Manipulation Of Diets To Minimize The Contribution To Environmental Pollution[1]

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▪ Introduction

In areas with intensive pig production, pigs can contribute to environmental pollution. In Canada, this negative effect of pig production on the environment is one of the main factors that limits the expansion of the pork industry and affects the attitude of the general public towards animal production. This negative effect is the result of odours released from swine facilities and the disposal of nutrients and potentially harmful micro-organisms with swine manure. In several countries legislation has been introduced, or recommendations have been made, to reduce or to minimize the contribution of animal agriculture to environmental pollution (Williams and Kelly, 1994). These imposed regulations, or recommendations, generally increase production costs and have forced the agricultural industry to seek means to reduce the production of animal waste.

In this paper some nutritional means to control odours and to the excretion of nutrients in pig manure will be described briefly. Nutrients that are of prime concern in regards to nutrient management are copper (Cu), zinc (Zn), nitrogen (N), and phospohorus (P). The primary focus will be on swine. However, many of the described concepts will also apply to other animal species. In addition, some areas where further information is required are identified.

▪ Odour

Odours are the result of volatile 'smelly' compounds that pigs excrete with manure and/or that are released from pig manure during storage. Over 160 volatile compounds have been identified in swine manure (O'Neill and Philips,

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1992). At least thirteen of these contribute to odour in fresh pig manure (Hobbs et al., 1996). These represent four groups of compounds: the volatile fatty acids (acetic, propionic, butanoic, 3 methyl butanoic and pentanoic acids); the phenolic compounds (phenol, 4-methyl phenol and 4-ethyl phenol); the indoles (indole and skatole) and the sulfides. The sulfides are produced in variable amounts after several days of anaerobic storage. Other compounds - such as ammonia, SO_2 and NO_2, and a variety of amines and other derivatives of amino acids - are produced by fermentation of manure. Although ammonia levels do not show a good correlation with odour strength, it is still desirable to reduce ammonia emission from swine operations. A main challenge with odourous compounds is that it is extremely difficult to objectively assess odours. Different people perceive odour in different ways and odour is often more of an emotional issue than a 'scientific' issue.

From the above it can be inferred that a reduction in N excretion with manure will likely result in a reduction in odour emission from swine facilities. For example, Hobbs et al. (1996) demonstrated that a reduction in dietary protein levels, while maintaining the intake of balanced or ideal protein, resulted in a significant reduction in several, but not all, of the odour causing compounds. Furthermore, the manipulation of hind gut fermentation represents a means to control the production of odour causing compounds. The latter was demonstrated by Agergaard et al (1995) who reduced excretion of skatole in feces by adding fiber to the diet. Furthermore, Jensen and Jensen (1995) showed that an increase in gut pH by feeding bicarbonate changed the production of skatole to the production of indole in the hindgut. Finally, the strategic use of anti-microbials, including acids, and the use of binding agents may alter the production and release of odour causing compounds (e.g. Den Broek and Verdoes, 1997). Promising results have been obtained for various feed additives. It is important that these feed additives be properly evaluated, both under closely controlled laboratory conditions and under practical conditions, and that cost-benefit relationships are established.

In addition to diet manipulations, proper manure management will affect the production and release of odorous compounds from swine facilities. For example, the effective manuring area in pig pens should be minimized, manure should be moved quickly from the warm pig barn to cooler manure storage facilities to reduce fermentation, and manure storage facilities should be covered. In the short run, odour is better addressed via manure management than via diet manipulation.

▪ Copper and Zinc

In general, Cu and Zn in pig diets are much higher than the minimum requirements for normal performance (i.e.: 5-25 Cu and 50-125 ppm Zn for the various classes of swine). These minerals act as growth promotants when included at levels much higher than minimum requirements. In Canada, the federal Feeds Act limits the maximum level of Cu and Zn in the diet to 125 ppm and 500 ppm respectively, but in the US, much higher levels are common. In some countries, like the Netherlands, growth-promoting levels of Cu and Zn are no longer allowed in finisher pig diets due to the impact on the environment. As long as minimum requirement levels of Cu and Zn are maintained, the excretion of these minerals in pig manure is not a concern; the focus then switches to P and N excretion.

▪ Mineral balances

The whole farm or animal efficiencies with which minerals are retained in useable animal products are generally low. On swine farms, the efficiency of mineral retention is very low for potassium (3.6 to 10%) and somewhat higher for nitrogen and phosphorus (18 to 40%) (Table 1). The efficiency of mineral retention on swine farms is generally lowest in sows and highest in starter pigs.

On a typical farrow to finish operation, growing-finishing pigs produce most of the manure. For this reason ‘average’ farm values will be close to those for growing-finishing pigs (Table 1).

These low efficiencies of mineral retention indicate that there is room for improvement, i.e. that the excretion of minerals with manure can be reduced.

It should be noted that there is a tremendous amount of variation in the efficiency of N, and P retention between different pig farms. This can be attributed to various feed and animal factors, including:

- feed wastage;
- the availability of N (amino acids; AA) and P in the various feedstuffs or diets;
- animal performance levels; and
- discrepancies between requirements and dietary levels of available AA and P.

Given this large variation and environmental pressures, the need to closely monitor N and P balances on individual pig units will increase. This can be best accomplished by closely monitoring the amount and composition of feeds that are used and the number and weight of animals that are removed from the farm. In the Netherlands, such a mineral book keeping system is obligatory for farms that have more than 2.5 large animal units (about 10 growing-finishing pig places) per hectare of land. With support from Ontario Pork a simple spreadsheet has been developed for this purpose which is applicable to Canadian conditions (Birkett and de Lange, 1997). This approach is now included in the nutrient management program that has been developed by the manure systems group at the University of Guelph (Goss et al., 1997).

Table 1. Typical mineral balances (kg/animal) on Dutch pig farms (Jongbloed, 1991).

	Nitrogen	Phosphorus	Potassium
	I. growing pigs (25-106 kg live weight)		
Dietary levels (%)	16.7*	.52	1.22
Intake (kg/pig)	6.36	1.23	2.90
Excretion (kg/pig)	4.48	.83	2.73
Retention (kg/pig)	1.88	.40	.17
Recovery (%)	29.5	32.5	6.0
	II. Sows, including nursing piglets		
Dietary levels (%)	15.7*	.59	1.32
Intake (kg/sow/yr)	27.57	6.53	14.52
Excretion (kg/sow/yr)	22.50	5.5	14.0
Retention (kg/sow/yr)	5.07	1.03	.52
Recovery (%)	18.4	15.8	3.6
	III. Starter pigs (9-25 kg live weight)		
Dietary levels (%)	18.4*	.67	1.25
Intake (kg/pig)	.94	.21	.40
Excretion (kg/pig)	.56	.13	.36
Retention (kg/pig)	.38	.08	.04
Recovery (%)	40.5	39.4	10.0

*Total protein (Nx6.25) rather than N.

▪ Nutritional means to reduce mineral excretion

Over the last few years some extensive reviews have been published in which various nutritional means to improve the efficiencies of N and P retention in pigs are addressed (e.g. Verstegen et al., 1993; de Lange, 1994; Lenis and Jongbloed, 1995; Coelho and Kornegay, 1996; Jongbloed and Lenis, 1997). In this paper, only the main and most relevant means to improve the efficiency of N and P retention will be discussed.

Improving the Efficiency of P Utilization in (Grower-Finisher) Pigs.

Improving P availabilities in pig diets; assessing P availabilities in feedstuffs

The major reason for the inefficiency of P utilization in monogastric animals is the poor digestibility and/or availability of P that is present in plant products (Table 2). P in plant products is included in complex structures (phytates) that are poorly utilized by pigs. In contrast, the availability of P in animal and inorganic sources (meat and bone meal, di- and mono-calcium phosphate) is much higher (65 to 90%). For this very simple reason, pig diets should be formulated on an available basis, rather than a total P basis.

Some plant products, in particular wheat products, contain some natural enzymes (phytases) that can liberate P from these phytates and contribute to improvements in P availability in these ingredients.

In terms of determining the availability of phosphorus in ingredients for swine, two distinctly different techniques can be recognized. On one hand, the technique that is used in the United States is based on a slope-ratio assay in which bone characteristics are related to the inclusion level of the test source of phosphorus in the diet (Cromwell, 1993). Values are compared to a standard source of phosphorus, monosodium phosphate. The alternative procedure (CVB), used in The Netherlands and France, is to determine faecal phosphorus digestibilities in the different phosphorus sources at low levels of phosphorus intake (e.g. Jongbloed, 1987). In a direct comparison of the two techniques, the digestibility assay appeared less variable and more repeatable than the bone-breaking strength assay (Jongbloed, 1987; Yi and Kornegay, 1996). A comparison of estimated availabilities of phosphorus in the various ingredients using the two techniques is provided in Table 2.

Table 2. Phosphorus availability (%) according to NRC (1998) and CVB (1990; 1998) in various pig feed ingredients.

Ingredient	NRC (1998)	CVB (1998)
Corn	14	23
Barley	30	34(45)
Wheat	50	30(55)
SBM, hulled	31	45
SBM, dehulled	23	45
Canola meal	21	31
Meat and bone meal	90 (sometimes as low as 70)	93
Peas	-	52
Dicalcium Phosphate $2H_20$	95-100	80
Monocalcium Phosphate	100	100

* CVB values are divided by .87 for comparison with NRC values.

** Values in between brackets include endogenous phytase activity.

The CVB (1998) digestibility values are divided by .87, the digestibility of monosodium phosphate, to allow for a direct comparison to the NRC (1998) availability values. The data shows some general agreement for most feed ingredients. However for some ingredients, like canola meal, dehulled SBM and dicalcium phosphate, some important differences can be noted. Research to explain these apparent discrepancies in estimated P digestibility/availability between North America and Europe seems needed. In The Netherlands, these data have lead to an increase in the use of monocalcium-phosphate, rather than dicalcium-phosphate, as the mineral source of choice in pig feeds.

Over the last few years, “synthetic” phytases have become. When these phytases are properly used they can improve P digestibility (Table 3). As a result the total P levels in the diet can be reduced, the efficiency with which phosphorus is retained in the animal is improved, and the excretion with P into the environment is reduced.

Table 3. Effect of microbial phytase on phosphorus digestibility in growing pigs (Simons et al., 1990).

	Control	+ 1000 IU/kg phytase
	Corn – soybean meal diet	
Total Phosphorus (g/kg)	3.3	3.3
Phosphorus digest. (%)	20	46
	Practical Dutch grower diet*	
Total Phosphorus (g/kg)	4.1	4.1
Phosphorus digest. (%)	34	56

*Contains tapioca, hominy feed and soybean meal as the major ingredients.

When including phytases in pig diets, various points should be considered:

- Different commercial products differ in the content of active phytase. Phytase units (PTU) may be used to compare different products using a standardized test.
- The efficacy of phytates is not the same for all types of diets (Table 3).
- Phytases are quite unstable when exposed to heat. During pelleting the temperature of the feed should not exceed 70-75^{o}C when phytases are included. Phytase activity should be checked in the complete, processed feed.
- Phytases not only increase the digestibility of P; they also increase the digestibility of calcium (Ca) and other trace minerals that are tied to the phytate complex (Cu, Zn, etc.). Some recent studies from Europe also suggest that phytase can improve feed utilization (by 1-2%) in starter and grower pigs by making other nutrients more available as well. This results in additional “value” of added phytase.
- When determining the value of phytase, the effects of reducing the P and Ca levels in the diet should be considered. In particular, in high energy diets in which (expensive) fat is used, a reduction in mineral levels will be associated with a reduced need to use fat as there is

more “space” in the feed formula. This results in reduction of ingredient costs.

- There is still some debate on how much phytase should be included in practical diets and by how much the available P levels in the diets can be reduced. The value of phytase is larger at low levels (less than 200 PTU/kg of feed: .2 g extra dig. P/ kg of feed per 100 PTU) than at intermediate levels (200 to 1000 PTU/kg of feed: .13 g extra dig. P / kg of feed per too PTU). At high levels (more than 1000 PTU), improvements in P digestibility are minimal. Furthermore, there is still some debate about the effect of pig age/weight on the response to phytase (it may be better than the indicated values at higher body weights).
- The utilization of P is affected by the calcium to P ratio in the diet; these should be maintained low (see next section).

Given the above considerations and given today’s prices of phytase and inorganic P sources, the use of phytase does not appear to increase feed cost: the cost of the product is largely offset by the reduced need for P and Ca in the feed.

Feed P more closely to the pigs’ requirements

The actual P (and other nutrient) levels in diets are often higher than levels that are actually required by pigs. These “safety” margins are sometimes very large. Reasons for these safety margins (and means to reduce these) include:

- To account for potential errors in feed preparation and delivery (calibrate feed mixing equipment; sample and analyze ingredients and prepared diets).
- Only a few diets are used to meet the nutrient requirements of a wide range of pigs (apply phase and split-sex feeding; keep and manage breeding stock separate from market hogs).
- The Ca to P ratio in the diet is too high (keep it around 1.2) which reduces P utilization. According to Jongbloed et al. (1993), dietary Ca levels should be related to digestible (or available) P levels rather than total P levels in the diet. These authors suggest that the ratio between total calcium and digestible P be between 2.8 and 3.3.
- The perceived requirements of some groups of pigs, with high performance potentials, are higher than the actual requirements (use common sense; follow published guidelines; develop a factorial or modelling approach to estimate the P requirements for different groups and genotypes of pigs).

In the Netherlands, the available P allowances for the various classes of swine are 0.41% for starter pigs, 0.25% for grower pigs, 0.20% for finisher pigs, 0.25% for dry sows and .36% for nursing sows (CVB, 1990). In particular, the available P levels for the finisher pigs and dry sows are lower than these in practical diets in Canada. A reduction in available P allowances will reduce the excretion of P with swine_manure and reduce feed costs. A reduction in P intake by 10% will reduce P excretion with manure by at least 15%.

Improving the Efficiency of N Utilization in (Grower-Finisher) Pigs

Improve the dietary amino acid balance

The balance in which amino acids are supplied in the diet differs substantially from the balance in which they are required for optimum performance by the various classes of swine. In typical corn and soybean meal based diets fed to grower pigs, about 25% of the ingested protein is supplied by "unbalanced" amino acids. Unbalanced amino acids are degraded, are used as an expensive source of energy, and contribute to N excretion with urine. Just under half of N excretion in pig manure can be attributed to the poor amino acid balance in the pigs' diet (Table 1). Furthermore, in recent experiments conducted at the University of Guelph we were able to reduce N excretion in growing pigs fed corn-soybean meal diets by close to 40% by manipulating the dietary amino acid balance (Tuitoek et al., 1997a,b).

A simple means to improve the dietary amino acid balance is to replace some of the standard protein sources (e.g. soybean meal) with purified synthetic amino acids (lysine·HCl, threonine, methionine, tryptophan). If these diets are properly formulated and produced they should support at least the same levels of performance than corn soybean meal based diets (Tuitoek et al, 1997a,b). In Table 4, potential reductions in N excretion are presented for diets that differ in protein levels but are balanced for amino acids. The estimated costs of these diets are given as well (based on prices in March 1997). If some of the soybean meal is replaced with lysine·HCl, both feed cost and the excretion of N with pig manure are reduced. But there is a large cost associated with large reductions in dietary protein levels. Given the costs of synthetic amino acids, it does not make economic sense to include synthetic amino acids other than lysine·HCl in grower pig diets. This will change with the availability and price of the other synthetic amino acids.

There are two additional benefits of reducing the total protein levels in pig diets:

- Excessive protein intake may induce scours, in particular in young pigs,
- There is a metabolic cost associated with excreting N in urine.

In young pigs and pigs under heat stress, feed intake and performance will be slightly improved when low protein diets are fed that are properly balanced with amino acids. This should be considered in least cost feed formulation. For example, the calculated net energy (NE) content of a 16% protein corn-soybean meal based diet increases by approximately 1% if 1 kg per tonne of lysine·HCl is used to replace SBM while maintaining the apparent ileal digestible supply of lysine (de Lange, 1995). The calculated DE content of the diet is slightly reduced with added lysine (.1%). The increase in NE content is about four times larger than the GE content of Lysine·HCl.

Table 4. Estimated cost of corn and soybean meal based grower-finisher diets with varying protein levels but balanced for amino acids using synthetic amino acids. The estimated reduction in N excretion with manure as compared to the "standard" corn soybean meal based diet is given as well.

	Corn-SBM-pmx	+ Lysine	+ Lysine +Threonine +Tryptophan
Ingredient comp. (%):			
Corn	75.85	79.38	83.28
Soybean meal	21.15	17.50	13.40
Premix	3.00	3.00	3.00
Lysine.HCl	-	0.12	0.25
Threonine	-	-	0.06
Tryptophan	-	-	0.02
Calculated content (%):			
Total protein	16.5	15.2	13.7
Dig. Lysine	**.70***	**.70**	**.70**
Dig. Threonine	.46	**.42**	**.42**
Dig. Tryptophan	.14	**.12**	**.12**
Dig. Methionine	.24	.22	.21
Dig. Met + Cys	.47	.44	**.41**
Ingredient cost ($/tonne)	220.6	218.7	239.1
Reduction N excretion %[#]		-11%	-24%

* values that are printed in bold are levels that are first or equally limiting in the diet.
[#]% reduction as compared to feeding the corn-SBM-premix diet without any added synthetic amino acids.

There is still some debate about the optimum amino acid balance over the various body weight ranges. In the interpretation of optimum amino acid balances, the units in which amino acid levels are expressed, i.e. total vs. apparent ileal digestible vs. true ileal digestible, should be considered carefully. In recent studies in Guelph, we were unable to reduce protein levels (and N excretion with manure) in the finisher diet to the same degree as that in the grower diet (Tuitoek et al., 1997a,b).

Some of the benefits of using synthetic amino acids also apply to other protein sources with a good amino acid balance (fish meals, meat meals, etc.).

Feed Lysine more closely to the pigs' requirements; assessing lysine availabilities in feedstuffs

Just like P, lysine levels in diets are often higher than levels that are actually required by pigs. Again, these "safety" margins are sometimes very large and expensive. If we stick to some important principles (quality control on ingredients, feed preparation and delivery; feeding according to lean growth potentials; phase and split-sex feeding; minimize feed wastage; maintain a good health status) both feeding cost and the excretion of N with pig manure can be reduced. Some examples include:

- A reduction in diet Crude Protein (CP) levels by 10% will reduce N excretion with manure by at least 15%.
- Improving lean growth potentials as a result of feeding entire males rather than barrows (*an improvement of about 15%*) will reduce N (and P) excretion in manure by about 15%.
- N excretion will be reduced by about 15% when a 16% CP grower diet is replaced by a 14% CP finisher diet at 60 kg body weight.
- In a low disease herd (SPF) N excretion with manure will be about 10% less than in a herd with a conventional health status (Keller, 1980).

The use of factorial approaches (simulation models) to predict AA requirements will certainly increase the accuracy with which the animals requirements can be estimated for individual situations (Pomar et al., 1991; de Lange and Schreurs, 1995; Lenis and Jongbloed, 1995; NRC, 1998).

As we feed pigs more closely to their requirements, it will become increasingly important that the AA availabilities in feedstuffs are accurately determined. It is generally accepted that the ileal AA digestibility assay provides reasonable estimates of AA availabilities in the various ingredients. Furthermore, true or standardized ileal AA digestibilities should be used in feed formulation. Unlike apparent AA digestibilities, true ileal AA digestibilities are additive in mixtures of feed ingredients (Nyachoti et al., 1997a,b). However, in heat treated protein sources, or in ingredients containing large quantities of anti-nutritional factors, the ileal digestibility assay may over-estimate AA availability. For example, in the case of lysine, the e-amino group can easily react with reducing sugars rendering the amino acid unavailable to the animal (Gall, 1989). Yet, during hydrolyses for conventional AA analyses, some of these compounds yield free lysine, suggesting that this lysine is available to the animal. Furthermore, some of these lysine complexes may be absorbed. The latter may explain some of the discrepancies that have been observed between ileal AA digestibilities and availabilities estimated using more expensive and time consuming slope-ratio assays.

Recently a relatively simple technique has become available to routinely estimate the amounts of ileal digestible, chemically available AA in the various samples of ingredients (Rutherfurd and Moughan, 1995). This technique has a much wider application that the older Carpenter lysine assay. Results obtained with this technique, based on the guanidation of lysine to homoarginine, indicates that the extent of heat damage is more severe and of concern in more ingredients than thought previously.

▪ Conclusions

In some areas of the world the contribution of animal agriculture to environmental pollution has become a serious concern. In some countries this has lead to the introduction of legislation to reduce mineral excretion by farm animals. However, via alternative management practices, the mineral balance on animal farms can be substantially improved. In particular via the use of phytase, synthetic amino acids and by feeding more closely to the animals requirements, the P and N excretion with swine manure can be reduced by up to 50%. Application of these alternative strategies will increase the need for precise feed ingredient evaluation, feed formulation, manufacturing, and delivery. Reducing water spillage from drinkers and reducing the amount of water needed for cleaning can reduce the manure volume.

We should focus our attention on nutrient balances rather than on developing diets that minimize the generation of odourous compounds from swine manure. Furthermore, nutritionists should work together with engineers, soil scientists and representatives of other disciplines to develop an integrated or modelling approach to properly utilize nutrients and organic material in swine manure, and to minimize the negative impacts of pork production on the environment. Finally, more basic information is required about the availability of phosphorus in various feedstuffs, the efficacy of exogenous phytase, phosphorus requirements of different genotypes of pigs, and about amino acid utilization in finishing pigs.

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