Modern pig nutrition for performance: minerals, metabolism and the environment

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Introduction

Worldwide the pork industry is undergoing rapid change in the way that it is structured and in the way that it operates. While the world demand for pork is expected to increase, especially with improved standards of living in developing countries, competition for these markets will be high (Mullan and D'Souza, 2005). Many producers may well question what security there is for themselves in the industry, since there are often large fluctuations in profitability despite the fact that pork is the most-consumed meat worldwide. The need to improve efficiency, lower production costs, and supply a product that meets consumer expectations are the key elements required for producers to remain profitable and viable.

A sustainable pig production system should, according to Honeyman (1996), enhance the following areas:

1. The environment and resource base (land, water, air, human, animal);
2. The quality of life for producers, pork consumers and society;
3. The profit level of producers;
4. The quality of pork produced.

Minerals play an important role in all of the above, because not only are many of them essential for growth and reproduction, their presence also influences quality of the end product and ultimately human health. However, simply supplying more minerals is not an option because of potentially harmful mineral, dietary, and environmental interactions. This paper looks at current dietary recommendations for several important minerals, and some of the options that are available to optimise animal performance while reducing effects on the environment.

The modern pig industry

One major change in the pig industry has been a reduction in the number of producers while the size of enterprises has increased. For example, between 1980 and 2000 the number of piggeries in the USA declined by almost 90% while there has been an almost 7-fold increase in the average number of pigs per operation (Stalder *et al.*, 2004). The increase in the size of pig units is usually brought about by a drive to reduce the cost of production since it gives the opportunity to spread the cost of overheads over a larger number of animals.

There has also been a decline in the pig industry in some countries whereas others are experiencing rapid growth for various reasons. Many of the countries that have been the traditional leaders in pig production are seeing their position challenged. Brazil, for example, is one country experiencing rapid growth. Between 1970 and 2003, while the size of the herd grew by only 10%, production increased by 261% (Rutz *et al.*, 2004). The rapid growth in productivity is attributed to the uptake of new technology during this period. While countries such as Brazil may not be constrained by the same environmental pressures as some European countries, they would do well to learn from the mistakes made by others and evaluate technologies that are available to reduce effluent load.

An increasing proportion of pigs is now also produced under contract with decisions on genetics, feed, building design and health programs not the direct responsibility of the person who is providing day-to-day care (Mullan and D'Souza, 2005). While this means that technical support can be provided by a range of specialists, integrating this information into the whole production system and making certain that changes are adopted in practice does not always follow.

A major reason for change in the pig industry is due to the many challenges that the industry faces. For example, in many countries the burden of disease has a major impact on animal performance and cost of production. At the same time, there is increasing concern about the use of antibiotics for reasons linked to antibiotic resistance in human health. The pig industry is also viewed by many as a major cause of pollution, in particular due to odours and contamination of water and soils. Hence the industry in many countries is in a position where there are a number of barriers to be overcome to remain viable.

Current and future challenges to the pork industry

There are a host of factors that will determine how the pig industry will be structured and operate in the future. Four factors of particular importance relate to the impact of the industry on the environment, the increased concern for the welfare of pigs, product quality and whether the industry is profitable. While the requirements differ between countries, the increase in international pork trading will mean that ultimately all producers will be affected in some way.

ENVIRONMENT

There are large differences in the density of pigs between countries with, for example, the Netherlands having an average of 14 pigs per hectare, whereas in Saskatchewan, Canada, the figure is 0.07 pigs per hectare (Stalder *et al.*, 2004). It is therefore not surprising that the pressure to reduce pig production in the Netherlands on environmental grounds is greater than it might be in Canada. Public concerns are mainly related to soil (accumulation and runoff of minerals from land where manure is applied), water (surface and ground water), and air quality environmental issues (Stalder *et al.*, 2004). While it is possible to reduce the environmental impact of minerals by the treatment of effluent, a more sustainable approach is to reduce the concentration in effluent by feeding the animal closer to its requirement and/or improving mineral bioavailability (Mullan and D'Souza, 2005).

WELFARE

Animal welfare activists have and will continue to have an important influence on the way pigs are reared in many countries. From a nutritional perspective, it is important that the mineral requirements of the pig are met so as to give it the best possible chance to cope with the conditions in which it is reared. For example, providing adequate levels of calcium (Ca) and phosphorus (P) for different life stages will alleviate risks of bone weakness and mitigate any related welfare concerns.

CONSUMERS

There is a growing awareness in the pork industry of the need to consider the requirements of the customer. Consumers require a product that they enjoy eating, is nutritious and has been produced with high standards of food safety (Mullan and D'Souza, 2005). Price is also a major factor that drives consumer choice, and so any interventions need to be achieved without any major increase in the cost of production.

PROFIT

Making a profitable return on the capital invested should always be the primary reason for being involved in the pig industry. There is usually little that producers can do to influence the price that they receive for their product, so most attention is focused on productivity and the cost of production. Despite a relatively large amount of funds having been spent on pig research and development in many countries, the improvements in productivity over time have been modest. There is still a large gap between what is achieved in commercial practice and what is possible. For example, while some producers are able to wean above 25 piglets per sow per year, the average for many is less than 20 (Close, 2004), yet we know that it is biologically possible for sows to produce more than 30 piglets per sow per year. Those producers and/or countries who will continue to be involved in pig production will be those that are prepared to evaluate and adopt new technologies to remain competitive in an increasingly global market (Mullan and D'Souza, 2005).

The success of the Premier Pig Program™, developed to provide independent technical information and support to the pig industry worldwide, is an excellent example of how often basic knowledge of pig husbandry is limiting performance on commercial farms (Close and Turnley, 2004). An important aspect of this program is to encourage producers to set target objectives for performance and to then identify actions and solutions that can be taken on-farm to enhance performance. In this way productivity and economic efficiency can be improved.

By far the largest cost in pork production is feed, making up between 60 and 70% of total production costs. As a consequence feed additives are often closely scrutinized, especially at times when the cost of the main ingredients is relatively high. There can be a temptation to remove some dietary additives as a way of reducing the cost per tonne. Hence it is important that those in the feed industry understand the reason why products such as organic minerals or enzymes have been included, and to have some idea of the cost-benefit relationship based on improvements in productivity that have been achieved in well-controlled studies under commercial conditions. This understanding is particularly important with respect to organic minerals, since the benefits of using these products are often long-term (e.g., increased number of piglets born alive per litter or reduced culling rate of sows). Unfortunately, the long-term nature of these beneficial responses can be easily masked by other deleterious events or independent variables.

Mineral requirements

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 (Close, 2003). Much of the research to determine mineral requirements was conducted more than 40 years ago with genotypes and rearing systems much different to those in a modern commercial piggery. As a consequence recommended mineral allowances have evolved over time and it is not surprising that when Whittemore *et al.* (2002) conducted a survey of dietary mineral additions in several European Union countries, there was wide variation, with some three to four times higher than those recommended by the ARC or NRC (Table 1).

To a large degree the European Union has become the benchmark for how governments will continue to place constraints on the inclusion rate of minerals to reduce environmental pollution. For example, the use of copper (Cu) and zinc (Zn) in pig diets has been severely restricted in recent times. Both are viewed by industry as inexpensive options as a growth promotant and as an approach to reduce the incidence of post-weaning diarrhoea, respectively.

COMMERCIAL PRACTICE

In an extensive review of how trace minerals are used in industry, Mateos *et al.* (2005) recorded the mineral content of a total of 32 premixes of minerals being used in commercial industry in Spain and compared this with recommended values. In general, the concentration of trace minerals used by industry was higher than that recommended by research institutions. The biggest differences observed were for Cu and manganese (Mn) in sows and for cobalt and iodine in all classes of pigs (Table 2). This practice demonstrates the different requirements of various sectors of the industry, but may also suggest a lack of confidence by industry in the recommendations currently available (Mateos *et al.*, 2005).

Table 2. Composition of trace mineral premixes in mg/kg of feed for growing-finishing pigs and sows in the Iberian Peninsula[1]

	Mean	CV, %	NRC (1998)	BSAS (2003)
Growing-finishing:				
Iron	94	35	60	80
Copper	99	47	4	6
Zinc	109	30	60	100
Manganese	46	18	2	30
Selenium	0.19	47	0.15	0.20
Iodine	0.77	44	0.14	0.20
Cobalt	0.27	62	-	0.20
Sows:				
Iron	82	27	80	80
Copper	16	64	5	6
Zinc	105	21	50	80
Manganese	55	25	20	20
Selenium	0.22	47	0.15	0.25
Iodine	0.95	35	0.14	0.20
Cobalt	0.41	61	-	0.20

[1]Mateos *et al.*, 2005.

Table 1. Range of dietary mineral additions in several EU countries (per kg feed)[1].

Body weight (kg)	Piglet 0 - 20	Growing pig 20 – 50	Finishing pig 50 – 120	Breeding sow
Zinc, mg	10 – 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

[1]Whittemore *et al.*, 2002.

In a study with sows over two parities conducted by Peters and Mahan (2004), NRC (1998) standards for dietary trace minerals were compared with what was considered to be normal industry standards (Table 3). The same study evaluated inorganic and organic sources of trace minerals (Cr, Cu, Fe, Mn, Se and Fe). Reproductive performance of animals over two parities was improved when trace minerals were fed in the organic form (Bioplex™, Alltech Inc.), but performance was reduced when the industry average levels were provided (Figure 1). Mahan (2005) suggests that when additional trace minerals are added to the diet at 'insurance levels,' they may in fact contribute to the accumulation of free radicals which can result in a decline in performance when the animal is placed under stress. The findings of Mateos *et al*. (2005) and Mahan (2005) highlight the importance of knowing the optimum dietary concentration of minerals, taking into account their form, if we are to achieve maximum productivity.

Table 3. NRC (1998) mineral levels (ppm) and those recommended by industry and university nutritionists for the breeding sow[1].

Mineral	NRC (1998)	Industry and university
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, 2005

ESTABLISHING REQUIREMENTS

It is clear that we do not know enough about the requirements of the modern genotype under commercial conditions. Van Lunen and Cole (1998) have suggested that the mineral needs for growth in the modern fast-growing pig are about twice the level required by the slower growing pigs of some 20 to 30 years ago. Unfortunately the research to establish the requirement for individual minerals is expensive and complicated to conduct, let alone extrapolate to take into consideration the influence of factors such as genotype and environment.

The mineral requirement for pigs challenged by disease is a good example of how we need to approach the problem. Most pigs in commercial facilities are challenged by one or more diseases at some time during their production cycle. Williams (1998) has demonstrated that when there is minimal activation of the immune system, feed intake is increased and the rate and efficiency of growth is greater compared with animals subject to a disease challenge. It was therefore suggested that disease status has a direct bearing on the nutrient requirements of the animal, and Williams (1998) demonstrated this by showing how the requirement for lysine is affected by immune system activation. In regards to mineral requirements, most experiments are conducted in high health status research facilities and we know little about the requirement for animals challenged by disease in commercial facilities. Nevertheless, we can speculate that the mineral

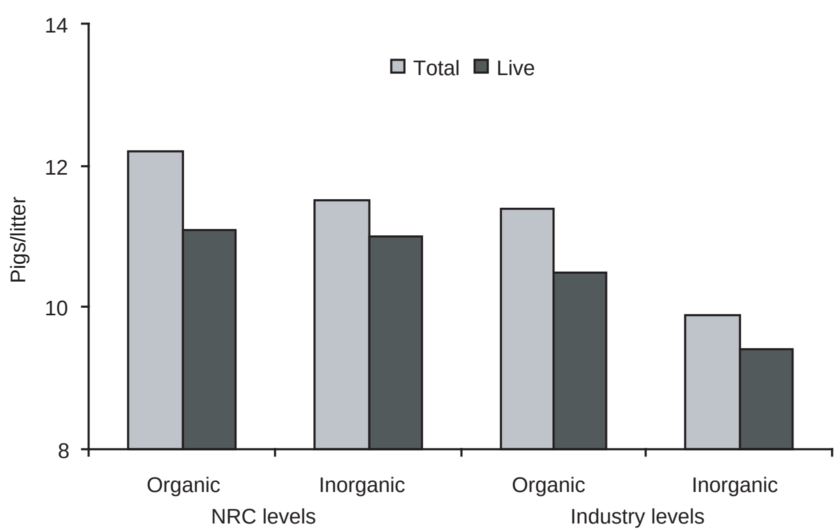

Figure 1. Reproductive performance of sows over two parities provided either inorganic or organic trace minerals (Bioplex™, Alltech Inc.) at levels recommended by NRC (1998) or by Industry (Peters and Mahan, 2004; referenced by Mahan, 2005).

requirement would change under stress, especially for those minerals with a direct role in the function of the immune system, and that organic minerals would be of greater benefit than similar minerals in the inorganic form because of their higher bioavailability.

Research into the requirement for trace minerals needs attention and perhaps a fresh approach. Co-ordination between different centres would be a benefit; at the same time allowing individual groups scientific freedom is also essential.

ORGANIC *vs* INORGANIC MINERALS

Inorganic salts, such as sulphates, carbonates, chlorides and oxides are traditionally added to the diet to provide the assumed correct levels to meet the animals' needs (Henman, 2001; Close, 2003). These salts are broken down in the digestive tract to form free ions that can form complexes with other dietary molecules, making them more difficult to absorb. The free ions are also very reactive and interactions between various minerals have to be taken into account when developing a nutritional program. For example, when Mullan *et al.* (2002) fed diets containing 0, 1.5, 3.0 or 4.5 kg/tonne of zinc oxide (ZnO), the concentration of Zn in plasma increased. However, there was a negative correlation between plasma Zn and plasma Cu; a 3-fold increase in plasma Zn corresponded to a 4-fold decline in plasma Cu, sufficient enough for individual pigs to be deemed Cu deficient. Interactions such as these may explain why at times animals do not respond to an increased supply of an inorganic mineral in the way that we might otherwise expect.

Inorganic minerals may also interact with other components in the diet thus influencing their bioavailability. For example, phytate has a high binding affinity for Cu and Zn (Mateos *et al.*, 2005). Wedekind *et al.* (1992) has demonstrated that a high concentration of either phytate or Ca in the diet reduced the bioavailability of Zn from Zn sulphate but not that of organic Zn (Zn methionine). Consequently, the use of exogenous phytase and the reduction in dietary Ca should be beneficial for pig growth (Adeola *et al.*, 1999).

Close (2003) reviewed results from a number of studies where the bioavailability of inorganic minerals was measured. Bioavailability was 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. With Zn, for example, it was suggested that 75 to 80% of the ingested Zn from inorganic sources is excreted by animals. It is therefore little wonder that there is interest in using forms of minerals that are better absorbed and utilized by animals. Through better availability, organic minerals can replace inorganic sources at a lower level while performance is maintained or enhanced (Fremaut, 2003). Organic minerals are also less reactive with other minerals, making the design of a mineral supplementation program much more reliable.

Role of organic minerals in the pig industry

Since organic minerals are more expensive to add to diets than are inorganic minerals, it is important to balance the additional cost against benefits in pig performance and product quality, and a reduced impact on the environment.

PERFORMANCE

Weaner nutrition

The use of ZnO has been considered an inexpensive alternative to the use of antibiotics for the control of post-weaning diarrhoea, and one that does not require veterinary approval. As a consequence the supplementation of diets with ZnO for 2 to 3 weeks after weaning has been widely practised. However, the high concentrations of Zn in faecal matter are of concern, and the use of high levels of ZnO is now banned in some countries. A number of studies have thus been undertaken to evaluate the use of Bioplex™ Zn as a possible alternative to ZnO, because of its higher bioavailability. In one study, Mullan *et al.* (2002) fed pigs weaned at 21 days either a Control diet containing no added Zn other than that included in the mineral premix, 1500 to 2250 ppm Zn from ZnO, or 100 or 250 ppm Zn from Bioplex™ Zn. Piglets receiving the diet containing Bioplex™ 250 had a significantly ($P<0.05$) higher growth rate and at the end of the experiment (60 days of age) were 11% heavier than those on the Control diet (Figure 2). These results suggested that adding 250 ppm Zn from Bioplex™ to the diet of weaner pigs has advantages over the current recommendation of adding high levels of ZnO. However, this study did not directly answer the question of how well Bioplex™ Zn would control post-weaning diarrhoea or scours.

Zinc also has a positive effect on both the immune response to pathogens and the prevention of disease by maintaining healthy epithelial tissue (Close, 2003).

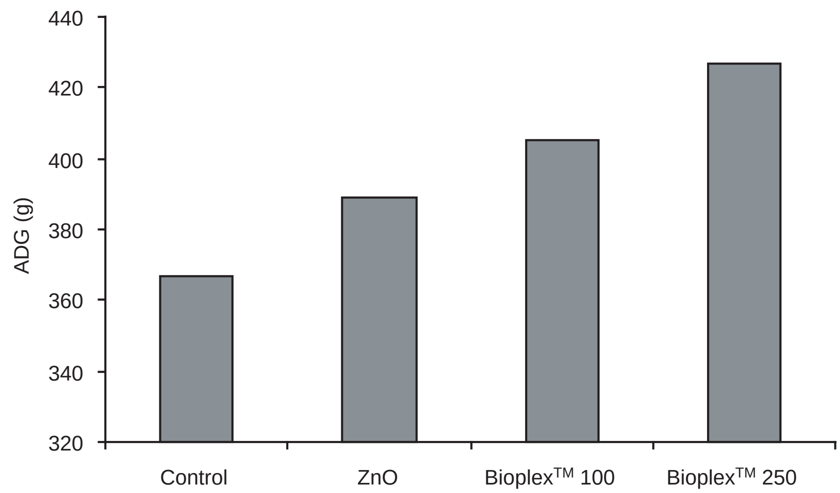

Figure 2. Average daily gain (ADG) of weaner pigs fed diets containing either ZnO (Control 190 ppm, ZnO at 2300 ppm) or Bioplex™ Zn (100 or 250 ppm) for the 39 days post-weaning (Mullan *et al*., 2002).

Carlson *et al.* (1998) have reported that high levels of ZnO altered duodenal morphology (deeper crypts and greater total thickness) and increased intestinal metallothionein concentration, which suggests that high amounts of Zn may have an enteric effect on the pig. Zinc oxide is also recognised as changing the diversity of the microbiota in the gastrointestinal tract (Katouli *et al*., 1999). With the move to restrict or ban the use of antibiotics in pig diets, it is important that we know more about the way minerals such as Zn might influence the microflora of the gut and its function so that we can develop feeding strategies that are beneficial to the animal, are cost effective and friendly to the environment.

Growers and finishers

By far the largest proportion of feed is used by grower and finisher pigs, and thus there is interest in anything that will improve growth rate, feed conversion and carcass quality without detriment to welfare or food safety. Henman (2001) evaluated the effects of diets containing $CuSO_4$ or Bioplex™ Cu on grower-finisher pig performance. Compared with the basal diet, providing 200 ppm of $CuSO_4$ improved growth rate by 5% and feed conversion by 3% (Table 4). There was no difference in performance between the pigs given 100 ppm Bioplex™ Cu and those fed 200 ppm $CuSO_4$, indicating that inorganic Cu could be successfully replaced by lower concentrations of organic Cu. Data such as these from a large commercial piggery provide the opportunity to compare the cost effectiveness of the organic alternative with inorganic Cu.

Table 4. The growth performance and carcass characteristics of male pigs fed diets containing two levels of $CuSO_4$ and Bioplex™ Cu[1] .

Copper level	$CuSO_4$ 20 ppm	$CuSO_4$ 200 ppm	Bioplex™ Cu 100 ppm
Start weight, kg	28.0	27.5	27.9
Final weight, kg	88.7	90.7	91.7
Average daily gain, g	726	731	766
Feed:gain	2.51	2.44	2.43
Average daily intake, kg	1.82	1.78	1.86
Carcass weight, kg	64.3	67.7	68.8
P2 fat thickness, mm	9.6	9.6	9.7
Dressing percent	74.5	74.8	75.1

[1]Henman, 2001

In a more recent experiment, Hernandez, Pluske, Turnley, Smith and Mullan (unpublished) compared Cu and Zn provided in either the inorganic or organic form to pigs from 25 to 107 kg live weight. Neither the form of trace mineral nor the concentration in the diet had any significant effect on growth rate, suggesting that higher concentrations of inorganic minerals can be replaced with lower concentrations of organic Cu and Zn without any detrimental effect on performance (Figure 3).

Breeding pigs

Mahan and colleagues have undertaken an extensive series of experiments to determine the influence of organic minerals on performance of breeding pigs, and demonstrated very clearly the advantage of supplying adequate minerals in a bioavailable form. For example,

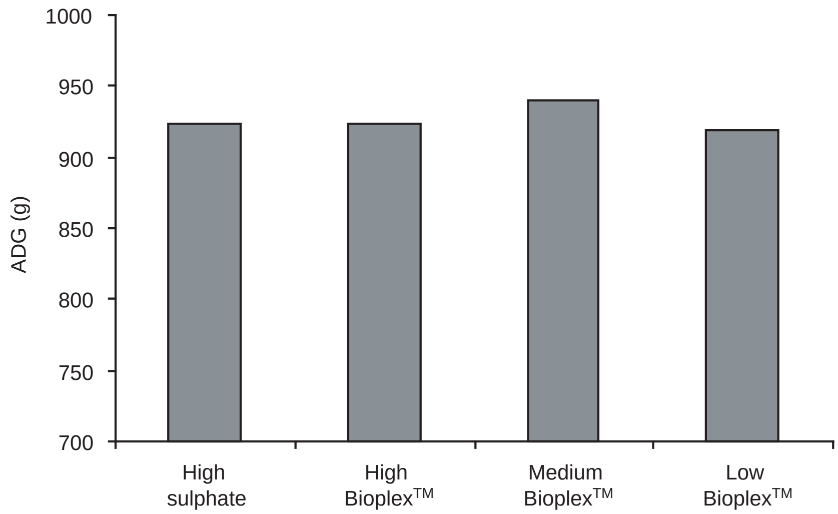

Figure 3. Average daily gain (ADG) of pigs from 25 to 107 kg live weight fed diets containing different concentrations (ppm) of Cu and Zn (High, 160 and 160; Medium, 80 and 80; Low, 25 and 40, respectively) in either the inorganic (sulphate) or organic (Bioplex™) form (Hernandez, Pluske, Turnley, Smith and Mullan, unpublished).

Mahan and Peters (2004) conducted an experiment that commenced when gilts were 28 kg and continued through to the end of the fourth parity. Animals were fed either a basal non-Se-fortified diet, or diets containing either selenite or Sel-Plex® organic Se, each providing 0.15 and 0.30 ppm Se or their combination (each providing 0.15 ppm Se). There was a greater transfer of selenium to the neonate, colostrum, milk, weaned pig and sow tissues when sows were fed the organic form compared to the inorganic form. Improvements in reproductive performance have been recorded when breeder diets have been supplemented with a range of organic minerals (Close, 1998; 1999).

The increased use of artificial insemination means that greater attention needs to be given to the nutritional requirements of the breeding boar. Relatively few studies have been conducted with the breeding boar, but a number of trace minerals are known to play an important role in sperm production (Close, 1999; Mahan *et al.*, 2002). In a study reported by Mahan *et al.* (2002), when boars were fed diets fortified with organic chromium (Cr), Cu, Zn, Mn, and Se for a one-year period, the average number of doses per ejaculate increased from 10.9 to 23.4. Boars fed diets low in selenium also produce a higher percentage of abnormal sperm (Marin-Guzman *et al.*, 1997).

PORK QUALITY

Food safety, price, nutritive value, meal convenience and appearance play an important role in determining whether consumers purchase meat, as well as the type and cut of meat (D'Souza and Mullan, 2001). However, it is the eating experience or the quality of the product that influences the consumer to re-purchase. There is intense competition in the food industry to attract and retain consumers, and it is this that has begun to give direction to the way we feed and rear pigs for slaughter.

A complex interaction of animal, pre-slaughter and post-slaughter factors can have a significant influence on meat quality (D'Souza and Mullan, 2001). Meat quality defects such as pale, soft, exudative (PSE) meat in pigs and poultry, and dark, firm, dry (DFD) meat in pigs, cattle and sheep still remain a major problem. While considerable research has been directed at identifying the best practice approach to optimising meat quality, these are sometimes difficult and expensive to adopt. An alternative strategy to improve meat quality has been research into pre-slaughter dietary nutrient supplementation, in particular the use of organic magnesium (Mg) and Se.

Magnesium

Magnesium (Mg) has a relaxant effect on skeletal muscle (Hubbard, 1973) and dietary supplementation has been shown to help alleviate the effects of stress by reducing plasma cortisol, norepinephrine, epinephrine and dopamine concentrations (Niemack *et al.*, 1979; Kietzman and Jablonski, 1985). Consequently, studies have been conducted to investigate the influence of dietary Mg supplementation on reducing the effects of stress and improving meat quality of pork.

The use of Bioplex™ Mg at 1.6 g elemental Mg for two days before slaughter (Table 5) resulted in reduced drip loss and a lower incidence of PSE (D'Souza and Mullan, 1999). In a study that compared the influence of organic and inorganic Mg compounds on meat quality, D'Souza *et al.* (2000) reported that the improvements in muscle colour, drip loss, and the reductions in the incidence of PSE were greater with organic Mg compounds. This difference was attributed to the increased bioavailability of elemental Mg when fed in the organic form.

Table 5. The effect of dietary Bioplex™ Mg supplementation on meat quality indicators in the *Longissimus thoracis* muscle 24 hrs post-slaughter[1].

Diet	Control	Bioplex™ Mg	Significance
Ultimate pH	5.39	5.40	NS
Surface lightness L*	54.10	52.30	NS
Drip loss, %	6.50	3.60	***
PSE, %	50.00	15.00	*

*P<0.05; ***P<0.001
[1]D'Souza and Mullan, 1999

In an Australian study conducted under commercial conditions, Hofmeyr *et al.* (1999) have demonstrated that dietary organic Mg supplementation is a viable method to improve meat quality in pigs. The incidence of soft, exudative (SE) pork in all three replicates was significantly reduced when pigs received a diet containing organic Mg for two days pre-slaughter (Figure 4). The unusually high incidence of SE pork in Replicate 1 was due to a high number of halothane gene carrier pigs used in this replicate.

Selenium

Although inorganic Se (sodium selenite) is regularly used as a source of Se in diets for pigs of all ages, the use of organic Se (Sel-Plex®, Alltech, Inc.) has additional benefits that surpass that of selenite. When organic Se was fed to growing pigs there was a linear and significant increase in the Se content of muscle tissue (Mahan *et al.*, 1999). In the same study, supplementation with inorganic Se gave only a minimal increase in muscle Se concentrations. In addition, there were indications that when inorganic Se was fed it was bound to muscle tissue in a form that may be detrimental to muscle tissue, whereas Se in the organic form was incorporated into the muscle proteins and did not seem to affect quality of pork loins. In a recent study D'Souza (unpublished) investigated the use of Mg and Se in feed to enhance pork quality. Pork from pigs fed diets supplemented with 16 g Bioplex™ Mg and 0.4 g Sel-Plex® Se/kg had significantly better meat colour at 24 hrs post-slaughter and lower drip loss at 24 hrs, 7 and 21 days post-slaughter compared to pigs fed the control diet.

Apart from possible effects on pork quality, perhaps the greatest interest in feeding grower pigs Sel-Plex®

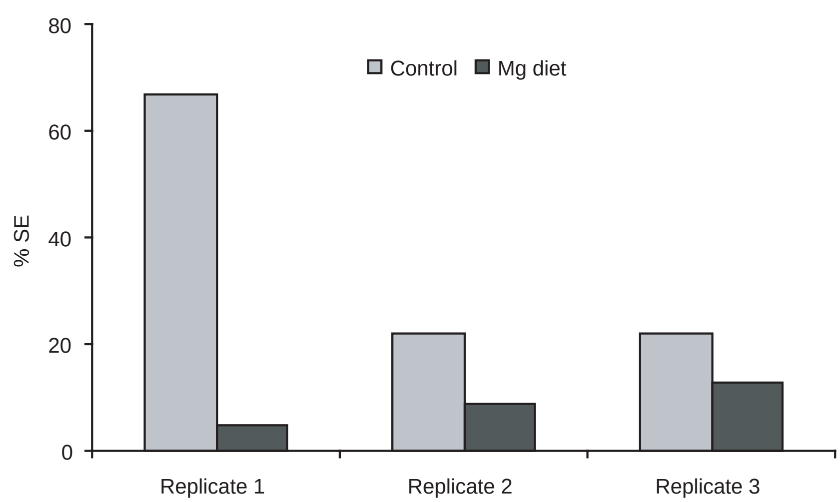

Figure 4. Effect of organic Mg supplementation on the incidence of soft and exudative (SE) pork in the *longissimus thoracis* muscle (Hofmeyr *et al.*, 1999).

organic Se is to increase Se concentrations in the meat, with subsequent health benefits to consumers. Schrauzer (2002) presented evidence that a daily extra-dietary supplement of 200 µg Se reduces cancer risk and increases resistance to viral infections. In Korea this has been taken a step further where the pig industry has capitalized on Se-enriched pork as a functional food and are currently incorporating Sel-Plex® in pig diets. The product is marketed as Se-enriched pork (SelenPork) as a functional food benefiting human health and nutrition. Consumer feedback also indicates that Koreans regard SelenPork as being juicier and having better appearance (D'Souza and Mullan, 2001).

Use of organic minerals for meat quality by industry

Supplementing pig feeds with organic Mg and Se has been shown to have positive effects on pork quality, which is of direct benefit to the processing sector through a reduction in drip loss and to consumers through an improvement in eating quality and nutrient content. Despite this, the adoption rate of both practices has been slow in most countries. It is common in many countries for producers to be paid on the basis of carcass quality (e.g. % lean or depth of backfat) rather than on aspects of meat quality. This is partly due to it being more difficult to measure meat quality on the processing line, but also due to many processors failing to recognize the value in meat quality improvements. Unless producers are rewarded financially for improving meat quality then the adoption of these nutritional strategies will remain low. However, in many countries the link between retailers, processors and producers is becoming stronger and thus it is only a matter of time before the use of organic minerals are considered part of best practice.

ENVIRONMENTAL IMPACT

Intensive animal production will come under increasing pressure to account for its effects on the environment. Consumers, already increasingly wary about intensive animal farming, will have little sympathy for an industry that does not consider the environment as a high priority. Few people realise that a 500-sow, farrow-to-finish operation producing 20 pigs per sow per year produces an amount of effluent comparable to a town of 25,000 people (Headon, 1992). On this basis, it is hardly surprising that the environmental guidelines for piggeries are frequently under review.

The expansion and concentration of the pig industry in many areas of the globe has caused increased concern about the disposal of effluent. Most attention is given to the levels of nitrogen (N) and P, but trace minerals such as Cu and Zn are also important since they too can cause problems for aquatic organisms, grazing livestock and/or soil micro-organisms if the effluent is not contained and/or treated. With an estimated 60% of N and 80% of P that is ingested being subsequently excreted (Lenis and Jongbloed, 1994), there would appear to be ample scope for improvements. Much of the attention has rightly been focused on the growing-finishing pig, since these contribute 60-70% of the total effluent produced from a typical commercial piggery (Lenis and Jongbloed, 1994).

There are two basic options for reducing the amount of effluent produced by pigs. The first is to reduce any oversupply of nutrients, and the second is to improve the efficiency with which nutrients are utilized by the animal. The cost, and hence impact on profitability, of both options needs to be taken into account, whilst maximising the quality of the end-product. It is also important to consider the economic value of piggery effluent, although this will not be discussed in this paper.

Nitrogen

A proportion of dietary protein is indigestible and this is excreted in the faeces, along with some losses from endogenous sources. However, a much higher proportion of the N excretion appears in the urine, mainly as a result of an oversupply and/or imbalance of amino acids which cannot be used for body protein deposition (Jongbloed and Lenis, 1992). A major concern about N pollution is the leaching of nitrate into supplies of drinking water, and N pollution also results in emission of ammonia into the air, contributing to bad odour and to acid rain (Lenis, 1989). In this respect, Lenis (1989) considered N pollution to be of greater significance than that of P. A number of strategies are available for the conservation and reduction of N loss in animal production (Rotz, 2004).

Calculation of N requirements

Computer modeling techniques have been used extensively in recent years to calculate the optimum amino acid requirement for animals in commercial piggeries. Simulation models, such as those developed by Whittemore (1983), Black *et al.* (1986) and Moughan *et al.* (1987) can be used to calculate the amino acid requirements of pigs of different genetic potentials and live weights under a range of environmental and physiological conditions. Others

(Lenis and Jongbloed, 1994; Henry and Dourmad, 1993) have developed models to look specifically at the issue of N production in effluent. According to Smits and Mullan (1995), in some instances commercial diets are over-formulated by 30% or more, and the re-calculation of those requirements would mean a major reduction in feed costs without any adverse effect on animal performance, as well as a possible reduction in N excretion.

Feed enzymes

Protein digestibility is highly variable and often low in primary feedstuffs which leads to significant variations in faecal N excretion (Gatel, 1993). Some of this variability is related to the protein itself (quality and quantity), and some is dependent upon other components of the diet (e.g., occurrence of anti-nutritional factors, fibre content). Improving protein digestibility by the addition of appropriate enzymes to the diets of growing pigs is one way that we can reduce N excretion without affecting pig performance. For example, Pluske and Mullan (unpublished data) reduced the daily excretion of N by approximately 10% (P=0.099) when grower pigs were fed a diet with 300 g/kg Australian Sweet Lupins that was supplemented with Allzyme™ Vegpro.

Feeding system

An animal's requirement for amino acids is a function of body weight and hence for the growing pig is continually changing. Traditionally, up to three different diets have been fed to pigs from the time of weaning until they are slaughtered at about 100 kg live weight. It is now more common to use an approach called phase-feeding, whereby a greater number of diets (e.g., six) are fed to a pig from weaning until sale. Each diet is progressively lower in its content of amino acids and, therefore, more closely matches the requirements of the animal. Dourmad *et al.* (1992) have calculated that the adoption of a phase-feeding strategy during the grower period should result in a 15 to 20% reduction in the N content of effluent.

A further advancement of phase-feeding is called blend-feeding, in which the diet is changed on a weekly, or even daily, basis by mixing together, in various ratios, diets of different composition. In this way, a large range of diets (e.g., 12 from weaning until slaughter) can be prepared from a smaller number of base feeds. Using two diets, which were blended on a weekly basis, Mullan *et al*. (1997) found significant reductions in N intake (20%) and urinary excretion of N (25%) when pigs were blend-fed in comparison with being fed a single diet during the growing period. There was no effect of reducing N intake on performance. The cost of more complex feed delivery systems, and the need to have a small weight range within the group of pigs being fed, obviously needs to be taken into account.

Use of synthetic amino acids

Another approach to ultimately reduce N excretion is to reduce the crude protein content of the diet by adding synthetic amino acids, while maintaining a balanced supply of essential amino acids. Latimier and Dourmad (1993) concluded that improving the amino acid balance, and hence lowering the crude protein content of the diet, was an efficient way to decrease both N output in the slurry (by 23%) and gaseous N emission from the building (by 25%). The potential to reduce N excretion by increasing the biological value of pig diets has been well proven, but the adoption of this approach will ultimately depend on its effect on profitability (Pluske *et al.*, 1997).

Phosphorus

Phosphorus is an essential element in animal diets; it is essential for the development and maintenance of skeletal tissue, and has an important role in a host of biochemical and metabolic functions. Sixty to 90% of the total P in plant feedstuffs is in the form of phytic acid or phytate-P. Phytates are poorly digestible because pigs lack the phosphatase enzyme required to cleave the phosphate groups from the phytin molecule (Cromwell *et al.*, 1993). Phytic acid carries up to 12 negative charges and has a tremendous chelating potential to combine with positively-charged nutrients, including Ca and some trace minerals (Pluske *et al.*, 1997). Phytate-mineral complexes such as these are unavailable for absorption.

To counteract the low availability of phytate-P, animal by-products such as meat and bone meal, and mineral (inorganic) P compounds such as dicalcium phosphate, both of which have a high concentration of P and a high availability (70-90%), are commonly added to pig diets (Jongbloed and Kemme, 1990). However, the continued supplementation of pig diets with inorganic P, together with indigestible phytate, ultimately means that there is an increase in the amount of P excreted and hence present in piggery effluent.

Calculation of P requirements

The most logical way to reduce the amount of P excreted by the pig is to supply P in better agreement with the requirement. The NRC (1998) publication cited 151 references related to the P requirements of pigs, but only 37 were from work published in the 1990s, and only one of these 37 addressed the bioavailablity of P from feed ingredients (Knowlton *et al.*, 2004). The accuracy of these estimations and the relevance that they have to current production systems was hence questioned by Knowlton *et al.* (2004). Jongbloed *et al.* (2000) estimated that P excretion of a growing-finishing pig was reduced by 60% between 1973 and 1998, due in part to the reduction in dietary P content from 7.4 to 4.7 g/kg. While reductions in dietary mineral supply are clearly beneficial from a pollution perspective, research needs to be conducted to ensure that any recommended reductions in requirements do not compromise the health, well-being and performance of the pig.

Feeding strategies to reduce the P in effluent

As with N, a better agreement is needed between P supply and requirement, and one strategy to ensure this agreement is phase-feeding. In the simplest instance, the use of a grower diet from 45 to 70 kg and a finishing diet from 70 to 106 kg instead of a single diet over the same weight range reduced P excretion by 6% (Coppoolse *et al.*, 1990; cited by Jongbloed and Lenis, 1992).

The use of phytase

Undoubtedly the major advance in recent years to increase P digestibility and reduce P excretion is the addition of phytase enzymes to the diets of growing pigs. In a study by Lynch *et al.* (2001), P digestibility was increased from 52 to 67% when 500 PU/kg of Allzyme™ Phytase was included in the diet of grower pigs (25 to 35 kg), and P content of the faeces was reduced by 30%. In other studies with weaner pigs, growth rates were improved when the diet was supplemented with phytase (Campbell *et al.*, 1995), a result attributed to improvements in the availability of other nutrients in the diet. A number of factors will influence the response to phytase (Kornegay, 1999), and these must be considered when formulating diets and developing feeding strategies.

Based on the data of Mullan *et al.* (1994) in which a lower P diet was fed in addition to using a phytase enzyme, it was estimated by Pluske *et al.* (1997) that the addition of phytase to a diet containing a low concentration of P would result in a reduction in total P excretion of 60% from the grower/finisher herd. For the piggery where this study was conducted (approximately 41,000 pigs sold/year), this dietary change reduced P excretion from 21.8 t/year to 14.0 t/year.

Copper and Zinc

Copper and Zn are often oversupplied in pig diets, and Jondreville *et al*. (2003) have calculated the number of years based on current practices before the concentration in soil reaches maximum values. Due to this environmental concern, there is a strong interest in evaluating the use of organic forms of Cu and Zn as replacements for inorganic forms.

Smits and Henman (2000) evaluated the performance of grower and finisher pigs fed diets supplemented with either $CuSO_4$ (150 ppm Cu) or organic (Bioplex™) Cu (40 ppm Cu). Those pigs fed the diets containing organic Cu at 40 ppm achieved similar levels of performance to those fed 150 ppm Cu from $CuSO_4$ (Table 6). However, the quantity of Cu excreted in the faeces was three to four times lower in the pigs fed the organic Cu. Pierce *et al.* (2001) have also measured the faecal Cu content of growing pigs when fed either a control diet, or diets containing $CuSO_4$ or Bioplex™ Cu. Those pigs fed the organic Cu had similar performance to those fed an inorganic source of Cu, but had a 46% decrease in faecal Cu concentrations.

Table 6. The growth performance and faecal Cu excretion of pigs fed different Cu sources[1].

Diet	Control (no added Cu)	$CuSO_4$ (150 ppm Cu)	Bioplex™ 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

[1]Smits and Henman 2000

In a similar study Veum *et al.* (2004) demonstrated a reduction in Cu excretion when Bioplex™ Cu was fed instead of $CuSO_4$ in nursery pig diets. While there was no significant difference in growth rate, faecal output of Cu was reduced by a factor of four (Figure 5). The benefits to growth of using Cu supplementation can be maintained through the use of organic forms of Cu, rather than $CuSO_4$, greatly reducing the level of Cu in effluent and hence reducing the impact on the environment.

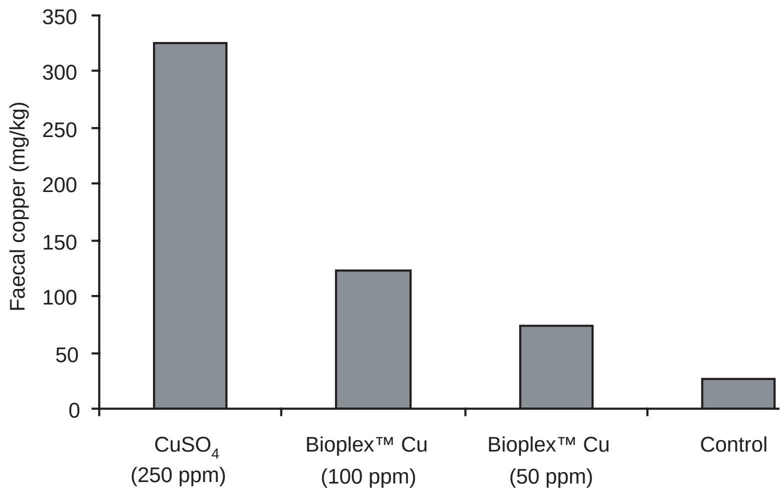

Figure 5. Faecal output of copper for weaner pigs fed either a control diet, or diets containing either 50 or 100 ppm organic Cu, or 250 ppm of $CuSO_4$ (Veum *et al*, 2004).

Several studies have evaluated the use of Bioplex™ Zn at lower concentrations (e.g., 100 or 250 ppm) as an alternative to using high concentrations of ZnO (2000 ppm) in the diet of weaner pigs (Wu *et al*., 2001; Mullan *et al.*, 2002). The concentration of Zn in faecal material was almost four times higher when inorganic Zn was fed at therapeutic levels as when Zn was fed in the organic form (Bioplex™ Zn). While the use of organic forms of Zn instead of ZnO will clearly reduce the Zn concentration in piggery effluent, it is still not clear if this strategy alone is sufficient to provide adequate protection against post-weaning diarrhea to gain industry acceptance.

In an experiment just completed, Hernandez, Pluske, Turnley, Smith and Mullan (unpublished) compared Cu and Zn provided in either the inorganic or organic form (Bioplex™) to pigs from 25 kg until slaughtered at 107 kg live weight. There was no difference in growth rate between pigs fed Bioplex™ at low (25 ppm Cu, 40 ppm Zn), medium (80 ppm Cu, 80 ppm Zn) or high (160 ppm Cu, 160 ppm Zn) levels of Cu and Zn compared with those fed similar levels to the high Bioplex™ diet in the form of sulphate. However, a reduction of 83% in Cu and 65% in Zn excretion was achieved when the low level of Bioplex™ was fed instead of the high level of Cu and Zn in the inorganic form (Figure 6).

Numerous studies have now been completed to compare pig performance when the traditional inorganic forms of Cu and Zn are replaced with the same or lower

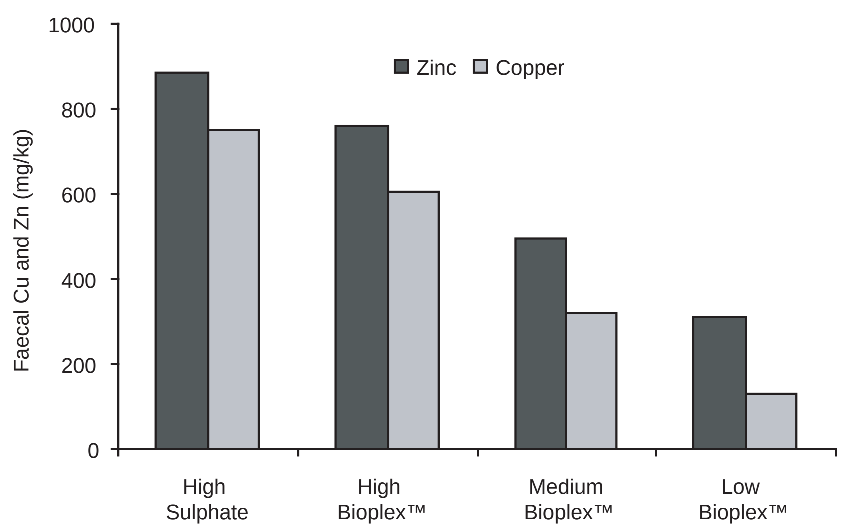

Figure 6. Faecal concentration of Cu and Zn for grower pigs fed diets containing either organic (Bioplex™) or inorganic Cu and Zn at different concentrations: Low (25 and 40 ppm, respectively), Medium (80 and 80 ppm, respectively) or High (160 and 160 ppm, respectively) (Hernandez, Pluske, Turnley, Smith and Mullan, unpublished**).**

concentrations in the organic form. The vast majority of studies have shown no compromise in pig performance but a large reduction in Cu and Zn in faecal output when the organic form is fed. Future studies need to focus on the requirement for these organic trace minerals under a range of production conditions, in view of their higher bioavailability and our need to ensure optimal animal performance.

Conclusion

There is increasing pressure on the pig industry worldwide to become more efficient, reduce the cost of production, and reduce the effect of the industry on the environment. At the same time the industry needs to improve meat quality of pork and its nutritional value in response to consumer expectations. A number of technologies, such as computer modelling, feed systems, feed enzymes and organic minerals can help achieve these goals. However, in most instances the cost benefit of instituting changes is not obvious, and hence uptake of new technologies is slow. Ultimately it will be through a well-managed program of research and development at all levels, backed up by independent technical support, that will ensure the pork industry receives the recognition it deserves as an important supplier of dietary protein.

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