Application of nutritional knowledge for developing econutrition feeding programs on commercial swine farms[1]

T. J. Prince[*], A. L. Sutton[†,2], R. D. von Bernuth[‡], and M. W. A. Verstegen[§]

[*]Akey, Inc., Lewisburg, OH 45338; [†]Department of Animal Sciences, Purdue University, West Lafayette, IN 47907; [‡]Department of Agricultural Engineering, Michigan State University, East Lansing 48824; and [§]Wageningen Institute of Animal Sciences, Animal Nutrition Group, Marijkeweg 40, Wageningen University, Wageningen, The Netherlands 6709PG

Abstract

Intensive pork production operations are being confronted by increased societal pressure due to the potential impact of swine waste on water, air, and soil quality. This review focuses on practical solutions and future opportunities to use diet manipulation and feeding management technologies to reduce nutrient excretions and gaseous compounds emitted from manure. Nutrient mass balance will become more critical for pork production units to avoid water quality problems and excessive soil nutrient accumulation in soil. Diet manipulation techniques adaptable to commercial pork production include reduction of crude protein level by using synthetic amino acids; reduction of supplemental inorganic P and use of phytase; and use of organic forms of Cu, Zn, Fe, and Mn. Feeding management technologies that will enhance feed efficiency and reduce nutrient excretion include formulating diets to more precisely meet nutrient requirements (sex, genetic potential, phase feeding). Effectiveness of using nonstarch polysaccharides in swine diets to reduce pH and ammonia emissions needs to be evaluated on commercial swine farms. Research is needed to determine the efficacy and impact of genetically modified feed ingredients in commercial diets. Best-cost formulations will include economic value for manure nutrient levels and utilization costs. Diets may be modified to create nutrient-balanced manure for sustainable crop production. In some situations, nutrient management and pig performance can be compatible; however, in some situations optimal whole-system performance may not coincide with maximum productivity, daily weight gain, and feed efficiency. Future econutrition research needs to be conducted with a multidisciplinary approach with consideration of available land, animal health and behavior, quality of animal products, and nutrient balance in the whole-farm system.

Key Words: Nitrogen, Phosphorus, Nutrient Balance, Pollution, Water Quality, Odors

Introduction

The pork industry is undergoing rapid and significant changes. There are decreased numbers of pork operations today, but because of increased average size of each operation and production efficiency, total pork production has been sustained. However, with the increased size of operations, there has also been an increased concern of potential impacts of the pork industry on the environment. Over 405,000 ha of U.S. farmland are lost to urban development each year (Sorensen et al., 1997). With increased population growth and global demand for meat consumption (CAST, 1999a), the challenge is to sustain the economic viability of pork production during severe economic pressures and increased environmental regulations. Agriculture, including animal production, has been identified as a leading source of water quality impairment in the nation's waters (U.S. EPA, 1995). Over 56,000 km of rivers in the United States have been estimated to be damaged by animal feeding operations, and 40% of these are unfit for fishing or swimming (U.S. EPA/USDA, 1998). A comprehensive nutrient management plan (**CNMP**) has been proposed by U.S. EPA/USDA (1998) to control nutrient recycling to minimize water and air pollution. Feed management is one component identified in the CNMP. The purpose of this paper is to identify potential impacts of swine manure on the environment, to discuss diet formulation and feeding management impacts on whole-farm system nutrient flows, to demonstrate practical dietary methods for nutrient control, and to identify future nutritional strategies that may reduce environmental impacts.

Problem Areas

Water Quality

Over 50% of the U.S. population uses ground water for drinking. In rural areas, 95% of the drinking water is obtained from ground water supplies. Nutrients, especially N and P, organic matter, and microbial organisms are the primary pollution concerns originating from animal manure. Ammonium N can be toxic to aquatic life, and organic matter degradation reduces dissolved oxygen levels in water, killing fish. Elevated P levels in water results in algal blooms and eutrophication of water, resulting in reduced oxygen levels and fish kills. On an annual basis, total waste produced by cattle and humans provides significantly more total N, P, and biochemical oxygen demand (**BOD_5**) than waste from swine or poultry in the United States.

Increased nitrates in water can cause methemoglobinemia, commonly called the "blue baby syndrome" because infants are more susceptible to nitrate than adults. The nitrate molecule replaces oxygen on hemoglobin and starves the infant for air. In addition, other health issues related to manure contamination of water are diarrhea and pathogenic infections. *Escherichia coli H 0157* (primarily with ruminants), *Salmonella enteriditis*, Giardia, *Cryptosporidium parvum*, and *Pfiesteria piscicida* are some organisms that cause human diseases and are potentially related to animal manure contamination. *Pfiesteria piscicida* is a dinoflagellate isolated in salt water areas that kills fish and has recently been accentuated by nutrient enrichment of the water. In all of the cases of pathogen contamination of water, the source of pollution has not been verified. Clearly, there are several potential sources of nutrient and pathogen contamination of water supplies. These include animal manure, rural septic systems, municipal sewage treatment plants, and wildlife. In addition, nutrient contamination alone can originate from commercial fertilizer applications, wind and water erosion, atmospheric and dry fall deposition, volatilization, and denitrification processes.

There are approximately 18,000 km^2 of a hypoxic "dead" zone in the Gulf of Mexico. This is the largest water body adjacent to the United States that is affected (CAST, 1999b). The hypoxic condition is derived from nutrient enrichment, primarily from organic matter (sediment) and N and P flow into the Mississippi basin. Over 50% of agricultural land in the United States drains into the Mississippi River basin, and the greatest nitrogen contribution to hypoxia (55%) is from inorganic fertilizer. Other problem areas in the United States include the upper east coast shoreline (North Carolina and Chesapeake Bay), upper northwest shore line (Oregon and Washington), and southern California shoreline.

Air Quality

Contaminants in air from swine production systems have caused concern due to potential effects on human health, greenhouse gases, and ammonia, and the effects of acid rain (NO_x, SO_4) on land and surface water. Nuisance complaints from local residents have also increased. Hobbs et al. (1996) identified several compounds in swine manure odors but suggested that there were about 11 prominent compounds causing the odor nuisance. In addition, endotoxins, bacterial organisms, dust, and pests (mosquitoes, flies, and gnats) have been identified as air contaminants that potentially originate from manure sources. Nonodorous compounds such as carbon dioxide and methane, produced during manure decomposition, may contribute to greenhouse gas emissions, which may reduce the earth's ozone layer.

Recent cases of allergies, anxiety, depression, and altered blood chemistry have been associated with odors from pork production units (Schiffman et al., 1998). In addition, there have been estimates that animal operations contribute more than 50% of ammonia emissions to surface water in the eastern part of North Carolina during aerial deposition processes (North Carolina Department of Environmental and Natural Resources Division of Air Quality, personal communication). State air quality regulations focusing primarily on gas and odor emissions from livestock operations, have been implemented in Iowa, Missouri, North Carolina, Minnesota, Colorado and California. Research efforts are being directed toward developing reliable techniques for determining the source of pollutants in soil, water, and air. This will aid in solving pollutant problems and provide reliable data to ascertain true effects of implementing best management practices. Accurate detection and correlation between olfactometry and chemical methods are needed before standards for air quality regulations are established.

Soil Quality

Total collectable manure produced in the United States amounts to about 56 million dry metric tons per year (CAST, 1996). This amount of manure can be used as a plant nutrient resource. The nutrient value of this quantity of manure has an economic value of $3.4 billion per year and would replace 15% of the fertilizer N and 42% of the fertilizer P purchased for crop production, respectively. The swine industry alone produces 7.5 million metric tons of collectable manure annually, which provides approximately 500,000 metric tons of N and 165,000 metric tons of P. In certain locations in the United States there is more manure produced than arable land available to utilize the nutrients. Excess application of manure to the soil is one of the greatest concerns regarding livestock production. This creates accumulation of nutrients, with the potential impact of enriching water sources during run-off or leaching into groundwater supplies. Soil nutrient imbalances can also impair nutrient uptake and cause nutrient deficiencies in plants. The nutrients that may cause soil quality problems or threaten water quality when excess levels accumulate in the soil include N, P, Cu, Zn, Na, and K (CAST, 1996).

When comparing the estimated nitrogen produced from confined animals in the United States with plant uptake and removal from crops grown in similar locations, only 50 counties in the United States have surplus N (Lander et al., 1998). Similarly, only 107 counties in the United States have surplus P. Except for these specific sites, there is sufficient land in the United States to utilize manure nutrients ecologically. However, many producers apply commercial fertilizer on land where manure has been applied, resulting in excess soil nutrients. When manure nutrient production exceeds the capability of the land to use the nutrients agronomically, manure must be transported from the site of origin or treated to remove nutrients before effluent application. The Netherlands has considerably less land available for manure application than does the Unites States, Mexico, or China (Table 1). China is intermediate in pigs per hectare of arable land. In addition to the land mass available, different cropping systems, climate, and regulatory structure in each country are factors influencing the impact of pork production operations on the environment.

Other factors causing manure management problems include excessive nutrients in swine diets, variation in composition of feed ingredients, inconsistent nutrient composition of manure, and nonuniform nutrient application onto the soil.

Whole-Farm Nutrient Balance

Within the boundaries of a pork production operation, there is a flow of nutrients (Figure 1). Inputs into the nutrient flow include water and feed, which produce animal products, manure, and odors. The manure nutrients can be recycled as plant nutrients after being applied to the soil and subsequently utilized to produce feed ingredients for use in animal diets. For some operations, nutrients from inorganic fertilizers, irrigation water, and legume nitrogen fixation are part of the total nutrient cycle.

Using agronomic (plant uptake) rates of 2,508 kg/ha for soybean yield and 8,779 kg/ha for corn yield, about 4 ha of land are required for 100 finisher pigs. Assuming the NRC (1998) recommended P requirements for a 70-kg pig, and feeding a 25% soybean and 75% corn diet, it would take .02 ha per pig for soybeans and .02 ha for corn to provide the necessary amount of these feed ingredients needed for each pig (NRC, 1998). When manure is applied to meet the N requirements of crop production, P is applied in excess. The pig will retain about 46.5% of P intake. The remainder of the P can be utilized with crop production, but only about 35.6% of the remainder is actually utilized. Consequently, at least 1.7 times more land is required for P application than for N application, assuming no N losses in manure. Nitrogen, however, due to its mobile nature, can volatilize from the slurry pit and land application systems. With immediate manure incorporation into soil, N losses can range from 45 to 55%. If applying manure to cropland based on N remaining in the manure to meet typical corn production yields, overapplication of P will be 3.8 times higher than the corn plant can utilize. Phosphorus is firmly attached to soil particles but can be solubilized and transported with surface runoff and soil erosion (Sims et al., 1998).

Reducing the percentage of P from the NRC (1998) nutrient recommendations by altering diet ingredient proportions or including alternative feed ingredients in the diet to increase available P will significantly reduce the amount of land necessary for manure application to attain P balance in the cropping program (Figure 2). In addition, methods to remove P from the manure such as solid-liquid separation may be required to balance the P cycle within the operation. Short-term nutrient management plans will require annual manure application amounts based on current manure analyses to determine nutrient content, soil analyses to monitor nutrient accumulations, and recommended plant uptake rates. Long-term nutrient management plans will require a whole-system approach to achieve a total mass balance for the operation, including removal and disposal of manure in storage facilities.

Strategies for Reducing Nutrient Excretion

The annual feed, N, P, and Cu inputs for a commercial 4,000-animal feeder-finisher operation are shown in Table 2. This is assuming a feed:gain ratio of 2.8, a 90.7-kg live weight gain, and a four-phase feeding program using corn-soybean-based diets. Based on average N and P content of the swine manure at the time of land application, it would require 104 ha of land for N-based manure application and 264 ha for P-based manure application. Jongbloed and Lenis (1993) in The Netherlands indicated that pork production would allow 67.5 pigs per hectare based on P for manure application.

Diet manipulation and feed management techniques can significantly reduce the nutritional inputs and nutrient content of effluent from swine. Reducing intact crude protein content of the diet (generally soybean meal) and replacing it with crystalline lysine and corn will reduce N input by 13.2%. Further reducing the intact crude protein content of the diet and supplementing synthetic lysine, threonine, methionine, and tryptophan will reduce N input by 25.8%. This reduction in dietary N will also reduce manure odors by 40 to 86% and decrease *p*-cresol, a volatile organic compound that significantly affects odor, by 43% (Hobbs et al., 1996).

Diet formulation based on true digestibility of nutrients can also reduce dietary nutrient levels and nutrient excretion as compared to apparent digestibility of these nutrients. The proportions of dietary and endogenous N components in feces and urine in the pig are illustrated in Figure 3 (Huisman et al., 1993). A considerable amount of endogenous N is recycled, and digestibility of endogenous N is lower than that of many ingredients. Feed ingredients and complete diets must be evaluated on a true digestibility basis rather than on an apparent digestibility basis. Due to different endogenous N losses, the true digestibility of skim milk, soybean meal, and fish meal are virtually the same (Table 3) (Makkink, 1993).

Phosphorus requirements vary depending on the response criteria measured. Increased dietary levels are needed for maximum bone-breaking strength compared to the amount of P needed to maximize bone ash or growth rate. Diets are often formulated to provide a safety margin above the actual dietary P requirement. Significant reductions of P inputs and excretion can be attained if diets provide only for optimal growth rate and if the animals are not intended to be used as breeding stock replacements. Reducing the safety margin will decrease P input by 8% (Table 2). The use of phytase and reduction of inorganic P in the diet to increase the bioavailability of plant P sources will reduce P input by 20%. If both practices are incorporated, P input is reduced by 27.7% and excretion is reduced by approximately 30%.

Copper and zinc inclusion at high levels in the diet for growth promotion purposes will significantly affect Cu and Zn excretion. Adding copper sulfate at 125 or 250 ppm to the diet will increase Cu input by 7.8 and 16.7 times a control diet (15 ppm of Cu), respectively. Use of organic forms of Cu that provide similar growth promotion benefits (Figure 4) increases Cu inputs in the diet only 2.1 times the control.

Table 4 shows the effect of using reduced inorganic and reduced organic sources of Cu, Zn, Fe, and Mn on the excretion of these minerals (Spears et al., 1998).

Diet formulations are often based on industry average recommendations and do not account for differences in performance due to genetic ability for growth or environmental factors that may affect requirements. This practice results in overfeeding the below-average pig and underfeeding the genetically superior pig. Formulating farm-specific diets to provide the specific nutritional requirements of a specific genetic line will improve feed efficiency, reduce nutrient inputs, and reduce nutrient outputs (Figure 5; T. J. Prince and D. A. Cook, unpublished data). Use of subtherapuetic levels of antibiotics will increase feed efficiency and reduce nutrient excretion (T. J. Prince and D. A. Cook, unpublished data). However, antibiotic growth promoters are being severely restricted or completely banned for use in animal feeds in several countries.

Future Nutritional Strategies

The challenge for manipulation of swine diets is to determine how much dietary nutrients can be reduced without significantly reducing efficient pork production. Because of potential limited use of antibiotics in feeds, research is needed for alternative nutritional strategies. Potential techniques to accomplish this include utilizing feed ingredients with high digestibility, changing diets more frequently to meet a pig's needs, using amino acids and enzymes to meet specific nutrient needs, and using fermentable feed ingredients to produce low-odor and nutrient-balanced manure for crop utilization. There is a need to balance pork production within the concept of sustainable agriculture. Therefore, input and output relations will need to be balanced with a whole-system approach, including animal, soil, and crop production.

Ammonia and gas emissions resulting from the degradation of manure may cause additional stress on pigs and the caretaker in the swine facility. Two methods to reduce ammonia emission include decreasing the pH of manure and feeding nonstarch polysaccharides (**NSP**). Feeding NSP causes a shift in N excretion. With less N absorption in the large intestine, more N is incorporated in intestinal bacteria and is excreted in the feces, resulting in less N excreted in the urine. This is accomplished by increasing the amount of soluble NSP reaching the lower gastrointestinal tract (cecum and colon) of the pig and increasing the fermentation activity of resident bacteria. As the amount of NSP intake increases, the pH of the manure decreases (Figure 6) (Canh, 1998). This may be due to the increased volatile fatty acid production and concentration in the manure (Figure 6). An added benefit of enhanced VFA production from NSP is the contribution of VFA absorbed in the large intestine to a pig's energy supply. Ammonia emissions will significantly decrease with the increase in NSP intake (Figure 6).

Increased use of N digestibility data on individual feed ingredients for formulation could reduce N excretion by 10%, and providing three or more phases in feeding management programs can reduce N excretion further by 4 to 8%. Similar techniques with P in feed ingredients could reduce P excretion by 16%, and by an additional 6% with three or more phase in the feeding program. Tables 5 and 6 show the expected reductions in N and P if certain management techniques are implemented on a growing-finishing operation and sow operation, respectively. Significant reductions of P and N are obtained by reducing feed spillage, lowering the initial live weight of the pigs, and optimizing feeding schedules. Using early weaning to reduce pig weaning weights and early delivery to finishing units will significantly reduce N and P flow on a sow operation. Optimizing the feeding program using automated systems can limit feed intake in castrates to reduce the feed:gain ratios by .04 to .05, reduce P excretion from .11 to .12 kg per pig per year, and reduce N excretion from .25 to .26 kg per pig per year. Reducing feed spillage during all phases of production can provide for improvement of feed:gain ratio by .05. Future econutrition research needs to be conducted with a multidisciplinary approach in a wider context, including consideration of available land, animal health and behavior, quality of animal production, and nutrient balance in the whole-farm system.

Implications

The goal of pork production is to produce nutritious, wholesome (healthy) pork efficiently and profitably compatible with environmental stewardship and sustainability. Several diet manipulation and feeding management techniques identified in this paper will reduce nutrient excretions and enhance air quality by reducing odors and gas emissions. Other technologies discussed will require further refinement, evaluation on commercial operations, and careful economic evaluation. Implementing econutrition practices will improve water, air, and soil quality but will require continued monitoring. Future nutrition research will require a whole-system and multidisciplinary approach.

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Notes

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2. Correspondence: phone: 765-494-8012; fax: 765-494-9347; E-mail: asutton@ansc.purdue.edu.

Table 1. Comparison of pig and people densities on arable land only in various countries[a]

Item	United States	Netherlands	Mexico	China
Arable land, ha	177,000,000	920,000	27,300,000	135,000,000
Population	271,648,000	15,661,000	94,281,000	1,243,738,000
Pig inventory	60,915,000	11,438,000	10,520,000	475,000,000
People/ha	1.53	17.02	3.45	9.21
Hogs/ha	.34	12.43	.38	3.52
People/hog	4.5	1.37	8.96	2.62

[a] Adapted from FAO Yearbook (1998).

Table 2. Annual feed nutrient inputs and reductions with diet manipulation for a 4,000-space swine feeder-finisher unit

Diet manipulation	Nutrient input, kg/yr	Ratio, %
Nitrogen		
Corn-soy diet	73,586	100
Corn-soy diet + lysine	63,886	86.8
Corn-soy diet + lysine, threonine, methionine, tryptophan	54,653	74.2
Phosphorus		
Corn-soy diet	14,367	100
Corn-soy diet with reduced safety margin	13,228	92
Corn-soy diet + phytase	11,522	80
Corn-soy diet with reduced safety margin + phytase	10,384	72.2
Copper		
Corn-soy diet (15 ppm Cu)	43	100
Corn-soy diet + 250 ppm Cu	719	1670
Corn-soy diet + 125 ppm Cu	360	780
Corn-soy diet + organic Cu	89	207

Table 3. Apparent and true nitrogen digestibility for protein sources[a]

Item	Skim milk	Soybean meal	Fish meal
Apparent ileal N digestibility, %	84.4	76.5	73.0
Endogenous N loss, mg/d	768	1,422	1,558
True ileal N digestibility, %	92.7	90.6	89.3

[a]Adapted from Makkink (1993).

Table 4. Effect of mineral level and source on fecal mineral excretion[a]

	Treatment		
Mineral	Control	Reduced inorganic	Reduced chelate
	---------------------------- mg/kg feces	--------------------------------------	
Copper	163.6	92.2	79.6
Zinc	835.1	458.7	394.2
Iron	2,430	2,115	2001.3
Manganese	581	343	311

[a]Adapted from Spears et al. (1998).

Table 5. Expected effects of management practices on a grow-finisher unit to reduce phosphorus and nitrogen excretions[a]

Item	Phosphate	Nitrogen
	----------------------------kg/(pig· yr)	-------------------------
Optimum feeding schedule	–.12 to –.10	–.28 to –.25
Reducing feed wastage	–.20 to –.17	–.46 to –.42
Deliver at standard weight	–.07 to –.05	–.15 to –.13
Optimize groups	–.09 to –.07	–.24 to –.21
Lower nutritional weight	–.18 to –.12	–.41 to –.32

[a]In comparison to the initial situation of 4.2 kg and 12.2 kg per pig per year for phosphate and nitrogen excretion, respectively.

Table 6. Expected effects of management practices on a sow unit to reduce phosphorus and nitrogen excretions[a]

Item	Phosphate	Nitrogen
	---kg/(sow• yr)---	
Optimum feeding schedule	–.51 to –.45	–1.18 to –1.00
Reducing feed wastage	–.51 to -.45	–1.18 to –1.00
Lower delivery weight of piglets	–.93 to –.80	–2.48 to –1.90

[a]In comparison to the initial situation of 14.0 kg and 28.0 kg per sow per year for phosphate and nitrogen excretion, respectively.

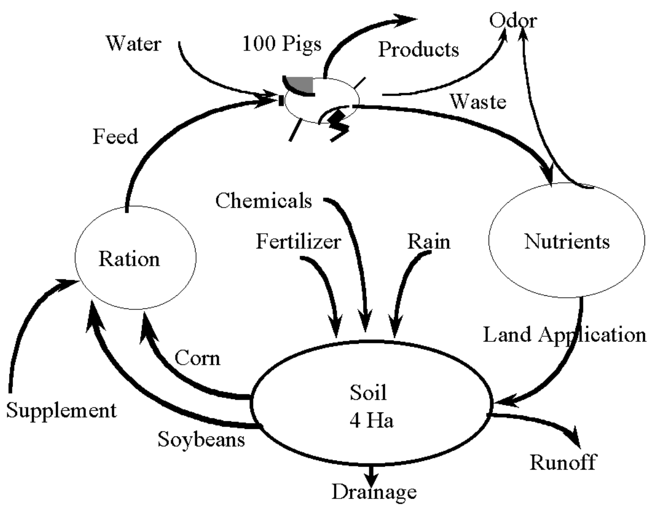

Figure1. Cycle of nutrients within a farm boundary of a pork-crop production system.

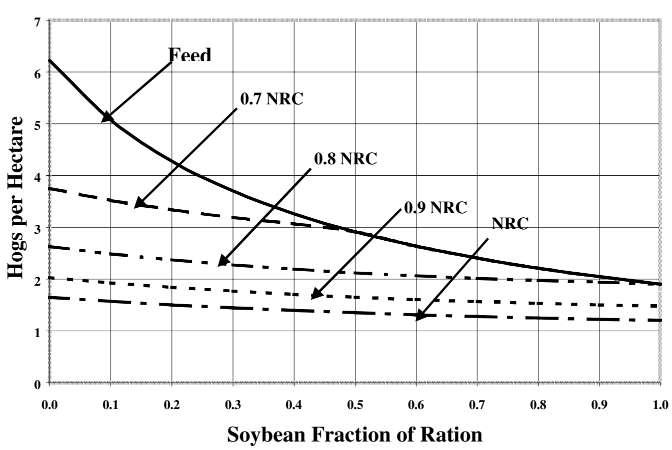

Figure 2. Cropland required to utilize manure nutrients from pigs fed reduced levels of phosphorus from soybeans based on different levels of NRC recommendations.

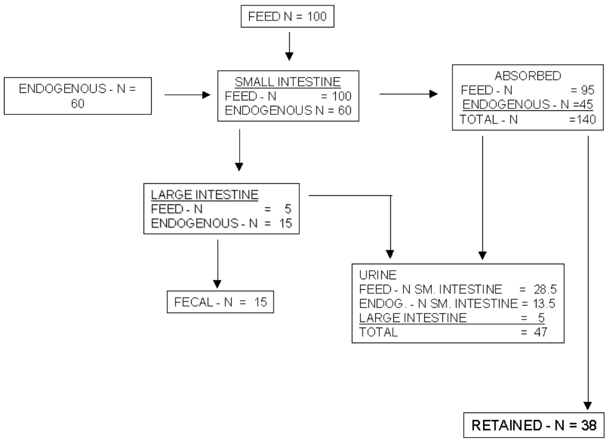

Figure 3. Proportions of dietary and endogenous nitrogen components in feces and urine in the pig (Huisman et al., 1993).

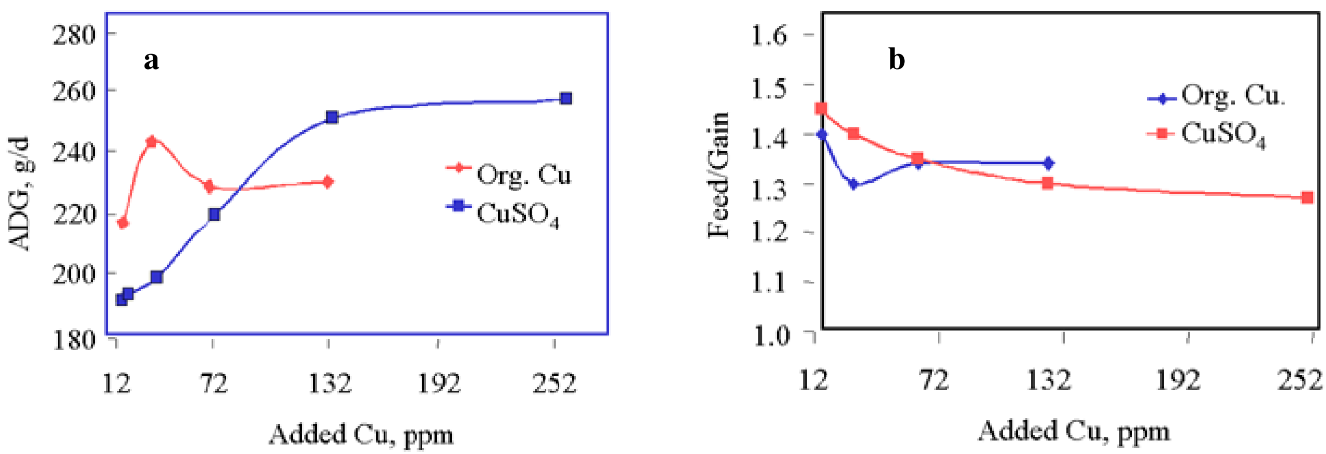

Figure 4. Effect of copper source and level in pig diets on (a) average daily gain and (b) feed efficiency (T. J. Prince and D. A. Cook, unpublished data).

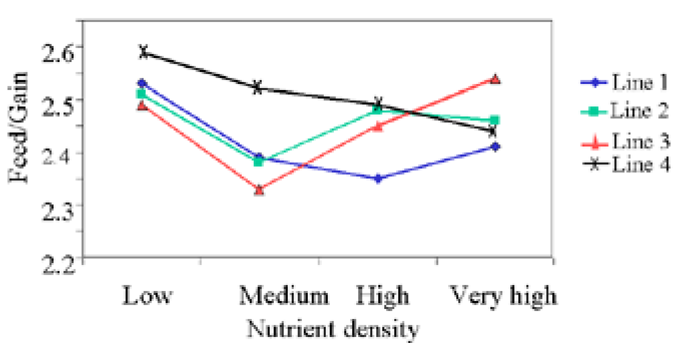

Figure 5. Effect of dietary nutrient levels on feed efficiency response of different genotypes (T. J. Prince and D. A. Cook, unpublished data).

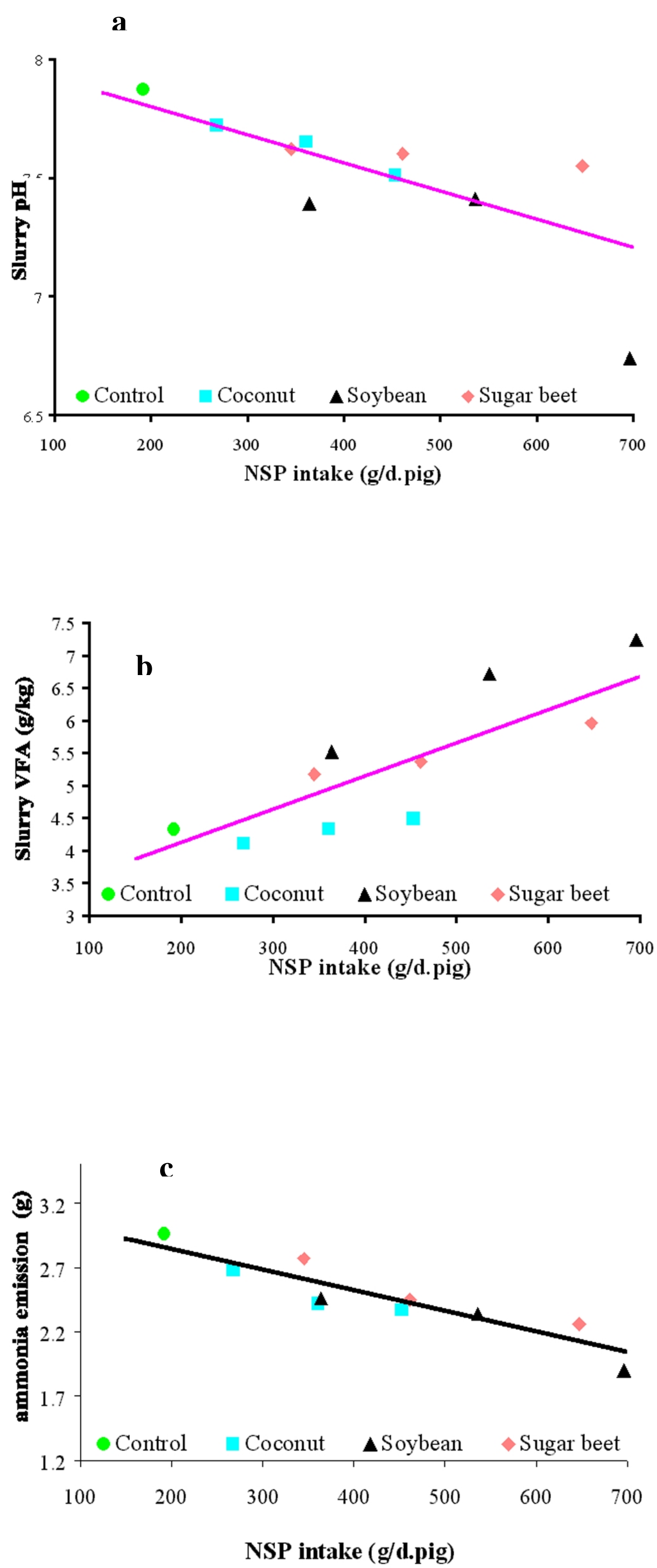

Figure 6. Relationship of dietary nonstarch polysaccharide intakes on (a) pH level in swine slurry, (b) total volatile fatty acid concentration in swine slurry, and (c) ammonia emissions from swine slurry (Canh, 1998).