Economic Evaluation of Nutritional Strategies that Affect Manure Volume, Nutrient Content, and Odor Emissions

Department of Animal Science
University of Minnesota, St. Paul

Introduction

The ability to manage modern pork production systems for minimal environmental pollution has improved dramatically during the past decade, but continues to be one of the most significant challenges facing the pork industry around the world. Nutrition plays a significant role in environmental sustainability of pork production, but the development and implementation of “eco-nutrition” swine feedings programs is in its infancy.

Until recently, most manure management research has focused on manure storage and land application methods and technologies. However, the quantity and composition of manure is primarily affected by nutrient digestibility of dietary ingredients and the amount of feed and water wastage. Nutrient composition of swine manure (especially nitrogen and phosphorus) is affected by the amount of excess dietary nutrients above the animal’s requirements, nutrient digestibility of ingredients, and method of manure storage and land application. Both the quantity of manure and the concentration of nutrients in manure, along with soil nutrient levels, soil type, and type of crop to be produced, determine the number of crop acres necessary for environmentally responsible land application of manure.

Nutrition can also affect odor and gas emissions from swine facilities. Dietary nutrient levels, nutrient digestibility, and the nature and extent of microbial fermentation in the lower gastrointestinal tract can affect the proportions of odor-producing compounds found in fresh swine manure. However, method of manure handling, storage, and land application also play a critical role in odor control.

The amount of manure produced in each stage of pork production is directly related to feed and water consumption and wastage, as well as the digestibility of nutrients in dietary ingredients. In a farrow to finish production system, the majority of feed is consumed in the grow-finish phase (75 %), followed by breeding-gestation (12%), nursery (8%), and lactation (4%). The amount of manure produced/head/day from various production phases is shown in Table 1. Even though a lactating sow produces more manure/day than a finishing pig on an individual basis, the number of grow-finish pigs in a production system easily exceeds the number of sows in the farrowing facilities of that system.

Table 1. Estimated Manure Produced/Pig in Various Phases of Pork Production.
The table below shows the daily nitrogen, phosphorus, and potassium excretion (lb/pig/day) in different phases of production. The nutrients present in the greatest quantities in swine manure are nitrogen, phosphorus, and potassium. Nitrogen is excreted in the highest quantities, followed by potassium and phosphorus. Significant reductions in total manure production can be achieved by reducing feed and water wastage in the grow-finish phase of production.

### Manure Produced/Pig

<table>
<thead>
<tr>
<th>Production Phase</th>
<th>lb/d</th>
<th>cu ft/d</th>
<th>gal/d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nursery pig (35 lbs)</td>
<td>2.3</td>
<td>0.04</td>
<td>0.27</td>
</tr>
<tr>
<td>Growing pig (65 lbs)</td>
<td>4.2</td>
<td>0.07</td>
<td>0.48</td>
</tr>
<tr>
<td>Finishing pig (150 lbs)</td>
<td>9.8</td>
<td>0.16</td>
<td>1.13</td>
</tr>
<tr>
<td>Finishing pig (200 lbs)</td>
<td>13.0</td>
<td>0.22</td>
<td>1.50</td>
</tr>
<tr>
<td>Gestating sow (275 lbs)</td>
<td>8.9</td>
<td>0.15</td>
<td>1.10</td>
</tr>
<tr>
<td>Sow and Litter (375 lbs)</td>
<td>33.0</td>
<td>0.54</td>
<td>4.00</td>
</tr>
<tr>
<td>Boar (350 lbs)</td>
<td>11.0</td>
<td>0.19</td>
<td>1.40</td>
</tr>
</tbody>
</table>

Adapted from Midwest Plan Service (1993).

**Note:** These estimates are based on manure excretion/pig/day and do not include large amounts of wash water, water wastage, and bedding. Estimates assume that manure contains 90.8% water.

Significant reductions in total manure production can be achieved by reducing feed and water wastage in the grow-finish phase of production.

One of the goals for designing and managing swine feeding programs is to maximize nutrient digestion, absorption, and utilization. By doing this, a minimum amount of nutrients will be excreted in swine manure. The nutrients present in the greatest quantities in swine manure are nitrogen, phosphorus, and potassium. Estimated amounts of these nutrients in swine manure for different production stages are shown in Table 2. Daily nitrogen excretion of nitrogen is highest, followed by potassium and phosphorus. Of these three nutrients, nitrogen and phosphorus are of greatest concern in regard to pollution and environmental management. Both nutrients become limiting during manure application of land, and cause significant environmental pollution through leaching (nitrogen) and erosion (phosphorus) into groundwater wells, creeks, and lakes.

### Table 2. Daily Nitrogen, Phosphorus, and Potassium Excretion (lb/pig/day) in Different Phases of Production.

<table>
<thead>
<tr>
<th>Production Phase</th>
<th>N</th>
<th>P</th>
<th>K</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nursery pig (35 lbs)</td>
<td>0.02</td>
<td>0.012</td>
<td>0.012</td>
</tr>
<tr>
<td>Growing pig (65 lbs)</td>
<td>0.03</td>
<td>0.022</td>
<td>0.023</td>
</tr>
<tr>
<td>Finishing pig (150 lbs)</td>
<td>0.07</td>
<td>0.050</td>
<td>0.054</td>
</tr>
<tr>
<td>Finishing pig (200 lbs)</td>
<td>0.09</td>
<td>0.067</td>
<td>0.072</td>
</tr>
<tr>
<td>Gestating sow (275 lbs)</td>
<td>0.07</td>
<td>0.050</td>
<td>0.050</td>
</tr>
<tr>
<td>Sow and Litter (375 lbs)</td>
<td>0.10</td>
<td>0.055</td>
<td>0.055</td>
</tr>
<tr>
<td>Boar (350 lbs)</td>
<td>0.09</td>
<td>0.064</td>
<td>0.064</td>
</tr>
</tbody>
</table>

Adapted from Midwest Plan Service (1993).
Nitrogen is an essential nutrient needed by all living plants and animals. However, nitrogen can also be a pollutant in certain chemical forms and locations in the environment (Schmidt and Jacobson, 1994). For example, nitrate nitrogen in soil is utilized as an essential nutrient for plant growth, but because it is soluble in water, it can be carried into lakes, streams and ground water supplies. When nitrate contaminated water is consumed by animals and humans, it may cause health problems after it is converted by bacteria in the body to nitrite. Nitrogen is also commonly found in the form of ammonium, which is another form of nitrogen used for plant growth. However, ammonium can easily be converted into ammonia, which is released into the atmosphere and can contribute to acidification of soil and water supplies.

Phosphorus is another essential nutrient needed by plants and animals, but can be a potential pollution hazard. The primary chemical form of phosphorus attaches itself to soil particles, which can be carried by erosion into lakes and streams (Schmidt and Jacobson, 1994). Phosphorus is a limiting nutrient for aquatic plant growth in most surface waters, and when introduced by erosion, there is a dramatic increase in plant growth. When these plants die, they are decomposed by aerobic bacteria, which deplete oxygen levels in the water and can cause fish kill.

Approximately 60-80% of the nitrogen and phosphorus consumed by swine is excreted in manure (Table 3). Although daily nitrogen and phosphorus intake increases with body size, the percent retention of these nutrients decreases, with only 17-19% of phosphorus and nitrogen retained by the sow. Therefore, significant opportunities exist to develop nutritional strategies to improve nutrient retention and reduce nutrient excretion.

### Table 3. Intake, Excretion, and Retention of Nitrogen and Phosphorus in Pigs.

<table>
<thead>
<tr>
<th></th>
<th>Young pig (20-55 lb)</th>
<th>Growing (55-235 lb)</th>
<th>Sow (19.6 pigs/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>N intake, lb</td>
<td>2.07</td>
<td>13.90</td>
<td>61.12</td>
</tr>
<tr>
<td>N excretion, lb</td>
<td>1.23</td>
<td>9.33</td>
<td>49.32</td>
</tr>
<tr>
<td>N retention, %</td>
<td>40</td>
<td>33</td>
<td>19</td>
</tr>
<tr>
<td>P intake, lb</td>
<td>0.46</td>
<td>2.68</td>
<td>14.43</td>
</tr>
<tr>
<td>P excretion, lb</td>
<td>0.29</td>
<td>1.80</td>
<td>11.92</td>
</tr>
<tr>
<td>P retention, %</td>
<td>39</td>
<td>33</td>
<td>17</td>
</tr>
</tbody>
</table>

Adapted from Jongbloed and Lenis (1993)

Research related to diet manipulation to reduce excretion of odor and gas producing products from animal manure has been limited. However, diet manipulation offers promise as a partial solution for reducing odors. Most of the research that has been conducted has focused on dietary modification to reduce ammonia emissions. Only a few studies have evaluated diet modification on odor or other odorous gases. Several odorous compounds have been identified in swine manure (Table 4). They can generally be subdivided into 5 categories: carboxylic acids, alcohols, phenolic compounds, mercaptans and sulfides (Zhu et al., 1997). As previously discussed, nutrient digestibility plays a significant role in the quantity and composition of swine manure. Nutrient digestibility may also affect microbial
fermentation of undigested and unabsorbed compounds in the lower gastrointestinal tract. Therefore, dietary manipulation has the potential to reduce odors in swine manure.

Odor production occurs in livestock manure as a result of several complex microbial fermentation interactions. Complex macro-nutrients found in swine manure are broken down into low molecular weight organic compounds and molecular hydrogen by fermentative microorganisms. These low molecular weight compounds are used as energy sources by sulfate-reducing bacteria to produce hydrogen sulfide in the presence of sulfate. Ammonia, phenol, p-cresol, indole, skatole and branched chain volatile fatty acids are produced via various pathways associated with degradation of protein in the diet. Tryptophan degrades to phenol and p-cresol, and tyrosine degrades to indole and skatole. Sulfide odors originate from the sulfur containing amino acids (e.g. methionine and cystine). Characteristics, exposure limits and human health concerns of common gases and odors produced in swine operations are shown in Table 4.
Table 4. Characteristics of Common Gases and Odors Produced in Swine Operations.

<table>
<thead>
<tr>
<th>Gas</th>
<th>Odor</th>
<th>Characteristics</th>
<th>Exposure Limits</th>
<th>Human Health Concerns</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ammonia (NH₃)</td>
<td>Sharp, Pungent</td>
<td>Lighter than air. Results from anaerobic and aerobic activity. Soluble in water.</td>
<td>10 ppm</td>
<td>Irritation to eyes and nose. Asphyxiating at high levels.</td>
</tr>
<tr>
<td>Carbon Dioxide (CO₂)</td>
<td>Odorless</td>
<td>Heavier than air. Results from anaerobic and aerobic activity.</td>
<td>5,000 ppm</td>
<td>Drowsiness, headache. Can be asphyxiating.</td>
</tr>
<tr>
<td>Hydrogen Sulfide (H₂S)</td>
<td>Rotten egg smell</td>
<td>Heavier than air. Low odor threshold. Soluble in water.</td>
<td>10 ppm</td>
<td><strong>Toxic.</strong> Causes headache, dizziness, nausea, unconsciousness, death.</td>
</tr>
<tr>
<td>Methane (CH₄)</td>
<td>Odorless</td>
<td>Lighter than air. Product of anaerobic activity.</td>
<td>1,000 ppm</td>
<td>Headaches, asphyxiating, explosive in 5%-15% mixture of methane with air.</td>
</tr>
<tr>
<td>Volatile Organic Acids</td>
<td>Strong</td>
<td>High odor potential under anaerobic condition, low odor potential under aerobic conditions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phenolic Compounds</td>
<td>Strong</td>
<td>p-cresol has lower odor threshold than hydrogen sulfide. Exists in raw manure and concentrations increase under anaerobic conditions.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Veenhuizen, 1995
Feed Processing / Form

Particle Size

It is well established that reducing particle size of grain improves nutrient digestibility and feed conversion, while reducing manure excretion. Reduction of particle size increases the surface area of the feedstuff, increasing exposure to digestive enzymes and therefore, improving overall nutrient digestibility.

In a review of data from several experiments, Hancock et al. (1997) concluded that gain/feed of grow-finish pigs improves 1.3% for each 100-micron reduction in corn ranging between 1,200 to 400 microns. This is equivalent to a 1.3% reduction in manure output for each 100-micron reduction in particle size of corn. Gieseman et al. (1990) reported an improvement in feed conversion with reduced particle size for finishing pigs fed a corn/sorghum-based diet. Mahan et al. (1966) and Lawrence (1983) also observed an improvement in feed efficiency when particle size of grain was reduced from coarse to fine. Wondra et al. (1995b) measured an 8% improvement in gain/feed for finishing pigs when corn was ground from 1,000 to 400 microns.

Similar results were also obtained comparing lactation diets containing corn milled to different particle sizes (Wondra et al., 1995a,b). Reducing particle size from 1,200 to 400 microns resulted in improved lactation feed intake, DE intake (14%), and litter weight gain (11%) while reducing fecal DM excretion (21%) and fecal N excretion (31%). The effects of corn particle size on nutrient metabolism in second parity sows is presented in Table 5.

Table 5. Effects of Corn Particle Size on Nutrient Metabolism in Second Parity Sows (Wondra et al., 1995b).

<table>
<thead>
<tr>
<th>Variable</th>
<th>1,200</th>
<th>900</th>
<th>600</th>
<th>400</th>
</tr>
</thead>
<tbody>
<tr>
<td>DM digestibility, %a</td>
<td>82.2</td>
<td>85.2</td>
<td>85.6</td>
<td>88.1</td>
</tr>
<tr>
<td>N digestibility, %b</td>
<td>80.7</td>
<td>85.6</td>
<td>86.9</td>
<td>88.5</td>
</tr>
<tr>
<td>Biological value, %</td>
<td>55.0</td>
<td>62.7</td>
<td>62.0</td>
<td>57.0</td>
</tr>
<tr>
<td>N retention, %b</td>
<td>50.9</td>
<td>63.0</td>
<td>63.2</td>
<td>56.7</td>
</tr>
<tr>
<td>GE digestibility, %a</td>
<td>81.9</td>
<td>85.5</td>
<td>86.3</td>
<td>89.9</td>
</tr>
<tr>
<td>GE retention, Mcal/da</td>
<td>13.2</td>
<td>14.1</td>
<td>14.4</td>
<td>14.3</td>
</tr>
<tr>
<td>DE kcal/kg dieta</td>
<td>3,513</td>
<td>3,668</td>
<td>3,705</td>
<td>3,857</td>
</tr>
<tr>
<td>ME kcal/kg dieta</td>
<td>3,399</td>
<td>3,572</td>
<td>3,601</td>
<td>3,745</td>
</tr>
</tbody>
</table>

a Linear effect of particle size reduction (P < .02).

b Quadratic effect of particle size reduction (P < .04).
Hammermills and roller mills are the two primary pieces of equipment used to decrease particle size. The initial cost of roller mills is higher than that of hammermills, but the cost of operating a hammermill (energy required and production rate per horsepower hour when grinding) is less than that of a roller mill. Wondra et al. (1995b) observed that milling energy increased and production rate decreased slightly as corn particle size was decreased from 1,000 to 600 microns (2.7 to 3.8 kWh/t, 2.7 to 2.6 t/h, respectively) when utilizing a hammermill. The energy required to reduce particle size from 600 to 400 microns was more than twice (8.1 kWh/t) that required to achieve 600 microns, and production rate decreased significantly (1.3 t/h). Additionally, type of grain milled affects energy usage and production rate. Healy et al. (1994) reported that less energy was required to grind sorghum to 500 microns than to grind corn to 900 microns. Baker (1960) found that sorghum grain was easier to grind than corn, and corn was easier to grind than oats.

Hancock et al. (1997) estimated total milling costs of $0.64/t for hard sorghum (900 microns) and $5.98/t for corn (500 microns). However, when these increases in diet cost were compared with improvements in feed conversion during a 35-day growth trial, the milling costs were more than offset, such that cost/lb of gain for these cereal grains decreased as particle size was decreased. Based on experiments with nursery and finishing pigs and lactating sows, it was determined than the optimum particle size for cereal grains was 600 microns or less.

Uniformity of particle size also appears to affect nutrient digestibility. Use of roller mills has been shown to improve particle size uniformity and result in a 19 and 12% reduction in fecal dry matter and nitrogen excretion, respectively, compared to corn milled to equivalent average particle sizes with a hammermill (Wondra et al., 1995c). Particles of hammermilled corn are also more spherical in shape with more uniform edges than those from roller milled corn (Reece et al., 1985). The spherical shape may reduce the ability of digestive enzymes to attack the particles, resulting in reduced nutrient digestibility in hammermilled corn.

Uniformity of Ingredient Distribution

Many factors are associated with increased variation in ingredient distribution in feed, including worn equipment, ingredient residue from previous batches, over- or under-filling a mixer, errors in weighing ingredients, and segregation of particles after mixing. Inadequate mixing, however, is most commonly indicated as the primary cause of inadequate diet uniformity (Hancock et al., 1997). Several investigators (Beumer, 1991; Lindley, 1991; Wicker and Poole, 1991) have stated that variation (measured as coefficient of variation (CV)) less than 10% indicates an adequately mixed feed batch. Wicker and Poole (1991), however, conducted a survey of commercial mixers and found that more than half yielded CV’s of greater than 10%.

Traylor et al. (1994) observed an increase in ADG from 267 to 379 g/d when diet uniformity increased (CV = 106.5 and 28.4 %, respectively) in diets fed to nursery pigs (initial body weight of 5.5 kg) during a 27-day growth study. A concomitant increase in ADFI (598 vs. 711 g/d) and gain/feed (0.446 vs. 0.533) was also observed. In these diets, mix time increased from 0 to .5 minutes. Increasing mix time to 4 minutes resulted in further improvements in reducing variation (CV = 12.3 %), ADG (402 g/d), ADFI (720 g/d), and gain/feed (0.558). A similar study utilizing finishing pigs (initial body weight of 56 kg) fed to slaughter weight (118 kg) resulted in a much lower response to increased mix time. Increasing mix time from 0 to .5 minutes decreased CV from 53.8 to 14.8 %, but resulted in only a modest numerical improvement in ADG (777 vs. 807 g/d) and gain/feed (0.263 vs. 0.278). Further mixing up to 4 minutes resulted in a lower CV (9.6
but did not affect growth performance or feed conversion. Part of the reason for these different results may be that .5 min resulted in a more adequate CV during the finishing trial compared to the nursery trial (14.8 vs. 28.4 %). Holden (1988), however, stated that improper mixing of one batch of feed rarely will cause serious problems in growing pigs because a single batch will be consumed in such a short period of time. These results suggest that ingredient nonuniformity within a batch of feed is more of a concern for nursery pigs compared to older growing pigs.

**Pelleting**

Feed can be fed in the meal (ground) form or further processed using heat and/or pressure. Thermal processing may be completed through pelleting, micronizing (roasting), extruding, or steam flaking ground diets. Due to cost, pelleting is the preferred type of thermal processing generally used in commercial pig diets.

Pelleting has been shown to reduce feed wastage, segregation of ingredients, dust production, and nutrient excretion while increasing nutrient digestibility and rate and efficiency of gain. Wondra et al. (1995b) demonstrated that pelleting reduced fecal N by 22% and fecal DM by 23%. In eight studies reviewed by Hancock et al. (1997), there was an average improvement of 6% in ADG and a consistent improvement of 6 to 7% in efficiency of gain in grow-finish pigs. It was not necessary to produce different pellet sizes for different ages of pigs, and a 4 to 5 mm die size appeared to be adequate, since the highest gain/feed came from 4 mm pellets. Although pelleting offers many benefits, if it is not done properly (i.e. excessive fines, excessive heat, moisture), the added benefits on performance quickly disappear. Pelleting may also increase ulcers in pigs, as can any of a number of factors, including: genetics; housing; stress; and management. These results suggest that significant reductions in manure and nitrogen output can be achieved by feeding pelleted diets.

**Minimizing Feed Wastage**

Feed wastage not only affects feed efficiency and feed cost/lb gain, but it is also a significant contributor to total manure output which affects manure storage, handling and application costs. Well managed nursery, grow-finish and sow feeders generally waste between 2 to 11 % depending on feeder design. However, feed wastage can exceed 25 % in poorly managed swine operations.

McG lone and Fumuso (1994) conducted a study to evaluate growth performance and feed wastage of nursery pigs fed from 17 commercially available nursery feeders made by 13 different feeder manufacturers. Pigs were weaned at 4 weeks of age and averaged 15.2 lbs. Average daily gain ranged from .37 to .50 lbs/day, ADFI ranged from .63 to 1.0 lbs/day, and feed/gain (adjusted for wastage) ranged from 1.51 to 2.12 for the first 3 weeks in the nursery. Feed wastage for these 17 commercial feeders ranged from 2.55 to 10.20%. As a result, differences between feed/gain ratios without feed wastage and feed/gain ratios including wastage ranged from .01 to .23 lbs feed/lb gain. This resulted in increased feed costs of $.05 to $1.10/nursery pig. It is reasonable to speculate that similar differences may also be found among commercially manufactured grow-finish and sow feeders.
Proper feeder adjustment is critical for preventing excessive feed wastage. However, feeders that are adjusted too tightly can also limit feed intake resulting in slower gains. Some feeders are easier to adjust than others, which generally determines whether or not feeders get frequently adjusted by barn managers. Feeder adjustment should be checked at least 3 times a week to minimize wastage. A good rule of thumb is to adjust feeder settings so that there is slightly less than 50% of the feed trough covered. This setting keeps feed fresh, minimizes spoilage and reduces feed buildup that contributes to wastage.

**Water Consumption**

Another area that impacts manure volume from swine is the level of water intake. Sow manure (slurry) has a high water content of 92-97%. Van der Peet-Schwering et al. (1997) examined water intake in pregnant sows and found that lowering the water:feed ratio from 3.6:1 to 2.0:1 reduced water intake from 2.43 to 1.43 gallons/day, and the subsequent manure production from 2.42 to 1.58 m³. The dry matter content of the manure and the concentration of ammonium nitrogen and total nitrogen were more concentrated from the sows with the lower water: feed ratio. This lowered manure handling costs (storage and disposal), as well, due to decreased total volume for transport. Sow performance was not adversely impacted by reduction of water. However, the water:feed ratio of 2.0:1 is too low when room temperature is high and sows begin to refuse feed. When room temperature increases above 20°C (68°F), water intake should be increased 0.05 gallons/day per °C above 20°C.

Although limited research has been conducted regarding restriction of water intake on nutrient intake and utilization, the information that is available suggests that water intake is not as critical as has been historically assumed. Water balance in the growing pig is illustrated in Table 6 (Patience and Zijlstra, 1998).

<table>
<thead>
<tr>
<th>Table 6. Typical Water Balance in Growing Pigs.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Intake</strong></td>
</tr>
<tr>
<td>Drinking water⁵</td>
</tr>
<tr>
<td>Food water⁶</td>
</tr>
<tr>
<td>Water of oxidation⁷</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
</tr>
</tbody>
</table>

Assumptions: 75 kg pig growing at a rate of 1,050 g/day, protein deposition rate of 155 g/day and eating 2,500 g/day of a reasonably well balanced commercial diet. All calculations are rounded to the nearest 5 g. Actual results may vary widely from this example due to environmental, nutritional, health and genetic factors.

⁵Assumes ad libitum water intake equal to 2.25 times feed intake. Actual intake under commercial conditions may vary depending on air temperature, feed composition, etc.

⁶Assumes feed contains 89% dry matter.

⁷Assumed to be 7.43 ml/kg body weight (Gill, 1989).
Assumed to be 48.3% of body weight (Lorschy et al., 1998).

 Assumes the dry matter digestibility of the diet 80%, and the feces to contain 30% dry matter.

 Estimated at 0.01 ml/kg body weight/day (Gill, 1989).

 Estimated at 13.2 ml/m²/hr (Gill, 1989).

 Calculated to maintain water balance.
As indicated in Table 6, urinary output is approximately 60% of the total amount of drinking water consumed. Dietary nutrient levels can alter water intake. Pfeiffer et al. (1995) observed that lower protein levels in the diet reduced water intake. Mineral levels in diets, particularly salt, can also greatly affect water intake. Care should be used to minimize excessive dietary salt levels in order to reduce water consumption and urine excretion.

With declining profit margins and increasing manure storage and handling costs, producers may need to consider methods to regulate water:feed ratios, particularly during the grow-finish phase of production. Mroz et al. (1996) observed that varying the water:feed ratio from 2:1 to 4:1 had no effect on apparent digestibility of dry matter, organic matter, ash, nitrogen, calcium or phosphorus in gestating sows. It did, however, increase daily urinary output from 2.9 to 6.5 L/day. Cai and Zimmerman (1992) found no effects of reducing the water:feed ratio to 1.5:1 for growing pigs. The Dutch government recommends a water:feed ratio of 2.5:1, 2.25:1 and 2.0:1 for growing pigs from 25 to 40 kg, 45 to 70 kg, and 70 kg to market, respectively (Central Veevoederbureau, 1993).

**Water Wastage**

The main contributors to water wastage include excessive cleaning water and improperly adjusted or leaking waterers. Use of high pressure (1750 psi), low flow rate (4.2 gallons/minute) washers for cleaning pens can reduce water usage by 50% in nursery and finishing pens compared to lower pressure (880 psi), higher flow rate (12 gallons/minute) washers for nurseries and finisher pens (Schmidt and Jacobson, 1994). Nipple drinkers are superior to cup or bowl type drinkers because no water accumulates to be fouled by feed or excreta. Well managed nipple drinkers generally result in less water wastage than cup or bowl waterers. However, nipple drinkers need to be checked frequently to insure that water flow is not obstructed. Depending on number of pigs/drinker, spacing between drinkers, and ease of adjustment of flow rate for specific nipple drinker brands, the flow rate can often be substantially reduced to minimize water wastage without adversely affecting pig performance (Schmidt and Jacobson, 1994).

McGlone and Fumuso (1994) also observed that water usage in the nursery ranged from .16 gallons/10 pigs/day to 1.81 gallons/10 pigs/day among the feeders compared. Results from this study clearly show the impact of feeder design on feed wastage, feed/gain ratios, water usage, cost of production, and manure volume in the nursery.

**Feed Ingredients**

*Anti-Nutritional Factors*

Ingredient selection and feed processing methods designed to reduce anti-nutritional factors have been shown to reduce nitrogen excretion (Jongbloed and Lenis, 1991). These anti-nutritional factors include sources of fiber, trypsin and chymotrypsin inhibitors, leptins, phenolic compounds, and tannins. Anti-nutritional factors in diets can result in any of the following: reduced body weight gain, reduced feed intake, reduced immune protection, increased water consumption, reduced reproductive performance or infertility, and reduced nutrient digestibility. In general, the health status of the pig is lowered, and its ability to efficiently incorporate feed
ingredients into body protein is reduced, resulting in greater amounts of nutrients being excreted per unit of performance. However, the technology for further processing feed ingredients to remove most anti-nutritional factors is not currently cost effective or feasible.

**Non-Starch Polysaccharides and Cellulose**

In swine, feeding diets containing a higher proportion of complex carbohydrates such as cellulose, B-glucans and other non-starch polysaccharides shift nitrogen excretion toward feces and away from urine, which reduces ammonia emissions (Kreuzer and Machmuller, 1993; Mroz et al., 1993). Feeding a low carbohydrate, high fiber diet (alfalfa meal and rice bran) to pigs reduces excretion of fecal volatile acids compared to pigs fed a corn starch and glucose diet (Imoto and Namioka, 1978). However, Hawe et al. (1992) showed that feeding a diet containing increased fiber from beet pulp, increased the concentration of two odorous compounds, skatole and indole, in feces, but levels of these two compounds tended to be reduced when pigs were fed the antibiotic tylosin phosphate. Lactose had no effect on reducing indole concentrations but did reduce daily excretion of skatole. More information concerning fiber sources and types is presented later in this paper under *Fiber Types and Sources*.

**Distiller’s Dried Grains with Solubles**

Initial studies have indicated that including distiller’s dried grains with solubles (DDGS), a co-product of the ethanol industry, can greatly affect nutrient content of manure but has a minimal effect on odor and gasses emitted. In one study, adding 20% distiller’s dried grains with solubles to swine diets had no effect on reducing odor, hydrogen sulfide, or ammonia emissions (Spiehs et al., 2000). A phosphorus digestibility study, however, indicated that phosphorus excretion can be significantly decreased with inclusion of 10 – 25% DDGS in the growing-finishing swine diet (Whitney et al., 2001). DDGS is an excellent source of digestible phosphorus. Unlike corn and soybean meal, which have digestibility coefficients of 14% and 23-31%, respectively, NRC (1998) lists the phosphorus digestibility (bioavailability) of DDGS at 77%. Whitney et al. (2001) determined the relative availability of DDGS from a new ethanol plant in MN to be 85 – 90%. This implies that a much lower level of inorganic phosphorus supplementation is needed, with a considerable decrease in subsequent phosphorus excretion. DDGS, however, also contains a high crude protein level and poor amino acid balance, similar to corn. This means a large amount of nonessential amino acids are subsequently excreted, increasing the nitrogen content of pig slurry. Inclusion of 20% DDGS in two studies (Spiehs et al., 1999; Spiehs et al., 2000) resulted in a 25% increase in nitrogen excreted. However, use of synthetic amino acids (L-lysine) and formulation on a digestible amino acid basis can decrease the total amount of nitrogen excreted.

**Use of Designer Grains**

Genetic selection and engineering technologies have resulted in a variety of “designer” corn and soybean varieties being produced in recent years. These new varieties provide value-added traits to the feed industry, including improvements in nutrient content and digestibility and other attributes to improve environmental quality, meat quality, and food safety (Stilborn, 1999). The quantity and quality of designer grains will increase in the future, but current grains that are
commercially available include high oil corn, high lysine and/or high methionine corn, low phytic acid corn, and low phytic acid/low-oligosaccharide soybeans.

High oil corn contains an increased oil content, and thereby increases energy concentration due to an increased proportion of germ relative to endosperm in the kernel (Stilborn, 1999). In addition, an increase in protein and amino acid content is associated with high oil corn due to the increased germ content (Araba, 1997). Replacement of yellow dent corn with high oil corn in swine diets allows the nutritionist to either increase the metabolizable energy density of the diet or replace part of the added fat normally supplemented in the diet. As is mentioned later in this paper, including fat in the diet improves indoor air quality and may decrease odor emissions in swine barns due to a decrease in airborne dust levels generated from the feed. Thaler and Pohl (2000) observed a 40% decrease airborne dust concentration during the growing-finishing phases when high oil corn replaced yellow dent corn in diets.

It is important to maintain the same lysine:calorie ratio when substituting high oil corn for yellow dent corn in swine diets. When utilizing high oil corn, it is important that the ratio of other nutrients, especially amino acids, be maintained relative to energy level (Thaler and Pohl, 2000). Although high oil corn contains increased protein and amino acid levels relative to yellow dent corn, the amino acid profile and digestibility is still inferior to soybean meal or other protein supplement sources. This implies that replacing soybean meal in the diet will ultimately result in an increase in nitrogen excretion if diets are not formulated on a digestible amino acid basis. However, Risley and Bajjalieh (1996) demonstrated that by increasing the energy density of the diet (through replacement of yellow dent corn with high oil corn), voluntary feed intake is decreased, but more efficient gain is realized during the grow-finish period. Depending on the increase in energy concentration of the diet and subsequent improvement in feed conversion, a potential decrease in nutrient excretion per unit of performance (gain) could be achieved, although research is needed in this area. Bowers et al. (2000b) observed 6.7% improvement in feed conversion during the grow-finish period when high oil corn replaced yellow dent corn on an equivalent weight basis.

High available phosphorus (low phytic acid) corn varieties have been developed that can potentially decreased the total amount of phosphorus excreted when incorporated into swine diets. Approximately 80% of the total phosphorus in normal corn is tied up in the phytate (phytic acid) form, which cannot be broken down by digestive enzymes and be absorbed and utilized by the pig. Low phytic acid corn, however, has only 35% of the total P bound in phytate form, resulting in an increase in the available phosphorus concentration of the grain. Sands and Adeola (2000) determined the phosphorus bioavailability of a high available phosphorus corn variety to be 62%, compared to 44% for normal dent corn in young growing pigs. When swine diets are properly formulated to account for the increase in available phosphorus content of low phytic acid corn, less supplemental phosphorus is required, dietary total P level is lowered, and subsequent P excretion is reduced. Sands et al. (2000) observed an increase in phosphorus retention and digestibility in young growing pigs when high available phosphorus (low phytic acid) corn replaced normal dent corn, and also tended to improve rate of gain and feed conversion efficiency. Utilization of low phytic acid corn may also improve sow lactational performance. Bowers et al. (2001) observed a 7.1% increase in sow feed consumption during a 22 day lactation period, in addition to a 7.9% improvement in litter weight gain and 5.7% increase in litter weaning weight when sows were fed diets with low phytic acid corn compared to sows fed a normal yellow dent corn in the lactation diet. Unfortunately, low phytic acid corn is not yet commercially available.
The nutritional quality and phosphorus digestibility of soybeans can also be improved by a reduction of the phytic acid content of the seed (Raboy and Dickinson, 1993). Approximately 70% of the total phosphorus in soybeans is present in the phytic acid form (Raboy et al., 1984), but low phytic acid varieties can reduce the phytic acid level by about two-thirds (Raboy et al., 1985). In growth performance and bone assay studies in turkeys (Ledoux et al., 1998) and broiler chicks (Denbow et al., 1998), supplying phytase either as a commercial supplement or in the form of soybean meal produced from low phytic acid soybeans resulted in improved growth performance and improved phosphorus availability compared to traditional soybean meal. Spencer et al. (2000) determined the relative phosphorus bioavailability of two types of soybean meals containing low levels of phytate phosphorus and oligosaccharides to be approximately 60 – 70%, compared to 30% for traditional soybean meal in young growing pigs, resulting in decreased P excretion in manure. Cromwell et al. (2000a) determined that the phosphorus in low-phytate/low-oligosaccharide soybean meal was 2 to 3 times as bioavailable as the phosphorus in normal soybean meal for growing pigs. The relative bioavailability of phosphorus, based on a slope-ratio assay compared to monosodium phosphate, was 49% for low-phytate/low-oligosaccharide soybean meal compared to 19% for normal soybean meal. Similar results were observed in finishing pigs by Frank et al. (2000). They determined that phosphorus digestibility was greater in two low-phytate/low-oligosaccharide soybean meals (55 and 58%) compared to a commercially available normal soybean meal (43%) for finishing (150 lb) pigs. Although these new low-phytate soybean varieties will effectively reduce P excretion, they are not yet commercially available.

Incorporating low-phytate corn and low-phytate/low-oligosaccharide soybean meal into swine diets has been demonstrated to dramatically reduce phosphorus excretion levels. Spencer and Allee (2000) reported a 56% decrease in phosphorus excretion from young growing pigs fed a diet containing low-phytate corn and low-phytate/low-oligosaccharide soybean meal compared to a diet containing normal dent corn and soybean meal. Diets were formulated on an equivalent available phosphorus basis, using values of .03 and .17% available phosphorus for normal and low-phytate corn, and .17 and .40% available phosphorus for normal and low-phytate/low-oligosaccharide soybean meal. Cromwell et al. (2000b) observed similar results. Growing pigs fed low-phytate corn and low-phytate/low-oligosaccharide soybean meal required less supplemental phosphorus to obtain equivalent growth performance and phosphorus retention, and excreted 55% less fecal phosphorus compared to pigs fed typical corn-soybean meal diets.

**Vegetable Oil / Animal Fat Inclusion**

Adding soybean oil to complete feeds, after grinding, reduces the amount of airborne dust from that feed. Dust concentrations are markedly reduced after adding 1% soybean oil and dust may be further reduced by adding 3% soybean oil. Low bulk density corn produces more dust than normal-bulk density corn. It is estimated that oil concentrations of greater than 3% will be required to get dust suppression similar to that of the 3% soybean oil/normal density corn blend. Reducing dust in hog facilities has been shown to reduce odor emissions from those facilities (Mankell et al., 1995).

Chiba and Peo (1985) measured decreases in aerial dust levels in modified open front confinement facilities of 21.4% and 49.1% with inclusion of 2.5% and 5.0% tallow in the diet for growing pigs. Similar decreases in aerial dust levels of 48.2% and 51.4% were achieved in
totally enclosed environmentally regulated growing-finishing facilities with 5% dietary tallow addition.
**Feed Additives**

**Yucca Schidigera**

Extracts and preparations of the desert plant *Yucca schidigera* can be added to the diet, slurry under slatted floors, or to the filter bed of biofilters to reduce ammonia emissions. Numerous studies have examined the beneficial effects of dietary inclusion for animals and humans. Sarsaponin, an extract of *Yucca schidigera*, is an inhibitor of urease activity in the gut in the pig. This, in turn, results in less nitrogen being converted to ammonia.

*Yucca schidigera* is capable of binding and retaining ammonia in a non-volatile, non-toxic form. Headon and Walsh (1993) predicted that the ability of *Yucca schidigera* to bind and reduce atmospheric levels of ammonia would assure its widespread use in confinement buildings. They found that extracts from the plant were efficient in reducing levels of ammonia by as much as 69% in swine buildings compared to buildings housing pigs fed an unsupplemented diet. The reduced levels of ammonia in confinement units can potentially improve animal performance and enhance the working environment for caretakers.

*Yucca schidigera* extract has been shown to reduce ammonia emission from manure by inhibiting urease activity (Ellenberger et al., 1985; Gibson et al., 1985; Goodall et al., 1988). Amon et al. (1995) demonstrated a significant reduction (26%) in the ammonia concentrations in swine finishing buildings over a 7-week experimental period compared to untreated control buildings. *Yucca schidigera* is typically added to animal feed at levels of 120 ppm. De-Odorase™, a commercial Yucca extract preparation from Alltech, Inc., was found to be effective in reducing ammonia levels (Headon and Walsh, 1993). The addition of De-Odorase™ (120 ppm level in feed) reduced atmospheric ammonia levels from 53.1 to 66.6% after 9 weeks inclusion in the diet for the test pigs, and once it was removed from the diet, ammonia levels increased. In another trial, the effect of De-Odorase™ on finishing pigs was examined. The experimental group received 150 ppm De-Odorase™, and a decrease in ammonia emissions of over 50% was observed.

Pig performance appears to be unaffected or may even be slightly improved when *Yucca schidigera* extract is added to swine diets. Cromwell et al (1985) reported a 5 – 10% increase in growth rate when growing pigs were fed *Yucca schidigera* extract at a rate of 62 – 125 ppm, but no significant improvement in growth rate when 250 ppm *Yucca schidigera* extract was fed. In a study conducted by Duffy and Brooks (1998), where pigs were fed from 60 - 190 lbs, the addition of 120 ppm De-Odorase™ extract to the diet significantly increased body weight gain by 0.11 lb/d. Days to market were decreased by 7 days compared to pigs fed the control diet. In addition, a 14% decrease in P2 backfat thickness at time of slaughter was also observed. Decreases of up to 36% in urine ammonia concentration during the nutrient metabolism portion of the study were also noted, but ammonia emission levels were not measured.

The beneficial effects of *Yucca schidigera* extract on ammonia emission appears to occur in younger pigs also. Colina et al. (2000) found significant decreases in aerial ammonia concentrations, despite overall low levels, when 125 ppm *Yucca schidigera* extract was fed to pigs beginning at 11 – 15 days of age over a 3-week trial. No differences in growth rate, feed conversion, or feed consumption were observed. In a follow-up study, Colina et al. (2001) reported similar findings. Addition of 125 ppm *Yucca schidigera* extract to weanling pig diets resulted in reduced aerial ammonia levels, without any differences in growth performance.
Sutton et al. (1992) observed that ammonia emission was suppressed by 55.5% in swine manure from growing pigs fed sarsaponin extract at a rate of 4 oz/ton of feed. However, Kemme et al. (1993) was unable to verify this response, and reported that much higher amounts of the extract (6000 ppm) were needed for maximal suppression of ammonia from urea. Therefore, it appears that *Yucca schidigra* is effective in reducing ammonia levels when added to swine diets, but inclusion rate may vary depending on diet characteristics and environmental and housing conditions.

**Zeolite**

Zeolites are both naturally occurring (volcanic mineral) and synthetically manufactured alumino silicate compounds that have the capability of effectively removing selected molecules from a medium through adsorption and ion exchange. There are 45 various types of zeolites with different cavity areas and selectivity to adsorb ammonium ions (Sersale, 1983). Zeolites are generally added to swine diets to improve feed efficiency, reduce the incidence of intestinal disease, and/or decrease ammonia and odor emission from manure (Airoldi et al., 1993). Zeolites have been shown to absorb phenolic compounds. However, studies involving the addition of zeolites to swine diets to reduce odor and improve animal performance have produced inconsistent results. The effectiveness of zeolites in promoting growth may be related to the specific type used, its properties, and level of supplementation in the diet (Mumpton and Fishman, 1977).

Airoldi et al. (1993) failed to show any significant effects of a specific zeolite (phillipsite) on ammonia air level or pig growth when added to the diet at a rate of 5%. A subsequent laboratory test by Airoldi et al. (1993) indicated a minimum dietary inclusion rate of 10% was necessary to reduce ammonia emission. These findings supported results of a previous study by the same group (Balsari and Bertolotto, 1991), indicating no differences in feed conversion, daily weight gain, or ammonia emission with 2.5 or 5% dietary inclusion. Krieger et al. (1993) tested the ammonia binding ability of a naturally occurring zeolite (clinoptilolite) in pig manure and found no benefit. Furthermore, Shurson et al. (1983) fed a diet containing 5% zeolite A (synthetic zeolite) to growing pigs and found an increase in fecal nitrogen excretion and an increase in urinary p-cresol excretion.

Other studies have shown that the addition of 5% zeolite to swine diets reduces odors and improves growing pig performance. Vrzgula and Bartko (1983) observed an increase of 0.15 lb/d ADG with 5% dietary inclusion of zeolite (clinoptilolite). They reported less odor and firmer feces from pigs with diarrhea within 24 hrs. Pond and Yen (1987) found a 14% improvement in weight gain in weanling pigs fed corn-soybean meal or rye-corn-soybean meal based diets with 2% clinoptilolite added. Barrington and El Moueddeb (1995) found no difference daily weight gain, but a net improvement in feed conversion (- 0.29 lb feed/lb gain) for pigs from 60 to 170 lb body weight. Ammonia levels tended to decrease from 20 to 50% with zeolite supplementation, with lower odor level detected by a human odor panel and olfactometry. In another study, Poulsen and Oksbjerg (1995) observed a shift in the nitrogen excretion pattern toward increased excretion in feces and decreased excretion in urine with 3% dietary inclusion of zeolite (70% clinoptilolite). Pigs did gain slightly less, due to decreased energy concentration of the zeolite diet, but protein retention was not adversely affected. Gao et al. (2000) observed a 29% decrease in accumulative ammonia emission with 0.6% dietary inclusion of zeolite.
**Bentonite**

Bentonite is another alumino silicate material different from zeolite. Bentonite is a type of clay (phylllosilicate) but does not have molecular sieve properties (Taylor, 1999). Similar to zeolites, it affects cation exchange, adsorption, and water uptake when used as a feed additive. Bentonite is often used as a binder in pelleted swine diets because of its high water-absorbing capacity.

Taverner et al. (1984) observed no significant differences in growth performance under ad libitum and restricted feeding regimes when wheat-barley based diets containing 8.8% sodium bentonite were fed to growing pigs from 45 to 150 lbs body weight. Additionally, Collings et al. (1980) found no effect of dietary sodium bentonite addition on energy or nitrogen digestibility in growing and finishing pigs fed corn-soybean meal based diets. However, the same author observed decreased nitrogen digestibility but improved rate and efficiency of gain in starter pigs fed 2 and 3% dietary bentonite levels.

Hornig et al. (1997) observed a 10 to 33% decrease in ammonia emission from stored manure obtained from growing pigs receiving 2% bentonite in the feed. Bentonite supplementation also resulted in a 26 to 37% reduction of odor emission. The ratio of ammonium to total nitrogen content in the slurry of pigs fed bentonite was 15 to 20% higher despite higher pH of the slurry. Bolduan and Beck (1991) also reported lower ammonia concentrations in the excrement of piglets which were fed bentonite. Another experiment with piglets receiving 2% dietary bentonite reduced ammonia and methane emissions (Wanka, 1996). Most recently, Gao et al. (2000) measured a decrease in accumulative ammonia emission by 27.4, 41.5, and 43.9% with 1.2, 2.4, and 3.6% dietary inclusion of diatomaceous earth in corn-soybean meal diets for growing pigs. Hydrogen sulfide emission from the slurry was also measured, but no treatment differences were observed.

**Jerusalem Artichoke**

Jerusalem artichoke (*Helianthus tuberosus L.*) is a native North American plant having a tuber that grows underground. The tubers are high in inulin, which can be broken down to fructooligosaccharide, a carbohydrate. Adding Jerusalem artichoke to growing pig diets has resulted in faster growth and improved feed conversion. In addition, inulin appears to increase growth of bifidobacteria in the pig, reducing diarrhea and swine manure odor. Farnworth et al., 1995 conducted a sensory evaluation study to characterize the smell of fresh (< 4 hours) swine manure obtained from pigs fed 0, 3, and 6% Jerusalem artichoke. As shown in Table 7, swine manure from pigs fed Jerusalem artichoke smelled sweeter, less sharp and pungent, and had less skatole than pigs fed the control diet. The observed changes in pig manure and subsequent odor are most likely due to the positive influence of Jerusalem artichoke on bifidobacteria in the intestinal microflora.
Table 7. Sensory Evaluation of the Smell of Manure from Pigs Fed Diets Containing Jerusalem Artichoke.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>0%</th>
<th>3%</th>
<th>6%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sweet</td>
<td>3.9</td>
<td>4.3</td>
<td>5.0</td>
</tr>
<tr>
<td>Earthy</td>
<td>2.5</td>
<td>2.4</td>
<td>2.4</td>
</tr>
<tr>
<td>Sour</td>
<td>2.9</td>
<td>2.9</td>
<td>3.3</td>
</tr>
<tr>
<td>Sharp, pungent</td>
<td>5.4</td>
<td>4.3</td>
<td>4.1</td>
</tr>
<tr>
<td>Skatole</td>
<td>6.0</td>
<td>4.0</td>
<td>3.9</td>
</tr>
</tbody>
</table>

(Farnworth et al., 1995)

Supra-Nutritional Trace Mineral Levels

With increasing societal pressure to eliminate the use of antibiotics as growth promotants in livestock feeds, use of growth promoting levels of copper and zinc will likely continue. Although these elements provide cost effective growth performance improvements, they are also excreted in high concentrations in manure. Jongbloed and Lenis (1993) calculated the acreage requirements for nutrient cycle balance for phosphorus, copper and zinc to be 27 pigs/acre, 3 pigs/acre and 4 pigs/acre, respectively. This disparity between the number of arable acres needed for crop removal of nutrients, and the relative quantities and proportions of nutrients excreted in manure affects the long term environmental sustainability of applying swine manure to crop land.

Alternative strategies such as the use of lower supplementation levels of more bioavailable organic trace minerals could provide comparable growth promotion benefits while reducing the quantity of trace minerals excreted. Inorganic sources of copper, zinc, iron, and manganese are the predominant forms used in commercially manufactured premixes primarily because of their low cost and relatively high bioavailability. However, organic trace mineral products (proteinates, amino acid chelates, mineral/amino acid complexes, and polysaccharide encapsulated trace minerals) are also used in some swine premixes. The primary disadvantage of using organic trace minerals in swine diets is that they are more costly. However, most of these forms are at least equivalent, and may be more bioavailable than inorganic sources. This means that less of these organic sources are needed to provide the same level of trace mineral nutrition as provided by inorganic sources, resulting in less excretion of excess trace minerals in manure. Unfortunately, more information is needed about the bioavailability of the various organic trace mineral sources in order to determine replacement rates and cost effectiveness compared to inorganic sources.

Antimicrobial agents such as antibiotics, copper sulfate, and zinc oxide alter microbial fermentation in the pig's digestive tract. Theoretically, this change in microbial fermentation could influence the production of odorous compounds. However, these effects have not been extensively studied and would likely vary considerably based on the relative sensitivity of gut micro flora to each antimicrobial compound. Armstrong et al. (2000) conducted two experiments with nursery pigs to examine effect of dietary copper source on odor from manure. In the first experiment, replacing copper sulfate with copper citrate in the diet, at levels of 66 and
100 ppm, resulted in reduced odor intensity and odor irritation intensity from pig feces compared to feces from pigs fed a control diet and a diet with comparable copper sulfate levels. Odor quality was similar to a 225 ppm copper sulfate supplementation level. In a second experiment, removal of an antibiotic from the diet resulted in decreases in odor intensity of feces from pigs fed copper citrate (33, 66, or 100 ppm) compared to the control, while copper sulfate supplementation (10, 66, or 225 ppm) did not alter odor intensity. Odor quality of feces was improved with 225 ppm copper sulfate and all diet concentrations supplemented with copper citrate compared to the control diet. In another study comparing copper citrate and copper sulfate combinations in nursery pigs, Dove and Schell (2000) observed similar increases in ADG, regardless of copper source, compared to negative control pigs. They concluded that combinations of the copper compounds were as effective at stimulating the growth of young pigs as each source separately, and that combinations of copper compounds can be used at much lower total concentrations of copper to achieve this growth response. Higher copper concentrations, however, appeared necessary to improve feed conversion.

Wu et al. (2001a) observed a linear increase in copper digestibility and retention with increasing level (50 and 100 ppm) from a copper proteinate (Bioplex Cu), although even greater increases were observed in pigs fed 250 ppm copper as copper sulfate. Copper excretion in manure was greater with copper sulfate supplementation, however, compared to the copper proteinate. The same group (Carlson et al., 2000a) had previously reported similar improvements in growth performance from 50 ppm copper as copper proteinate or 250 ppm copper as copper sulfate the first four weeks post-weaning. Other sources of copper that may be supplemented in replacement of copper sulfate include copper oxide, copper chloride, cupric sulfate, cupric citrate, and polysaccharide-copper chelates.

Zinc oxide is sometimes supplemented at supra-nutritional levels, instead of copper sulfate and/or antibiotic, as a growth promotant in nursery diets. Supplementation levels of 2,000 – 3,000 ppm are common, and a large amount of the zinc is subsequently excreted in manure. Meyer et al. (2000) reported a 14- and 21-fold increase in fecal zinc levels when weanling pigs were fed diets supplemented with 2,000 or 3,000 ppm zinc from zinc oxide. Pigs also absorbed greater amounts of zinc at these high supplementation levels (10x) compared to control pigs.

Alternative sources of zinc have been tested, with variable results. These include zinc sulfate, zinc-methionine and zinc-lysine complexes, zinc-amino acid complexes, zinc-polysaccharide complexes, and zinc proteinates. Carlson et al. (2000b) reported similar ADG, ADFI, and feed efficiency in weanling pigs fed 50, 100, 200, 400, or 800 ppm Zn from a zinc proteinate (Bioplex Zn) or 2,000 ppm zinc from zinc sulfate over a 28-d feeding period. A follow-up study by the same group (Wu et al., 2001b) showed a slight increase in zinc excretion and retention with 400 ppm zinc provided by zinc proteinate compared to pigs fed a control diet, but an even greater increase in excretion and retention with supplementation of 2,000 ppm zinc from zinc sulfate. Plasma zinc concentrations did not differ among the treatments. A nursery nutrient balance study conducted by Case and Carlson (2001) indicated that organic zinc sources minimize nutrient excretion by approximately 27% compared to inorganic zinc fed at the same dietary concentration (500 ppm). The two organic zinc sources tested were a zinc-amino acid complex (Availa-Zn) and a zinc-polysaccharide complex (SQM-Zn). The authors concluded that dietary concentration of zinc, independent of source, was the major factor affecting nutrient excretion in swine manure. A previous experiment from the same group (Case and Carlson, 2000) suggested that zinc supplementation by zinc-amino acid or zinc-polysaccharide complexes may improve growth performance slightly. Supplementation at levels of 500 ppm zinc, however, did not result in an improvement in growth performance observed with 3,000 ppm zinc from zinc oxide.
Selenium is another trace mineral of environmental concern. Selenium levels in corn and soybean meal are low relative to the pig's selenium requirement. Consequently, selenium from sodium selenite is added to swine diets at a rate of 0.3 ppm Se to meet the pig's selenium requirement under the majority of production conditions. However, vitamin E-selenium deficiencies in some commercial production conditions continue to exist. These deficiency occurrences have caused nutritionists to question whether 0.3 ppm Se is adequate and whether organic sources of selenium are better utilized than inorganic sources.

Mahan (1995) evaluated selenium retention and excretion of pigs fed 0, 0.1, 0.3, 0.5, and 1.0 ppm from inorganic (sodium selenite) and organic (selenium-yeast) selenium sources. Results from these studies showed increased Se retention and a 50% reduction in Se excretion when selenium-yeast was fed at the same supplementation level as Se from sodium selenite. Thus, selenium-yeast should be considered as a preferred source of Se to reduce Se accumulation in the environment, while providing equal or better selenium nutrition for the pig.

Diet Acidifiers and Electrolyte Balance

Use of diet acidifiers and formulation of diets based on electrolyte balance has received considerable interest recently, especially in Europe, where a wider variety of ingredients are available and fed to swine. The premise behind use or selection of diet acidifiers is to either change microorganism populations in the gastro-intestinal tract and/or decrease pH of slurry such that less ammonia, and therefore potentially less odor, is produced. It has been shown that slurry pH greatly affects ammonia emission (Hoeksma et al., 1993), and that lower pH results in decreased ammonia emission. Dietary electrolyte balance has also been shown to affect the pH of urine and slurry from grow-finishing pigs (Cahn et al., 1997).

Risely et al. (1992) showed that adding fumaric or citric acid to the diet at a rate of 1.5% had little effect on pH and volatile fatty acid production, which likely would have little effect on odor control. Overland et al. (2000), however, observed increased ADG for pigs fed a diet with 0.80% dietary K-diformate addition compared to pigs fed a control or 0.85% Ca/Na-formate diet. In addition, K-diformate reduced number of coliforms in the small intestine and rectum, which may affect odor or nutrient excretion, but odor emissions and nutrient excretion were not evaluated in that study. Previous research with K-diformate indicated growth promoting properties for both weanling and grow-finish pigs (Paulicks et al., 1996; Kirchgessner et al., 1997). Van Kempen et al. (1998) showed that adipic acid is effective in reducing urinary pH, but the magnitude of reduction in ammonia emission is yet to be determined. In a sow study conducted by Starkey et al. (2000), a decrease in sow body weight loss was observed during lactation when sows were fed a 0.50% cocktail of fumaric, lactic, citric, propionic, and formic acids (Acid Lac™). No differences in litter size or gain were observed, although days to rebreeding tended to be lower. Sows fed a 0.50% cocktail of phosphoric, lactic, and citric acids (Kemgest™) were not affected, however, compared to sows fed a control diet.

Diet acidifiers may also render nutrients more available to the pig. By decreasing dietary pH, stomach pH is lowered, and subsequent rate of gastric emptying is hypothetically reduced (Mayer, 1994). This increases the time for enzymes to break down nutrients before pH is increased. Roth et al. (1998) found that adding K-diformate to diets increased apparent digestibility and retention of nitrogen in pigs. Previously, Mosenthin et al. (1992) had reported that dietary acidification may enhance ileal protein and amino acid digestibility. Kemme et al.
(1999) found that dietary lactic acid addition (30 g/kg) stimulated apparent ileal digestibility of nitrogen and amino acids, but found no effect in increasing liberation of phytate to available phosphorus. Several other authors have hypothesized that organic acid addition may increase phosphorus digestibility, but no studies have been conducted to evaluate this possibility. Adding 3 and 6% citric acid to weanling pig diets resulted in improved weight gain and feed conversion in one study (Boling et al., 2000), but did not result in improvements in phytate-phosphorus utilization. Rice et al. (2000) found no differences in growth performance, feed efficiency, or phosphorus digestibility when 2.5 or 5.0 % of an organic acid salt-molasses mixture (30% acid) was fed to weanling pigs. Organic acid addition did, however, decrease diet and stomach digesta pH. Boling et al. (2000), however, found that chicks fed diets supplemented with 6% citric acid had improved phosphorus retention and availability. The authors concluded that dietary citric acid improved phytate P utilization chicks, but had a much smaller effect in pigs. The type and level of acid used, in addition to environmental conditions and diet fed, appears to play a large role in the effectiveness of diet acidifiers.

Use of calcium salts to alter dietary electrolyte balance have resulted in more consistent positive effects on reducing ammonia emission levels. Cahn et al. (1998) reported a decrease in urinary pH of 1.61, 1.66, and 1.80 units when calcium sulfate, calcium chloride, and calcium benzoate, respectively, replaced calcium carbonate in the diet of grow-finish pigs. Slurry pH followed a similar pattern. Ammonia emission was reduced by 30, 33, and 54% with calcium sulfate, calcium chloride, and calcium benzoate replacement of calcium carbonate. Similarly, Hendriks et al. (1997) observed a 37% decrease in ammonia emission with dietary replacement of calcium carbonate with a mixture of calcium salts.

**Exogenous Enzymes**

Several studies have been conducted during the past 20 years to evaluate the effectiveness of adding microbially produced enzyme preparations to livestock feeds for improving energy and protein digestibility, which results in decreased nutrient excretion. Some studies have shown positive responses resulting from enzyme supplementation in livestock feeds, but others have shown no benefit. One of the reasons for inconsistent performance responses has been attributed to the suitability of a particular enzyme to improve digestibility of the target nutrient compounds present in feed. Most of the enzymes used in the feed industry are either carbohydrases (breakdown of high molecular weight polysaccharides such as beta glucan, cellulose, starch, and pentosan gums) and proteases (breakdown of proteins). Choosing the right enzyme is dependent on the degree of specificity of the enzyme, gastrointestinal environment, ability of the enzyme to withstand processing conditions of the feed (e.g. high temperatures), and the cost/benefit relationship of using the enzyme.

When the correct enzyme is selected for the target nutrient compounds provided by ingredients used in specific diets, improvements in digestibility and animal performance have been achieved, which may result in decreased nutrient excretion and/or reduced manure volume via improved feed conversion. Enzyme supplementation of barley- and wheat-based diets has been studied extensively, since enzymes are available that target the mixed-linked β-glucans and pentosans present in these cereal grains. These largely indigestible components increase digestive viscosity and lower nutrient digestibility. The addition of β-glucanase enzyme to broiler diets containing high levels of barley (barley contains 2 to 6% β-glucans), growth rate increased 7 to 30% and feed efficiency improved 5 to 22% (Chesson, 1987). Supplementation of barley-based feeds with β-glucanases has resulted in improved growth performance (Thomke et al.,...
1980) and nutrient digestibility (Markstrom et al., 1985; Graham et al., 1986). Inborr and Ogle (1988) also demonstrated a decrease in the incidence and severity of diarrhea in early weaned piglets fed similar diets supplemented with β-glucanase.

Similar results have been obtained when a specific blend of amylase, protease and cellulase enzymes were added to a skim milk-oats-wheat based baby pig diet (Collier and Hardy, 1986). A few unpublished studies have shown positive effects from protease additions to baby pig diets. Inborr et al. (1993) reported an increase in β-glucan and non-starch polysaccharide digestibility from barley/wheat based nursery diets when a mixture of β-glucansase, xylanase, and amylase was provided in the diet. Clearly, it appears that fiber and starch degrading enzymes benefit young pigs when fed diets containing barley or wheat. Studies examining enzyme supplementation in grow-finish diets have shown less potential. Mavromichalis et al. (2000) found no benefit of xylanase supplementation in a wheat-based diet on growth performance or incidence of stomach lesions. Thacker et al. (1988) were unable to demonstrate any significant improvement in growth, feed intake, or feed conversion with β-glucanase supplementation of hulless barley grow-finish diets, although dry matter, nitrogen, and energy digestibility were improved.

Unfortunately, relatively few enzymes specifically designed to improve energy and protein digestibility of corn-soy based diets have been developed or identified. Addition of a β-mannanase enzyme to corn-SBM diets for growing pigs resulted in no differences in energy or nitrogen digestibility in one study (Pettey et al., 2000). Kim et al. (2001), however, observed an improvement in energy and amino acid digestibility when finishing pigs were fed SBM-based diets supplemented with a carbohydrase mixture (α-galactosidase and β-mannanase).

**Microbial Phytase**

Phosphorus bioavailability in corn, soybean meal and other plant materials used in swine diets is very low because the majority of phosphorus is in the indigestible form of phytic acid (Table 8). As a result, substantial quantities of inorganic phosphate (dicalcium phosphate) is added to swine diets to meet the phosphorus requirements of the pig. However, despite meeting the phosphorus needs of pigs through dicalcium phosphate additions to the diet, approximately 200,000 tons of phosphorus is excreted from swine in the U.S. annually as a result of their inability to utilize approximately two-thirds of the phosphorus in corn-soy based diets.
Table 8. Total and Phytate Phosphorus Content of Some Common Ingredients.

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>Total P</th>
<th>Absorption % of Total P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn, dry</td>
<td>0.25</td>
<td>10-15</td>
</tr>
<tr>
<td>Corn, high moisture</td>
<td>0.25</td>
<td>40-50</td>
</tr>
<tr>
<td>Barley</td>
<td>0.29</td>
<td>20-30</td>
</tr>
<tr>
<td>Oats</td>
<td>0.31</td>
<td>20-50</td>
</tr>
<tr>
<td>Soybean meal, 47%</td>
<td>0.60</td>
<td>20-30</td>
</tr>
</tbody>
</table>


Fortunately, phytase can be added to feed to increase digestibility of phytate phosphorus. By adding phytase to corn-soy based diets, the need for inorganic phosphorus supplements can be minimized, and potentially eliminated in some diets, and the amount of phosphorus excreted in manure can be reduced while maintaining satisfactory pig performance. In fact, phytase additions to finishing pig diets have been shown to reduce phosphorus excretion by 37 to 54% (Table 9) while maintaining growth performance and bone strength (Table 10).

Jongbloed et al. (1991) observed a 46 and 36% improvement in phosphorus digestibility of wheat and 40% wheat-corn-soybean meal based diets, respectively, when wheat phytase was included in the diet. They also observed a 42 and 20% improvement in phosphorus digestibility of wheat middlings and 20% wheat middlings-corn-soybean meal diets, respectively, when wheat phytase was included. Other studies have indicated an increase in nitrogen and amino acid digestibility when microbial phytase is added to diets. Williams and Kelly (1994) estimated a 5% reduction in N, in addition to a 5% reduction in P concentration in manure when fed diets containing microbial phytase.


<table>
<thead>
<tr>
<th>Practice</th>
<th>Requirement (NRC)</th>
<th>With Added Phytase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dietary P, %</td>
<td>0.5</td>
<td>0.4</td>
</tr>
<tr>
<td>P intake (g/day)</td>
<td>15.5</td>
<td>12.4</td>
</tr>
<tr>
<td>P retained (g/day)</td>
<td>4.0</td>
<td>4.0</td>
</tr>
<tr>
<td>P excreted (g/day)</td>
<td>11.5</td>
<td>8.4</td>
</tr>
</tbody>
</table>

Reduction in P excretion, %

From NRC: 37
From current practice: 54

Assumes a growth rate of 1.8 lbs/day and feed intake of 6.83 lbs/day, 5 grams of P retained. kg body weight gain, and 2 grams endogenous P/ kg body weight.

Table 10. Effect of Dietary Phytase on Performance and Bone Strength of Pigs Fed Adequate or Deficient Levels of Phosphorus.

<table>
<thead>
<tr>
<th>Dietary P Level</th>
<th>P in grower, %</th>
<th>P in Finisher, %</th>
<th>Phytase, units/gram</th>
<th>Experiment 1</th>
<th>Experiment 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>.5</td>
<td>.4</td>
<td>.3</td>
<td>1.94</td>
<td>1.87</td>
</tr>
<tr>
<td></td>
<td>.5</td>
<td>.4</td>
<td>.3</td>
<td>1.78</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>.5</td>
<td>.4</td>
<td>.3</td>
<td>1.58</td>
<td>1.61</td>
</tr>
<tr>
<td></td>
<td>.4</td>
<td>.3</td>
<td>.3</td>
<td>2.05</td>
<td>1.89</td>
</tr>
<tr>
<td></td>
<td>.4</td>
<td>.3</td>
<td>.4</td>
<td>1.96</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>.3</td>
<td>.3</td>
<td>.3</td>
<td>2.05</td>
<td>1.71</td>
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<tr>
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<td>.3</td>
<td>.3</td>
<td>.3</td>
<td>1.91</td>
<td>1.74</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>500</td>
<td>3.70</td>
<td>3.63</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>500</td>
<td>3.79</td>
<td>3.56</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>500</td>
<td>3.98</td>
<td>3.24</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1000</td>
<td>3.49</td>
<td>3.36</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3.63</td>
<td>3.43</td>
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<td></td>
<td></td>
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<td></td>
<td>3.70</td>
<td>3.43</td>
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<td></td>
<td></td>
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<td>-</td>
<td>3.27</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>-</td>
<td>3.56</td>
</tr>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>-</td>
<td>-</td>
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<td></td>
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<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Experiment 1

Daily gain, lb<sup>abc</sup> 1.94 1.78 1.58 2.05 1.96 1.91 -

Feed/gain<sup>bc</sup> 3.70 3.79 3.98 3.49 3.63 3.70 -

Bone strength<sup>bc</sup> 319 224 216 330 299 260 -

Experiment 2

Daily gain, lb<sup>abc</sup> 1.87 - 1.61 1.89 - 1.71 1.74

Feed/gain<sup>b</sup> 3.23 - 3.56 3.24 - 3.36 3.43

Bone strength<sup>bc</sup> 343 - 231 363 - 277 315

Adapted from Cromwell et al., 1991.

<sup>a</sup>Effect of phosphorus level (P<.05)

<sup>b</sup>Effect of phytase (P<.05)

<sup>c</sup>Phosphorus level x phytase interaction (P<.05)

Fiber Types and Sources

Fiber is a fairly non-specific term describing components of the plant cell wall that are indigestible to digestive enzymes produced from the pig, and includes nonstarch polysaccharides and oligosaccharides. These nonstarch polysaccharides and oligosaccharides are fermented by microflora in the lower gastrointestinal tract, and have been attributed with increasing specific microflora populations and altering the route of nitrogen excretion patterns and odor. Nonstarch polysaccharides include cellulose, hemicelluloses, pectins, fructans, glucomannans, and galactomannans (Grieshop et al., 2001). Oligosaccharides include fructooligosaccharides, mannan oligosaccharides, and galacto-oligosaccharides, and specially processed sucrose thermal oligosaccharides.

Feeding diets containing complex carbohydrates (fructooligosaccharides, mannan oligosaccharide, lactulose, galactan, ammonium propionate, and sucrose thermal oligosaccharides) or organic acids to swine alters the micro flora in the digestive system (Baily...
et al., 1990; Mathew et al., 1993; Sutton et al., 1991; Orban et al., 1997). Oligosaccharides have the ability to resist digestion by digestive enzymes in the small intestine, allowing these compounds to serve as growth substrates for some non-pathogenic organisms, such as clostridia, eubacteria, enterobacteria, and coliforms in the colon. Studies have shown that blood urea concentrations are reduced favoring a net transfer of urea to the cecal lumen. The ammonia generated by bacterial urease is used by bacteria for protein synthesis, causing nitrogen to be eliminated via feces.

One source of non-starch polysaccharides for swine diets is sugar beet pulp. Cahn et al. (1998) observed a large decrease in ammonia emission and slurry pH when a barley-sugar beet based diet containing large amounts of non-starch polysaccharides (31.2% NSP) was fed compared to manure from pigs fed a barley-wheat control diet (13.8% NSP). It was determined that for each unit decrease in slurry pH, ammonia emissions decreased by 45%. The increase in levels of NSP decreased urea content in the urine and subsequently the slurry, decreasing ammonium content and thereby decreasing ammonia emission. The authors stated that high levels of NSP enhance the microbial activities in the hindgut, increasing volatile fatty acid formation in feces. The high NSP diet caused a shift in nitrogen from urine to feces, resulting in a reduction of the ammonium content of the slurry. These results were in agreement with previous findings by the same group that feeding pigs a high-NSP diet lowered fecal pH (Canh et al., 1997). Feeding a grain-sugar beet pulp diet (31.2% NSP) resulted in a decrease in urea excretion of 22 – 37% compared to a barley-wheat control diet (13.8% NSP) in growing pigs. Nitrogen retention was higher, and more feces and less urine were produced.

Soybean hulls are also widely available and are an excellent source of non-starch polysaccharides. Mroz et al. (2000) reported a 26% decrease in quantity of ammonia emitted from manure when finishing pigs were fed diets containing 25% soybean hulls. The authors suggested that the reduction in apparent ileal digestibility of most nutrients affects the partitioning of fecal vs. urinary excretion of nitrogen, resulting in a concomitant increase in fecal volatile fatty acid and microbial protein output. Bakker et al. (1995) also observed a decrease in apparent digestibility of crude protein by 0.04 units in soybean hull diets and 0.12 units in cellulose diets. Another study (Hankins et al., 2001) found that addition of 10% soybean hulls to a low protein corn-soybean meal diet resulted in a 25% reduction in cecal ammonia nitrogen and cecal total nitrogen, with urinary total nitrogen decreasing by 36%. Bowers et al. (2000a), however, observed a decrease in ADG and G:F with increasing levels of soybean hulls (0 to 9%) in the diet. The authors suggested that adding 3% soybean hulls may improve growth performance of late finishing pigs, but the higher rates of inclusion, without subsequently increasing the energy density of the diet, resulted in the poorer growth performance.

Feeding fructooligosaccharides and sucrose thermal oligosaccharides to pigs and broilers has been shown to increase bifido bacteria and reduce odorous compounds in manure in some studies (Hidaka et al., 1986; Orban et al., 1993; Orban et al., 1997; Patterson et al., 1993), while having minimal or no effects on growth performance or microbial populations in other studies (Orban et al.,1997). Feeding mannanoligosaccharides (MOS) to improve piglet gut health and growth performance has also received a considerable amount of attention recently. MOS have not been shown to have a direct effect on odor or manure composition per se, but by including the yeast wall derivative in the diet of nursery pigs, it may decrease the amount of antibiotic and/or copper/zinc oxide supplementation necessary to optimize piglet growth, resulting in decreased excretion levels of copper and/or zinc. Mannanoligosaccharides have been shown to block the attachment of certain bacteria to the intestinal wall, and also appears to enhance non-specific immune function. Van der Beke (1997) observed a 7% and 5% improvement in growth rate and feed conversion rate, respectively, when Bio-Mos™ (commercial source of
MOS) was supplemented at a level of 0.2% in a barley-wheat based nursery diet containing an antibiotic. In addition, piglets that were smaller at weaning tended to respond better to mannanoligosaccharide supplementation than larger pigs. Kim et al. (2000) observed similar positive effects of MOS supplementation on growth rate and feed intake. Davis et al. (1999) reported a similar improvement in growth performance and feed intake when Bio-Mos™ (0.2%) or supplemental copper (185 ppm) were included in nursery diets. These results suggest that MOS can be used in replacement for supra-nutritional copper levels for growth enhancement during the early post-weaning period.

**Antibiotics**

Very little research has been done to determine the effectiveness of feeding antibiotics on odor and gas reduction. Some microbial groups that have an ability to produce or utilize odorous compounds have been identified, but considerably more research is still needed to identify groups of microflora that significantly contribute to the production of odorous compounds. The combination of chlortetracycline, sulfamethazine, and penicillin has been shown to reduce the amount of p-cresol produced in the gut and increase body weight gain of pigs (Yokoyama et al., 1982). Antimicrobial agents such as antibiotics, copper sulfate, and zinc oxide alter microbial fermentation in the pig’s digestive tract. Theoretically, this change in microbial fermentation could influence the production of odorous compounds. However, these effects have not been studied and would likely vary considerably based on the relative sensitivity of gut micro flora to each antibiotic.

**Tea Polyphenols**

Dietary inclusion of tea polyphenols has been shown to reduce the production of ammonia, phenol, p-cresol, ethylphenol, indole, and skatole in swine feces and chick cecal contents (Terada et al., 1993). Tea polyphenols have also been shown to reduce some pathogenic organisms including *Mycoplasma pneumonia*, *Staphylococcus aureus*, and *Clostridium perfringes* (Hara and Ishigami, 1989; Chosa et al., 1992). However, Veum et al. (1997) did not observe any beneficial effects of tea polyphenols on reducing odor compounds.

**Probiotics**

The effects of feeding specific microflora cultures (probiotics) to livestock on reducing odor, and the conditions where these microbial cultures have the ability to compete with indigenous populations in the gastrointestinal tract of pigs are poorly understood. In an earlier literature review, feeding microbial compounds resulted in no consistent effects on reducing odors (Kreis, 1978). Attempts to reduce digesta pH of weanling pigs by feeding *Lactobacillus acidophilus* in liquid or dry form had no effect on odor panel scores (Ingram et al., 1973). However, feeding dry *L. acidophilus* and yeast reduced skatole and indole after a two-week incubation period (Ingram et al., 1973). Whisenhunt et al. (2000) observed an improvement in growth rate and feed efficiency in nursery pigs when diets were dosed with *L. acidophilus* during a five-week feeding study. A low concentration of the probiotic (3x10⁸ cells/day) appeared as effective as when high concentrations (3x10⁹ cells/day) were fed. Knott et al. (2001) conducted a study to evaluate the effectiveness of a *Bacillus subtilis* microbial feed additive on reducing odor, hydrogen sulfide and ammonia emissions. Hydrogen sulfide emissions were reduced but there
was no effect on ammonia, odor detection threshold, odor intensity, or odor offensiveness. Davis et al. (2001) observed a 3% improvement in feed conversion when a *Bacillus* culture (Microsource™ S) was included at 0.5% of the diet for grow-finish pigs. Although no differences were noted for growth performance, pen cleaning time tended to decrease (12.5% less), due to enhancement of the manure decomposition process. This finding was consistent with the observation by Hammond et al. (1998) that viable *Bacillus* strains selected for their ability to alter the decomposition process can effectively prevent solids build-up in pits.

**Precision Feeding**

Dramatic improvements have been made in measuring and using key biological performance criteria for determining more precise nutrient requirements on individual farms. Feed intake, lean accretion curves, litter size and milk production measurements can now be used to determine energy and amino acid requirements using the factorial approach provided by the NRC (1998) models. In addition, use of the net energy system, digestible amino acids, and available phosphorus in selecting ingredients and formulating diets offer more precision than ever before in manufacturing diets that provide optimal performance while minimizing dry matter and nutrient excretion.

Ferket (1999) emphasized the importance of using formulation strategies to design feeding programs that ensure that the animal is receiving the appropriate balance of nutrients. In order to accomplish this, accurate feedstuff nutrient composition data are essential. Accurate and frequent feed ingredient analysis, quality control and mixed feed analysis are also necessary to accomplish this. Secondly, feedstuff nutrient variability must be minimized. Formulations need to accommodate nutrient variability by formulation margins while weighing the cost-benefit of potential for increased mineral emission vs. animal performance. Another related option not mentioned by Ferket (1999) is to evaluate ingredient suppliers that can supply ingredients with less variation. Ileal amino acid (AA) digestibility is superior to total or fecal AA digestibility. Ferket (1999) suggested that true ileal nutrient digestibility should be used rather than apparent because it includes correction factors for endogenous secretions unlike the apparent ileal digestibility values.

Feeding techniques such as phase feeding, split sex feeding and balancing the diet based on ideal protein levels can significantly reduce the nitrogen output in manure and urine. Nitrogen concentration in manure can be reduced 25-30%, with the theoretical potential of a 40-50% reduction by using these nutritional technologies (Miner, 1995).

**Phase Feeding**

Phase feeding has become a standard feeding management practice to minimize the amount of overfeeding and underfeeding of nutrients during a production phase. Although phase feeding offers significant performance and cost savings advantages, it also improves overall feed and nutrient utilization efficiency, and reduces the quantity of nutrients excreted and total manure produced. The use of feed budgeting to improve timing of diet changes in multi-phase feeding programs has greatly enhanced the rate of implementation of this method of feeding management.
Williams and Kelly (1994) estimated a 10% reduction in N and P concentration in manure with the use of phase feeding. Coffey (1996) summarized European studies that showed changing from the one phase feeding system, common in Europe, to a two phase system in grow-finish would reduce nitrogen excretion in swine manure by 13%. Additional phases could reduce nitrogen excretion further, although minute changes in diets between phases is limited by the error of feed processing, weighing of feed ingredients, and precision in estimating animal nutrient requirements.

An economic evaluation system for nutrition was developed by Boland et al. (1999). They designed the system using curvilinear relationships rather than animal growth and included the impact of diminishing returns. Their results showed that there are substantial economic incentives for producers to use multiple diets in a phase feeding program during the growing-finishing period. The highest overall returns occurred when feeding four diets. Adding additional diets, however, results in diminishing returns to management and operator labor. Feeding two diets rather than one had the biggest jump in returns (64% for gilts and 143% for barrows). The returns in dollars per day were as follows: one diet- $0.74, two diets-$1.18, three diets-$1.22 and four diets-$1.241. Their model also found that feeding lower protein levels than recommended by the industry was beneficial. The excess protein being fed was probably excreted as nitrogen in manure. As more nitrogen is excreted, the costs of managing it would increase as well. Thus, feeding less protein would lower diet costs, and subsequently reduce management time and costs.

**Split-Sex Feeding**

Similar to phase feeding techniques, use of split-sex feeding can significantly decrease overall nutrient excretion levels by minimizing the amount of overfeeding and underfeeding of nutrients during a production phase. It has been well documented that nutrient requirements, growth rates, and feed intakes differ considerably between gilts and barrows during finishing. In a review of literature comparing growth rate, feed intake, and feed conversion rates of gilts and barrows, it was noted that a large amount of variation exists among studies comparing genders (Ellis and Augspurger, 2000). Much of this variation may be attributed to differences in body weight ranges studied, genotypes used, and environmental conditions. An increase of 0.2 – 0.8 lb/d average daily feed intake and 0.1 – 0.2 lb average daily gain for barrows was generally observed in those studies. Barrows grow at a faster rate than gilts, beginning at approximately 50 lbs, consume more feed, but also tend to accumulate greater body fat stores, and thus have a decreased feed efficiency ratio. Because of these differences, lower concentrations of nutrients are required by barrows at similar weights compared to gilts. Feeding separate diets formulated to meet the specific requirements for barrows and gilts can have a significant effect on reducing excess nutrient excretion in manure.

**Available P Level for Formulation**

Formulating swine diets on an available phosphorus basis will also optimize nutrition and minimize excess phosphorus excretion in manure. However, available phosphorus estimates in feed ingredients and available P requirements for swine in various production phases need to be better defined in order to use these values with confidence for formulating diets.
Use of Available Amino Acid Levels for Formulation

Formulating diets based on apparent ileal or true digestible amino acid levels can greatly decrease the amount of excess nitrogen excreted in manure. Accurate digestible amino acid values for feed ingredients, however, are necessary to appropriately formulate such diets. In addition, accurate information concerning the amino acid requirements of pigs on individual farms must be determined. Development of lean growth curves for an individual herd is quite helpful in determining these needs, and should be incorporated with formulations to adequately meet, without exceeding, amino acid requirements. Current apparent ileal digestible amino acid values are available from NRC (1998) and other reference sources. The accuracy of true ileal digestibility values is not well established at this time.

Use of Highly Digestible Ingredients

In a study cited by Baker (1996) it has been shown that with a near perfect amino acid balance (in a chemically defined diet using only amino acids as the only source of dietary nitrogen) a 15 kg pig is capable of converting 87% of its absorbed nitrogen above maintenance requirements and converts it into carcass protein. However, some amino acids are used more efficiently than others. By using highly digestible ingredients in swine diets, the amount of nutrients digested and absorbed per unit of feed consumed is maximized, and the amount of undigested material (feces) is minimized. Therefore, feeding highly digestible, nutrient dense diets will decrease total manure output. Williams and Kelly (1994) estimated that a 5% reduction in concentration of nitrogen and phosphorus in manure could be achieved with use of highly digestible raw materials.

The two major ingredients used in swine diets are corn and soybean meal. These ingredients are the most economical sources of energy and protein and are also highly digestible. Throughout most of the Midwest, it is difficult to economically justify the use of other energy and protein sources. Occasionally, high fiber ingredients are used in sow diets. Because of the pig's relatively poor ability to effectively utilize fiber, energy digestibility of these ingredients is low, and consequently, total manure output is increased. Substantial use of high fiber ingredients can also increase manure handling problems due to increased solids accumulation in manure storage containments. Conversely, use of supplemental fat in grow-finish and lactation diets increases nutrient density, reduces feed consumption and reduces total waste output. However, using supplemental fat as an energy source may not be as economical as energy derived from corn and soybean meal.

Improvement of Feed Conversion

Numerous strategies may be used to reduce nitrogen excretion from swine. Coffey (1996) noted that an improvement in feed conversion of 0.25 units would reduce nitrogen excretion by 5 to 10%. Another method is utilizing synthetic amino acids to provide the correct levels of essential amino acids while avoiding large excesses. Coffey summarized studies which estimated that lowering the diet crude protein by 2.5% and using synthetic amino acids, for finishing pigs (growing from 120 to 220 lb), would decrease nitrogen excretion in urine by 29%.
**Low Sulfur Diets**

Whitney et al. (1999) demonstrated that by using low sulfur ingredients to formulate low sulfur starter diets while meeting all of the pigs nutrient needs, that hydrogen sulfide emissions can be reduced by approximately 30% without compromising pig performance. Preliminary work suggests that the use of synthetic amino acids to reduce the amount of soybean meal in the diet can reduce the concentration of sulfur in feces by 10-15% without affecting pig performance. This may translate into a significant reduction in hydrogen sulfide emissions.

**Reduced Crude Protein, Amino Acid Supplemented Diets**

Studies cited by Aarnink et al. (1997) indicated that the protein content of pig diets is approximately three percentage units higher than the minimum level for optimal production. This suggests the possibility of reducing nitrogen excretion by 25% by reducing the protein content of diets and adding supplemental amino acids. Williams and Kelly (1994) also estimated a 20 – 25% reduction of N in manure when reducing protein levels in feed and using synthetic amino acids.

Feeding low crude protein diets containing synthetic amino acids, and formulating for amino acid balance, can reduce urinary nitrogen excretion and odorous compounds by about 50% compared to a feeding a diet higher in dietary crude protein (Hobbs and Pain, 1995). Similarly, Sutton et al., (1995) showed a significant reduction in ammonia levels and altered the concentrations and ratios of selected volatile fatty acids in fresh manure of pigs fed amino acid supplemented diets compared to other diets. Other researchers have shown that reduced crude protein diets containing synthetic amino acids reduce nitrogen excretion by 25 to 30% in pigs, which can lead to reduced ammonia emissions (Bridges et al., 1994; Cromwell and Coffey, 1993; Jongbloed and Lenis, 1993; Hartung and Phillips, 1994). Reductions in ammonia emissions from 28 to 79% through diet modifications in swine have been reported (Sutton et al., 1999). Furthermore, feeding excessive levels of tyrosine (3% of the diet), increases p-hydroxphenylacetic acid and p-cresol in urine of pigs (Radecki et al, 1988; Lumanta et al., 1988).

Use of synthetic amino acids to reduce the crude protein and excess dietary nitrogen levels can have a significant impact on total nitrogen excreted from grow-finish barns. For example, in a typical grow-finish site with four 1000 head barns, with a 2.8 feed/gain using a four-phase corn-soybean meal feeding program, approximately 162,230 lbs of nitrogen would be excreted in manure annually. However, by adding synthetic lysine to these diets, nitrogen excretion is reduced by 13.2% to 140,845 lbs N/year. An additional 12.6% reduction in nitrogen excretion can be achieved by adding synthetic lysine, methionine, threonine, and tryptophan to the same corn-soybean meal diets, to further reduce total nitrogen output to approximately 120,489 lbs of N/year. Thus, using synthetic amino acids to reduce crude protein levels and excess nitrogen, can reduce total nitrogen excretion in the manure by 20 to 25%.

Reducing crude protein level by adding synthetic amino acids reduces nitrogen intake and urinary nitrogen excretion (Table 11). The amount of nitrogen retained and excreted in feces is unchanged as long as accurate assessment of digestible amino acid requirements is determined, amino acid digestibility of ingredients is known, and amino acid balance is achieved.
Table 11. Effect of Reducing Dietary Protein and Supplementing With Synthetic Amino Acids on N Excretion from 200 lb. Finishing Pigs.

<table>
<thead>
<tr>
<th>N balance</th>
<th>14% protein + lysine</th>
<th>12% protein + threonine</th>
<th>10% protein + tryptophan</th>
</tr>
</thead>
<tbody>
<tr>
<td>N intake (g/day)</td>
<td>67</td>
<td>58</td>
<td>50</td>
</tr>
<tr>
<td>N retained (g/day)</td>
<td>26</td>
<td>26</td>
<td>26</td>
</tr>
<tr>
<td>N excreted in feces (g/day)</td>
<td>7</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>N excreted in urine (g/day)</td>
<td>34</td>
<td>25</td>
<td>17</td>
</tr>
<tr>
<td>Reduction in N excreted (%)</td>
<td>-</td>
<td>22</td>
<td>41</td>
</tr>
</tbody>
</table>

Assumes an intake of 6.7 lbs/day, a growth rate of 2 lbs/day, a carcass lean tissue gain of 0.9 lbs/day, a carcass protein gain of 0.2 lbs/day, and carcass N retention represents 66% of the total nitrogen retention. Cromwell, 1993. NPPC Environmental Symposium, Minneapolis, MN.

Summary

Careful design and management of swine feeding programs can play a significant role in reducing the quantity, composition and odor levels produced from modern swine production facilities. Feeders and waterers should be properly designed, adjusted, and maintained to minimize feed and water wastage. High pressure, low flow pressure washers should be used to minimize waste water from cleaning buildings. Diets should be formulated with the goal of maximizing nutrient utilization and efficiency to optimize feed conversion and minimize excess nutrients excreted in manure. Use of synthetic amino acids to reduce crude protein along with formulating diets closer to the pig’s requirements and phase feeding will significantly reduce nitrogen excretion. Adding phytase to replace inorganic phosphorus supplements in swine diets, along with formulating diets closer to available phosphorus requirements and phase feeding, significantly reduce phosphorus levels in swine manure. The development of new varieties of corn and soybeans provides an opportunity to incorporate improved nutrient availability and/or levels in the grain or seed itself, and utilization of these feed ingredients in the future can greatly decrease nutrient excretion. Feeding lower levels of some organic copper, zinc and selenium significantly reduces excretion of these elements in swine manure. Formulating amino acid balanced diets using synthetic amino acids can significantly reduce ammonia and volatile fatty acid emissions. Use of low sulfur ingredients, and synthetic amino acids to minimize excess sulfur intake appears to be effective in reducing hydrogen sulfide emissions. Several feed additives also show promise in contributing to further reducing overall gas and odor emissions.
References


Chesson, N.A. 1987. Unpublished review article from Rowett Research Institute, Scotland, U.K.


