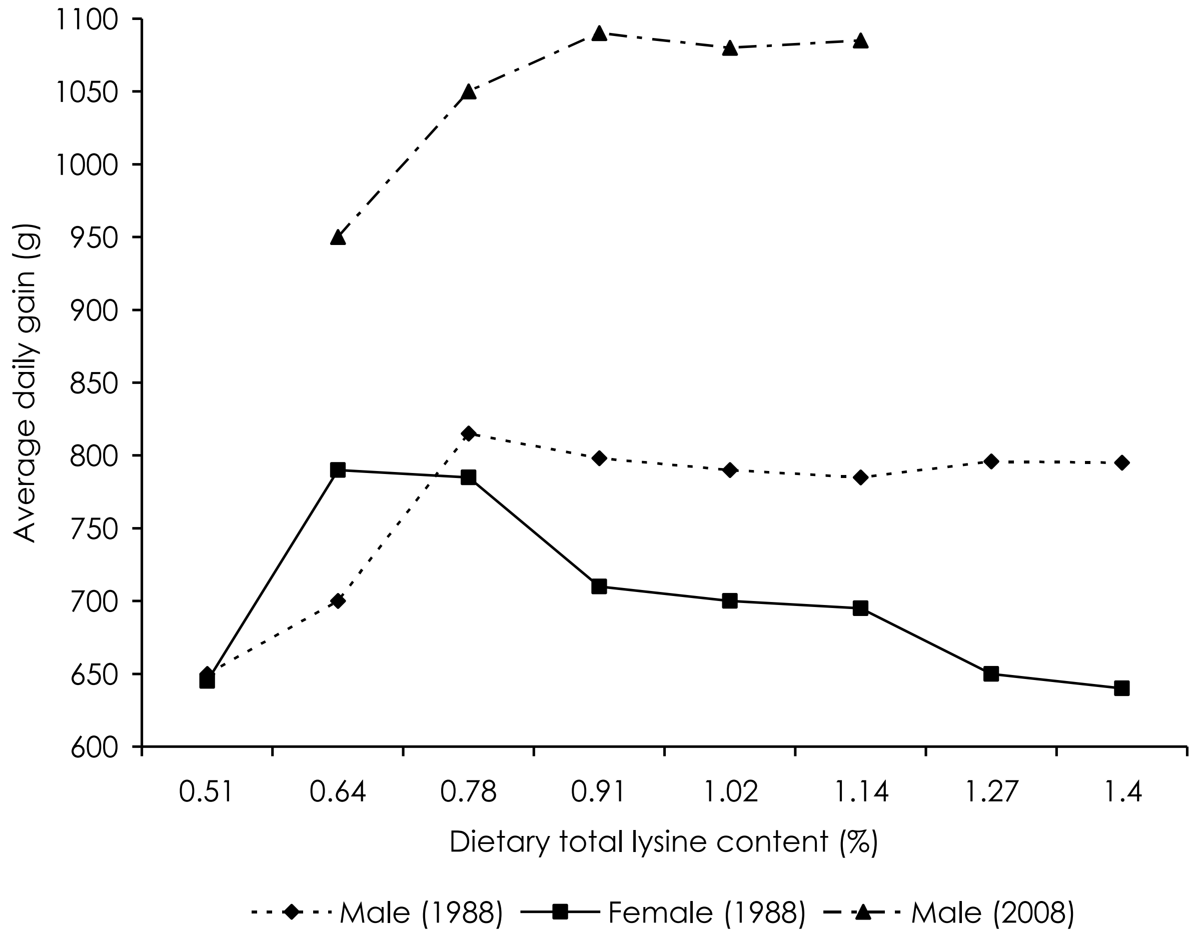

Figure 1. *Average daily gain (g) of growing pigs fed increasing levels of total dietary lysine (%) in 1988 (Campbell et al. 1988) and 2008 (Moore et al. 2009).*

Observed responses to pST administration on dietary calcium requirements and phosphorus requirements, together with the demands to impart structural conformity in modern lean genotypes have tended to see an increase in the dietary calcium content of growing pig diets compared with NRC (1998) recommendations with base levels of 0.9%-1.1% not uncommon in commercial diets. Aside from any changes that may have occurred in feed intake, this increase in dietary calcium content necessitates an increase in the base level of zinc in the diet, with calcium known to depress zinc absorption (NRC, 1998). Caperna *et al.* (1989) also demonstrated that feed intake *per se* had significant effects on the concentrations and total amounts of iron, copper and zinc in various tissues and may influence the metabolism of other dietary components.

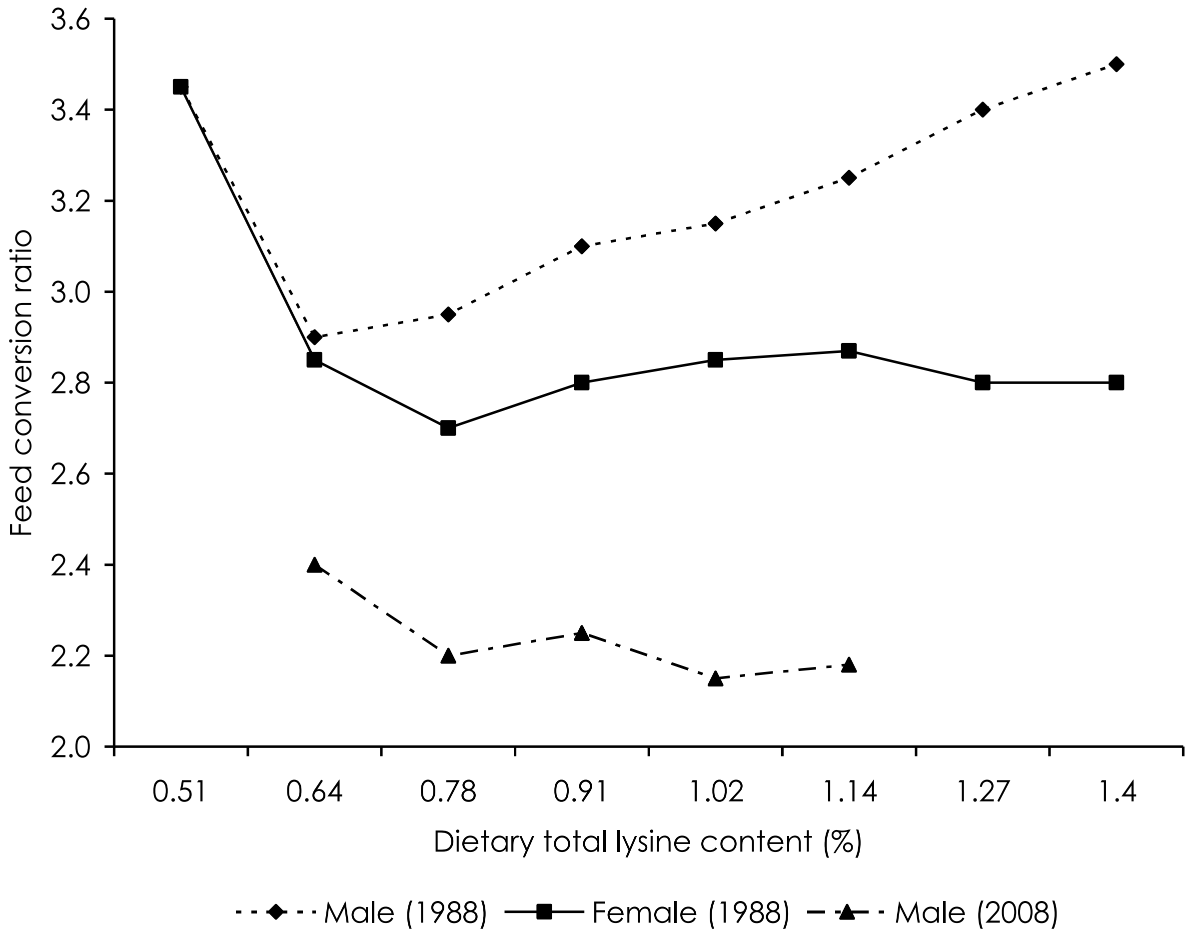

Figure 2. *Feed conversion ratio of growing pigs fed increasing levels of total dietary lysine (%) in 1988 (Campbell et al. 1988) and 2008 (Moore et al. 2009).*

Breeding pigs

Primary selection pressure on maternal traits in modern genotypes has been on litter size with the pressure being greater than ever before in the past 10 years. Close and Cole (2000) reported marginal change in pigs born alive/litter between 1970 and 1999 (Table 2) with this supporting minimal increases in the requirements for trace minerals over the same period.

Table 2. *Changes in sow performance between 1970 and 1999 (from Close and Cole, 2000).*

	1970	1975	1980	1985	1990	1995	1999
Litters/sow/year	1.9	2.0	2.18	2.25	2.23	2.25	2.25
Piglets born alive/litter	10.3	10.4	10.3	10.4	10.7	10.8	11.0
Piglets reared/sow/year	16.3	17.5	19.8	20.9	21.1	21.6	22.0
Annual sow disposals (%)	-	33.9	35.9	38.1	40.0	42.6	42.0
P_2 at 100kg (mm)	-	22.0	19.0	14.5	13.0	11.5	11.0

Pedersen (2010) showed similar increases in live born piglets per litter in Denmark up until 1999, but since then there has been an exponential rise in productivity with live born piglets approaching 14 per litter and pigs per sow per year exceeding 30 (Figure 3).

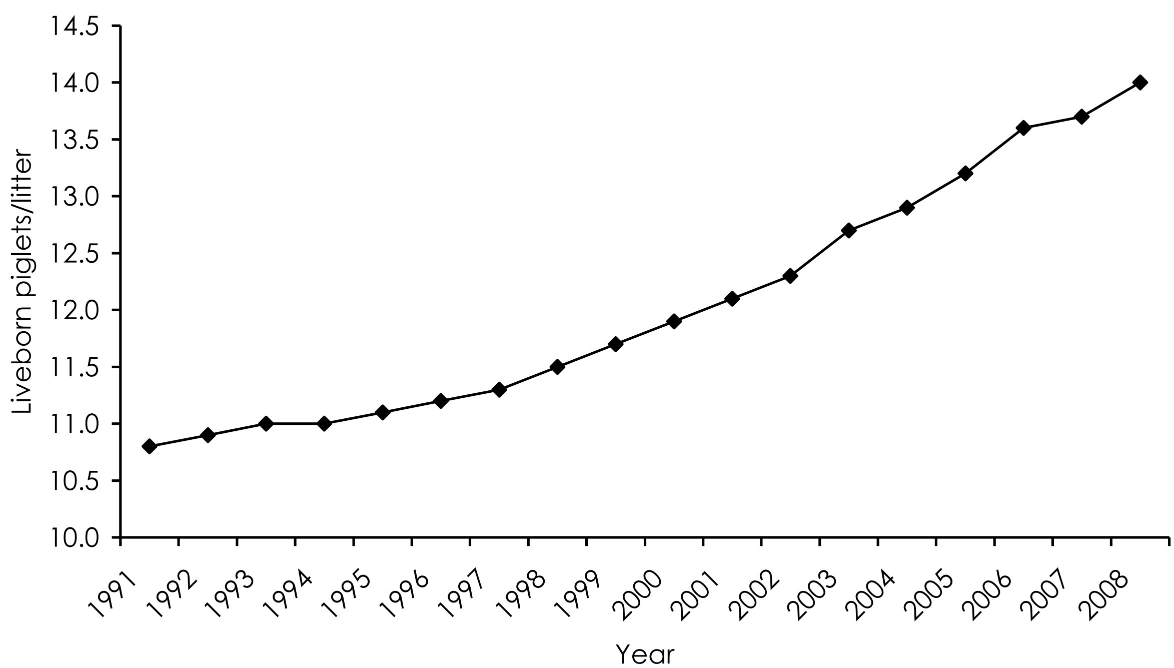

Figure 3. *Increase in live born piglets per litter in Denmark between 1991 and 2008 (from Pedersen, 2010).*

While other countries may not have reached the same performance levels as those achieved in Denmark, the selection pressure for litter size has remained with the consequence being additional nutrient demands on the sow during gestation and lactation. Recent research undertaken in Australia reveals that genetic selection alone cannot increase lactation feed intake fast enough to accommodate these increased demands (C. Lewis, *pers comms*). Lactation feed intake has a heritability of 0.18 which is far less than current estimates on finisher traits. As a consequence, dietary density of specific nutrients must increase to accommodate the increased demands on the sow and to ensure piglets are receiving an adequate level of trace nutrients that will support their rapid growth and development of the immune system.

During gestation, there is a high likelihood that increased litter size will also significantly increase the requirement for dietary zinc. Richards (1999) demonstrated that maternal levels of serum zinc decreased over the course of gestation to levels equivalent to those in the serum of piglets (Figure 4). As the level of serum zinc in piglets appears to remain constant over the course of the gestation, it is reasonable to assume that larger litters will result in a more rapid decline in maternal serum zinc levels which may subsequently compromise both the sow and the piglet.

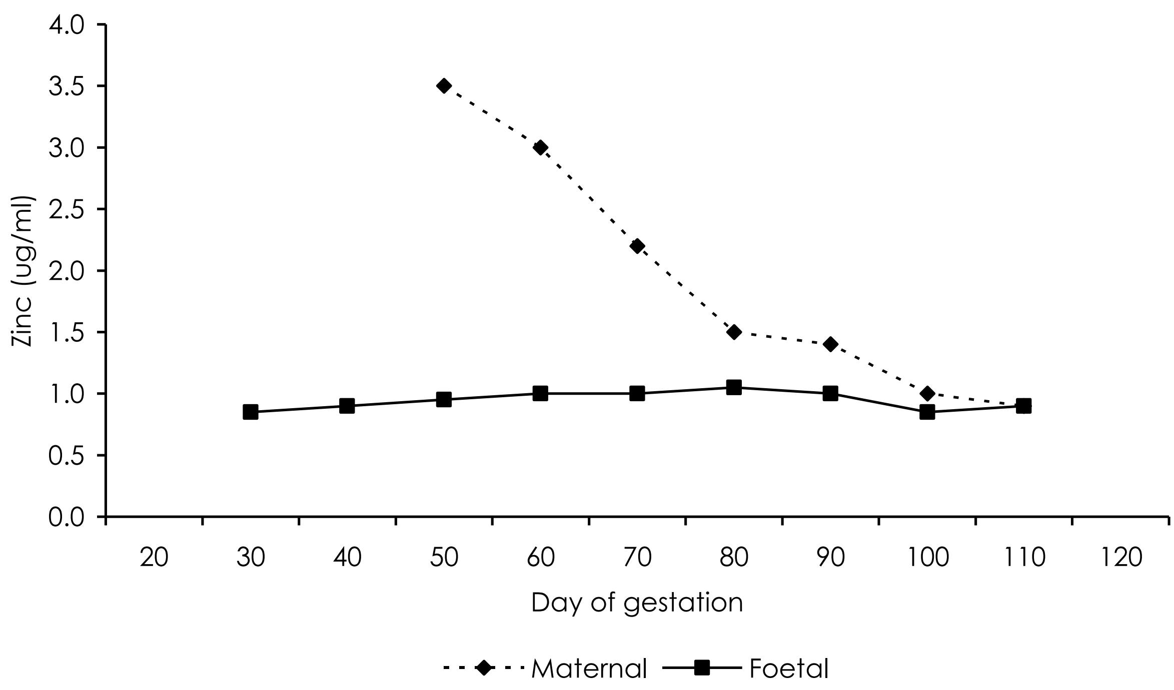

Figure 4. *Zinc concentration (µg/ml) in maternal and foetal serum as a function of day of gestation (from Richards, 1999).*

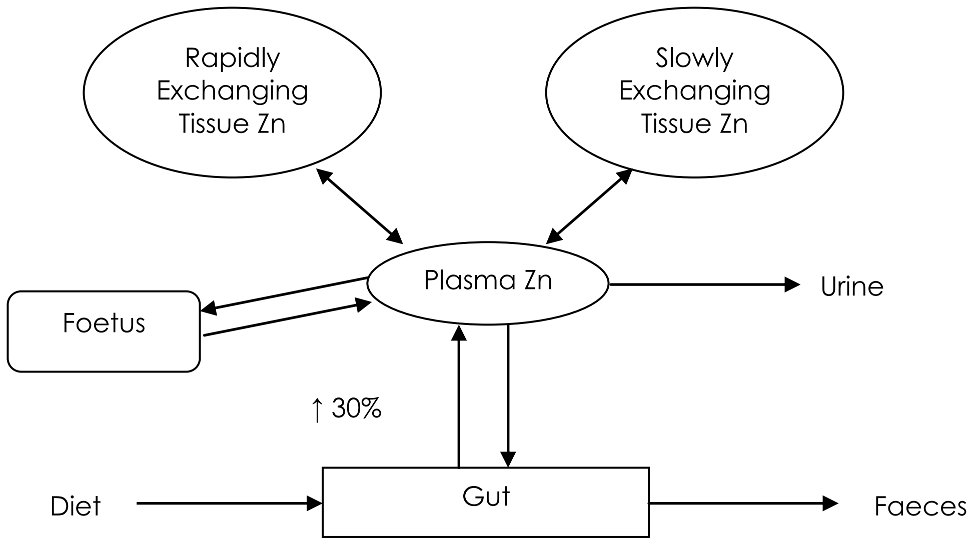

Figure 5. *Model of zinc metabolism in late pregnancy (from King, 2000).*

King (2000) developed a model for zinc metabolism in late pregnancy for mammals (Figure 5) and demonstrated that mobilization of zinc body reserves in the gestating female is inadequate to accommodate the zinc demands of the developing foetus and the a 30% increase in zinc absorption from the gut was required to accommodate these demands. Mahan and Newton (1995) demonstrated that sow mineral reserves are depleted over a 3 parity period, and that sows of higher productivity had a greater loss of both macro and trace minerals than sows of lower productivities. According to Mahan (2006) the critical stage of minerals for the sow appears to be during late gestation and lactation with approximately 50% of the total minerals (macro and trace) being retained in the body of developing foetal pigs. Clearly, with increasing litter size, this is a fundamental area of focus in we are to ensure modern sows are receiving adequate levels of trace minerals.

Overall, if we account for the genetic gains that have been made in growth and feed conversion in growing pigs plus the improvements in productivity of the breeding herd it appears that the allowances made in commercial premixes over NRC (1998) recommendations are possibly marginal and require review.

Diet Composition Changes

While genetic changes over the past 10 years are likely to have driven the requirements for key minerals up in both growing pigs and sows, changes in the base composition of diets is likely to have a more variable effect and necessitates a more strategic approach to trace mineral nutrition.

We can see that commercial premixes provide significant excesses to NRC (1998) recommendations and make little allowance for the base contribution of key minerals from the macro ingredients in the diet. However, most of the research compiled by the NRC (1998) is based on corn-soybean meal diets. Hence any change in these base ingredients should also result in a change in the composition of supplementary mineral premixes. In addition, we are well aware that the availability of various trace minerals can be significantly influenced by the levels of other minerals in the diet. When we change the base ingredients in the diet, we are changing these mineral ratios significantly and subsequently need to investigate potential negative interactions in the overall diets.

From a diet composition perspective, the most significant changes in pig diets in the past decade worldwide have been pressure against key energy sources such as corn and wheat, the widespread use of dried distiller's grains with soluble (DDGS), pressure to remove mammalian proteins from diets and a heavier reliance on vegetable proteins (particularly oilseed meals), and the use of dietary phytase. All of these factors will have had an influence on trace mineral supplementation, but over the same period changes in premix composition have been minimal.

Analysis of the zinc, copper and manganese content of key macro ingredients for pig diets (Table 3) demonstrates the change that can occur in background levels of these minerals with changes in diet composition. A reduced reliance on corn and soybean meal as a result of DDGS use is likely to reduce pressure on zinc requirements but increase pressure on copper and manganese. Reduction in the use of meat and bone meal will have a significant effect on the base levels of all minerals, whereas loss of blood meal will have less significant effects. Not only will these changes influence the efficiency of growing pigs, but they could have profound influence on the longevity and foot health of the breeding herd when these revised diets are fed over extended periods. These influences require quantification through additional research.

Table 3. *Trace mineral composition of key macro ingredients used in pig diets (from Premier Nutrition, 2008).*

Ingredient	Trace mineral (mg/kg)		
	Zinc	Copper	Manganese
Maize	20	6	5
Wheat	30	4	30
Soybean meal (48% crude protein, solvent extracted)	50	15	43
DDGS (US, alcohol manufacture)	87	5	14
Meat and bone meal	100	15	25
Blood meal	36	10	3

Increasing competition for cereal grain resources for biofuel production or as a consequence of drought has seen prices rise to unprecedented levels in recent years. An example of how fragile this cost structure can be was seen in July/August 2010 when a ban on Russian wheat exports as a result of fire and drought drove the price of Australian wheat up by more than $AUD100/tonne (more than 30%) in the space of 10 days. When formulating commercial pig diets, high cereal grain prices often result in the inclusion of low cost "fillers" under least-cost algorithms in an attempt to conserve the amount of grain used in the diet. A generous range in dietary calcium levels and the ratio of calcium to phosphorus means that ingredients such as limestone can often increase in use in these circumstances. While the dietary calcium level is still within acceptable limits, it is often much higher than when cereal grain prices are lower. As a consequence, the pressure on the availability of trace minerals such as zinc (which is reduced in the presence of high calcium levels) can be increased. This is of particular concern in gestating sow diets where there is a tendency for higher use of calcium sources such as limestone or clay minerals such as bentonite when grain price is high. In these instances, careful attention should be paid to the supplementary premix composition and the potential negative effects of some "fillers" on overall dietary nutrient availability.

A range of experiments compiled by the NRC (1998) demonstrated that the presence of phytate-bound phosphorus can significantly reduce zinc availability (and potentially other trace minerals and dietary nutrients). Since the publication of the NRC recommendations, access to, and use of microbial phytase in pig diets has become common practice, particularly when high levels of vegetable proteins are used. Again, this has prompted little change in the approach to the formulation of supplementary vitamin and minerals but based on research conducted by Revy *et al.* (2003) a review may be warranted. Revy *et al.* (2003) reported that the addition of microbial phytase to pig diets improves zinc bioavailability and estimated that the addition of 1000 units of microbial phytase/kg of diet was equivalent to the addition of 24 and 19 mg/kg of zinc added as zinc sulphate to the diets of piglets weighing 15 and 25 kg, respectively.

Parity and Environment

For mill logistics alone, supplementary vitamin and mineral premixes for gilts and sows tend to remain constant. However, herd structure and season can have a profound effect on feed intake and overall trace mineral consumption. If we observe mean lactation feed intakes of gilts and sows by month of farrowing over the course of a year (Figure 6), we see that gilts eat on average 25% less than sows across the year and that peak intakes can be almost 20% higher than the lowest intakes experienced in summer.

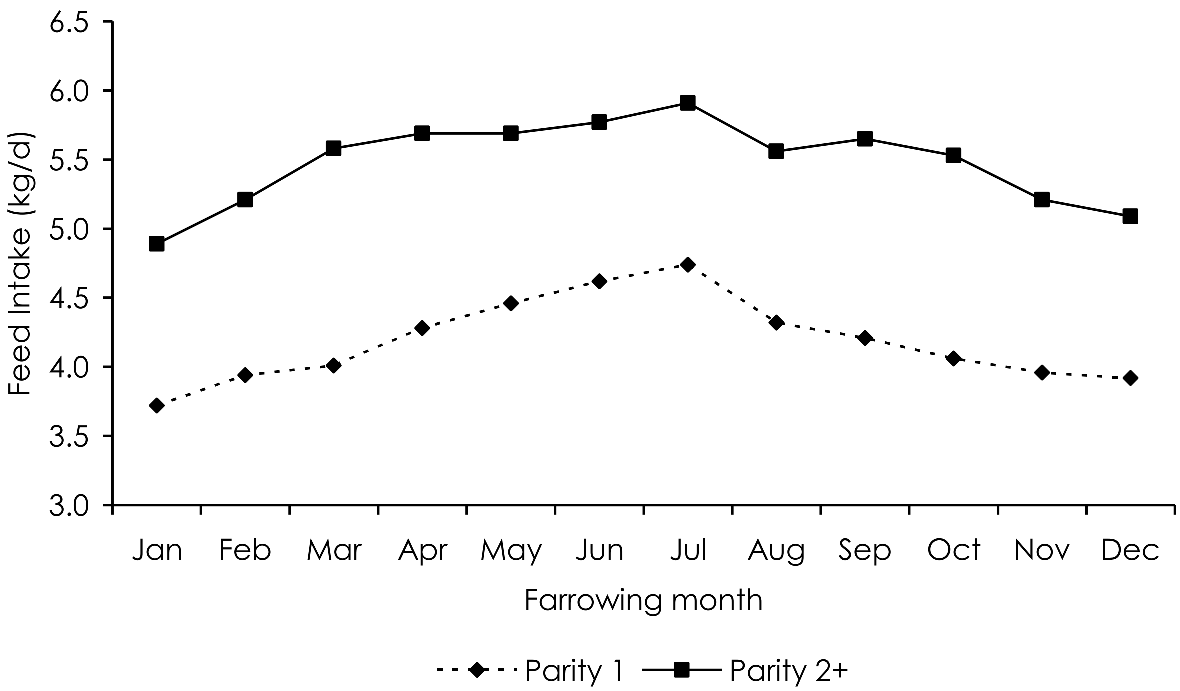

Figure 6. *Comparative mean lactation intakes of gilts and sows by month of farrowing (from Hermesch, 2008). Note this is southern hemisphere data so summer occurs in December-February.*

The differences in feed intake can equate to almost double the intake of trace minerals during winter months compared with summer months (Table 5). At the very least it would be worth considering a change in vitamin and mineral premix for the summer vs. winter months. Further to this, parity structure of the herd should also be accounted for in the base breeding herd premix. A low average parity herd will not only have lower mean lactation intakes, but the higher proportion of gilts in the herd will increase the range in intakes experienced during lactation (Figure 7).

Table 5. *Comparative trace mineral intakes from commercial premixes by highest and lowest consuming sows during lactation.*

	Trace mineral (mg/kg)		
Lactation Feed Intake (kg/d)	Zinc	Copper	Manganese
3.5	420	53	175
5.9	708	89	295

While variation in lactating gilt and sow intake as a result of season or parity has always been a challenge, the low lactation intakes of modern genotypes that have evolved over the past 10 years mean that any further depression in feed intake could bring trace mineral consumption down to very marginal levels.

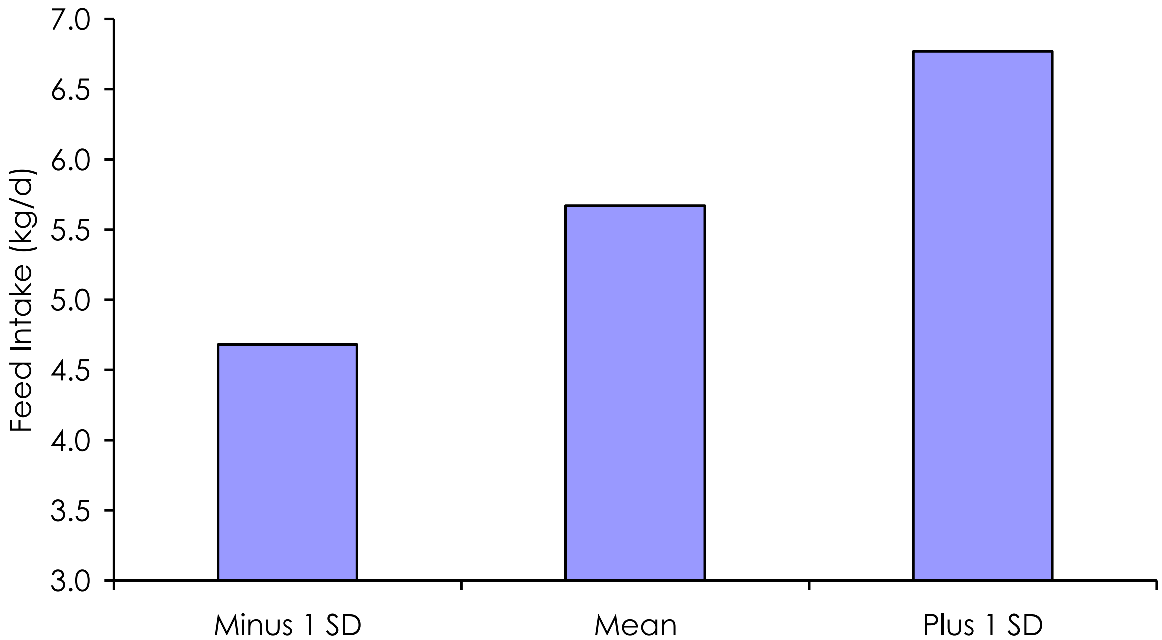

Figure 7. *Range in gilts feed intakes during lactation (from Smits et al. 2009)*

Management Changes

Factors such as genetic gain, diet composition, parity structure and environment and their influence on the trace mineral nutrition of pigs tend to reflect changes over the past 10 years. Moving forward, it is pig management that will have the greatest influence on mineral nutrition.

Two key changes in pig management will influence the focus on trace mineral nutrition – the removal of sow confinement during lactation and gestation and the need for sow longevity.

Consumer and retailer pressure is rapidly driving a change from predominantly stall housing of gestating sows to group housing. While most systems currently accommodate the use of stalls for at least 6 weeks post-mating prior to grouping, this use is also likely to diminish. It is also likely that the application of farrowing crates in production systems will come under increasing scrutiny in the future.

A primary consequence of the move to group housing of sows during lactation and gestation is the potential for lameness as a result of claw damage. Van Barneveld (2008) summarized a range of predisposing factors to claw lesions with those related to group housing including:

- Group penned sows are more likely to have all types of lesions in any claw and more severe lesions compared to individually stalled sows (Anil, 2007a).
- Claw problems increase the longer sows are housed in groups and the longer they are kept on slatted floors (Beers-Schreurs *et al*., 1991).
- Sows of parity ≤ 5 are more likely to have white line lesions in any claw than sows of parity > 5 (Anil, 2007b).

At present, our knowledge of trace mineral nutrition and the potential to alleviate claw damage in group situations is limited and requires further investigation. It is also likely that we will need to embark on breeding programs for more robust sows capable of withstanding group housing systems with a concurrent change in the base mineral requirements of these sows. Together with strategies that may include mating sows during lactation as a means of reducing the need for sow confinement, the next 10 years could see a new production paradigm with a concurrent widening of the gap in our knowledge of the base mineral requirements of the animals in these systems.

A further challenge in the modern pig production system will be the need to increase sow longevity while increasing the use of group housing systems. Herds worldwide already suffer as a result of premature culling of sows, and an increase in lameness as a result of claw lesions resulting from group housing will be counter-productive. Dhyuvetter (2000) reported that at least 3 litters from a sow are required to achieve true profitability within a herd with Huirne *et al.* (2003) calculating that 5.5 litters per sow lifetime is optimal. With this in mind, the base economic equation surrounding the feeding of developing, gestating and lactating gilts and subsequently sows changes significantly. Relative to the cost of having a high replacement rate in herds, there is significant scope and value in developing nutritional strategies that ensure long term sow conformation and productivity including novel trace mineral nutrition to prevent and alleviate lameness.

Conclusions

For a variety of reasons, basic research investigating the requirements of macro and trace minerals for growing and breeding pigs has progressed very little since the early 1960s. This is despite massive changes in the growth potential and management of modern pigs. While most commercial vitamin and mineral premixes provide significant safety margins above the base recommendations, a review of key nutritional drivers and the changes that have occurred over the past 10 years suggests that these safety margins may now be marginal at best. If we consider the significant management changes that are likely to occur in pig production over the next 10 years and how these may influence the mineral nutrition of the pig, there is an urgent need to revisit basic mineral requirements in pigs and to investigate the strategic use of trace minerals in efficient commercial production systems as a means of enhancing growth, immunity and preventing and alleviating lameness.

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