MASS BALANCE OF NUTRIENTS FOR THE SWINE FINISHING PHASE: EFFECTS OF DIETARY MANIPULATION ON NUTRIENT RETENTION, NUTRIENT EXCRETION, AND GASEOUS EMISSIONS

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Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
in partial fulfillment of
the requirements for
the Degree of
DOCTOR OF PHILOSOPHY
December, 2007

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ACKNOWLEDGMENTS

Thank God for making me feel than I have been always on your list of favorites, for giving me the blessings of working on my PhD at the OSU Animal Science Department, having new friends, and having Sofia in our family.

I would like to extend my most sincere appreciation to my major advisor, Dr. Scott Carter, for giving me the opportunity to come and study in the U.S., for his smart guidance, assistance, encouragement, time, financial support, and more than anything else, for making me feel a part of his family.

My sincere thanks to Dr. Doug Hamilton, Dr. Jeff Hattey, and Dr. Robert Teeter for their guidance, assistance, encouragement, and time.

I also would like to thank several other individuals that deserve recognition for their strong help in my data collection, especially Justin Bundy, Sherita Jenkins, Tat Buhay, Rodel Cueno, Zath Marable, the OSU swine research and education center (Kim Brock, Cecil Hooper, John Staude, and the farm crew) and FAPC (Dr. Brad Morgan, Kyle Flynn, Scott and the rest of their crew).

My appreciation to Spencer Mann for his time and dedication in the design and development of the air sampling system, and his continuous support in monitoring air sampling, gas analysis, and rates of flow determinations.

It is important to me to give recognition to members of the staff that were always willing to help especially Diana Bateson, Joan Summers (My official lab

angel), Donna Perry, Linda Guenther, and Krist Novoverek.

I would like to give special appreciation to Dr. Robert Wettemenn, Dr. Gerald Horn, Dr. David Buchanan and their families for their encouragement and friendship. My sincere thanks to my colleges graduate students in especially Mayte Aleman-Carter, Pauline Add, Dan Stein, Victoria Lehloenya, Miriam Velazco and Ivette Rubio. Thanks for making me, and my family, feel like been at home.

Thanks to Ralph's packing plant for allowing us to work in their facilities. Special thanks to the National Pork Board, Oklahoma Agriculture Experiment Station, Oklahoma Pork Council, and USDA – CSREES for their financial support of my research.

I am forever grateful to my parents Jesus and Nilda Lachmann for their love, encouragement and support all my life. I am also grateful to my cousins Monica Prado-Cooper and Chris Cooper for always been there for me.

My deepest appreciation is to my husband, Cesar Prado, for his encouragement, assistance, wiliness to help, and unconditional love.

God bless all the ones how helped me reach my goals, even those who made it possible and are not recognized for their contributions.

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CHAPTER I

INTRODUCTION

World population is concentrated in areas that offer improvements in life quality, basically represented by the availability of food and services. The accelerated growth in world population has increased food demand. Increased requirements for food open the opportunity to develop more intensive agricultural production systems. The intensification of food production has disrupted all nutrient cycles, increasing the rate of removal of nutrients from their natural accumulation areas, and increasing the rate of loading of those nutrients in areas of intensive production.

This trend includes swine production. On a global scale, pork production is growing. Approximately 107.5 million tons of pork were produced in 2006, and around 110.7 millions is the projected production for 2007 (FAO, 2007). The swine industry's capacity to supply nourishment has grown based on the intensification of the production system. The intensification of swine production results in concentration of pigs and their waste at the production sites, and has been associated with increased rates of nutrients loaded into the environment.

At the present time, nitrogen (N) and phosphorus (P) are the nutrients of greater concern in regards to environmental and public health risk. Land application of N and P in excess of crop requirements can result in P

accumulation in soil, N and P leaching into water bodies, in addition to the ammonia emitted to the atmosphere during application of manure. Also, trace minerals in swine waste can buildup in cropping areas after long term soil application.

This scenario is real on a global, national, and regional scale. It has captured the attention of scientists, governments, and the general population. All parties recognize the importance of reducing the environmental impact of swine production. However, it is also important to recognize that strategies to reduce environmental impact can not compromise national and global food safety.

In the US, as part of a national strategy, the Environmental Protection Agency (EPA) has implemented regulations to preserve the integrity of US water and air. Currently, the Clean Water Act regulates nutrient discharge from intensive swine production systems, based on the protection of water reservoirs. However, in the near future, the Clean Air Act (CAA), Comprehensive Environmental Response, Compensation and Liability Act (CERCLA), and Emergency Planning and Community Right-To-Know Act (EPCRA) will be the most limiting rules for production intensification, regulating ammonia and hydrogen sulfide emissions to less than 100 lb/day or less than 250 tons/year.

The swine industry, governmental regulatory agencies, scientific community, and the general public are demanding the development of comprehensive nutrients management plans. The comprehensive nutrient management plans should take into account all nutrients entering and leaving the production system,

and management practices that can be implemented to reduce nutrient loading rate into the environment.

Most of the nutrients that exit the production system as waste were introduced as feed. Traditionally, swine diets have been formulated to guaranty an optimal production and profits, regardless of the amount of nutrients accumulated in waste. At the present time, this is changing, and nutritionists are working in the development of strategies oriented to reduce the amount of nutrients exiting the production systems in waste. However, the lack of excretion data produced with group-fed pigs in production facilities is limited.

Based on the lack of data, and the need to develop dietary strategies that could be included in comprehensive nutrient management plans in swine finisher operations, a series of three experiments was designed to determine the effect of reducing dietary CP, P, and trace minerals on pig growth performance, slurry characteristics, nutrient excretion, carcass characteristics, bone strength, nutrient concentration in pork, ammonia, and hydrogen sulfide emissions, in addition, to estimate N and P mass balance in a grower-finisher system.

CHAPTER II

REVIEW OF LITERATURE

Impact of food production on nutrient cycles

The impact of human activities on global nutrient cycles has rapidly increased over the past few decades. Increased nutrient concentration in soil, water bodies, and atmosphere are the result of the accelerated growth in world population (Cleveland, 2007; Glibert, 2007; Khalil and Richards, 2007).

In ideal conditions, nutrient losses in agricultural production sites should not be greater that nutrient losses in natural ecosystems. The hypothetical ideal condition includes a stable human population and food production without external inputs of nutrients as part of the cycle (IFA, 2007). However, the real scenario includes a growing human population, concentrated in urban areas, with increasing demand for food. The growing demand for food has driven intensification of food production and with it the disruption of nutrient cycles all over the world (IFA, 2007).

The intensification of food production includes application of inorganic and organic fertilizers in cropping areas and the intensification of the animal production systems (Glibert, 2007, Khalil and Richards, 2007, IFA, 2007). Accumulation of swine manure may result in the disruption of nutrient cycles, with

greater environmental concern associated with the disruption of the N and P cycles.

The disruption of the N cycle in association with intensive animal operations is the one better documented. Currently, 67% of the N that is annually incorporated into the terrestrial ecosystem is anthropogenic nitrogen, and only 33% is incorporated by natural processes (Cleveland, 2007). In agricultural areas, nitrogen losses are mainly represented by NH_3 emissions, NO_3 leaking, and N_2 losses from NO_3 denitrification (IFA, 2007). Intensive swine production systems are important sources of ammonia emission and nitrate leaching. In Europe, approximately 30% of N excreted in swine operations is lost (19% as ammonia, 7% as NO_x, N_2O, and N_2, and 4% as NO_3 leaching) during storage (Velthof et al., 2007). On a global scale, animal waste accounts for approximately 38% of ammonia emissions (Galloway, 2005).

Appropriate documentation of the disruption of nutrient cycles due to swine production, including N, P, and minerals, is indispensable in the development of appropriate strategies to diminish nutrients overloaded in the production areas. Also, baseline information about nutrient inputs in natural conditions is required to measure the magnitude of the environmental disturbance that can be associated to swine production (Cleveland, 2007).

Intensification of swine production systems in US

Traditionally, swine production started around crop production areas. This was also the starting point of the swine industry in the U.S. Pigs were introduced

and concentrated around the Midwestern Corn Belt as a strategy to add value to corn when corn production was high and the prices were down. At this time, swine farms were farrow to finish units (Hollis and Curtis, 2001).

During the 19th and 20th centuries (1880-1940), lard was in large demand, and pigs were raised to produce meat and fat. Around 1950, swine production faced two new challenges: 1) an increasing consumer demand for leaner meat, and 2) rural labor exodus to urban areas. The reduction in rural labor was one of the factors that forced the reduction in the number of swine farms and intensification of the swine industry (Hollis and Curtis, 2001).

During the 1980s and 1990s, swine production was expanded to other areas of the US. The number of swine farms decreased and their size began to increase, to a point, which in 2,000, swine production was controlled by farms that produced over 2,000 heads per year on segregated production systems (Hollis and Curtis, 2001).

At the present time, the number of pig farms is nearly 2% of the number of farms in the 1950s. However, the size of the operation has increased dramatically over the last five decades, with 53% of the farms producing over 5,000 head per year (National Pork Producers Council, 2007). Today, China is the largest pork producer on a global scale. The U.S. shares second place with Denmark. The 10 largest swine production states in U.S. ranked in descendent order are Iowa, North Carolina, Minnesota, Illinois, Indiana, Nebraska, Missouri, Oklahoma, Kansas and Ohio (National Pork Producers Council, 2007).

With the aggressive growth of the U.S. swine industry, the general concern about environmental pollution in areas where swine operations are located has intensified. Intensification of swine production in specific geographic areas results in accumulation of manure, with very limited capacity for its disposal. As a result, the swine industry is dealing with a scenario where two new challenges have been introduced. These challenges are the reduction of nutrients excreted by pigs, and the development of more efficient nutrient recycling systems (Kornegay and Harper, 1997).

Typical diets for growing-finishing pigs

Pork is an important source of amino acids, energy, vitamins and minerals for human nutrition. These nutrients are supplied to the pig via feed, and used for protein and fat accretion, milk production, bones, organs, hair and skin growth. Different sources of nutrients are incorporated into swine diets; ingredients are mixed (nutrient sources) in specific ratios in order to meet or exceed pig nutrient requirements. The traditional ingredients employed are represented in high proportions by cereal grains and oilseed meals, with addition of other amino acids, vitamin, and mineral sources.

Cereal grains are the primary ingredient in swine diets. Cereal grains are energy dense. The main constituent of all cereal grains is starch. However, in corn and oats, fat can have an important contribution to their energy density. Cereals are also an important source of essential and non-essential amino acids, and their pattern and availability varies among different grains (Sauber and

Owens, 2001). They commonly supply 30 to 60% of the total amino acids required by pigs (NRC, 1998). However, based on the essential amino acid pattern of various cereals and the pig requirements, lysine is the first limiting amino acid in all cereal grains, followed by tryptophan in corn, and threonine in barley and sorghum (NRC, 1998).

Even though the list of cereals used in swine diets can be very long, the most commonly used are corn, barley, wheat, sorghum, and oats (Sauber and Owens, 2001). From this list, corn traditionally has been the most used cereal in the US for swine diets. Swine production in the US started in the Midwestern Corn Belt as a strategy to add value to corn prices during over production times (Hollis and Curtis, 2001). Later, swine production was expanded to other areas, and corn kept it place as the primary ingredient in swine diets. The inclusion of corn in swine diets is based on corn availability, energy density, easy to transport, traditionally consumed by swine, and cost effectiveness (Sauber and Owens, 2001).

Due to limitations of the cereal grains to offer an adequate supply of amino acids, other protein sources are included to ensure adequacy of dietary amino acid patterns (NRC, 1998). Oilseeds, such as soybean, rapeseed, sunflower, and peanut have been used in swine diets as amino acid sources. However, most oilseeds are low in lysine, with the exception of soybean. Therefore, soybean meal is the most popular source of amino acids incorporated to swine diets, due to its greater concentration of lysine in addition to other amino acids (Chiba, 2001).

The mineral content in cereal grains and oilseeds only represents a small fraction of the minerals required in swine diets. For example, calcium concentration in all grains is low, and most phosphorus is bound into an inositol molecule as inositol phosphate, commonly referred to as phytate. Approximately, 85 (in corn) to 50% (in wheat) of the phosphorus in grains is unavailable for swine (Sauber and Owens, 2001). The swine digestive system lacks phytase, which is the enzyme able to dissociate phosphate groups from the inositol ring. However, phosporus availability, in addition to the availability of other minerals, can be enhanced with addition of exogenous sources of phytase to the diet (Cromwell et al., 1995; Harper el al., 1997; Kornegay and Harper, 1997).

If minerals, such as calcium and phosphorus, are deficient in cereal grains and oilseeds used in diet preparation, supplemental calcium, phosphorus, and any other mineral needed, can be added to the diet. Mineral supplementation into the diet can be achieved by incorporation of mineral sources, such as dicalcium phosphate, limestone, bone meal, etc (Sauber and Owens, 2001).

This is also true for vitamins. Lipo-soluble vitamin concentrations in grains are insignificant, and some hydro-soluble vitamin concentrations are marginal in reference to pig requirements. Thus, swine diets are traditionally fortified with vitamins (Sauber and Owens, 2001).

The development of optimum feeding strategies account for multiple factors, such as ingredient availability, nutrient concentration and availability in ingredients, ingredient prices, and pig nutrient requirements. Therefore, two

concepts that widely contribute to adequate swine diet formulation are nutrient availability and amino acid supply on an ideal basis (Chiba, 2001).

The most common measurements of nutrient bioavailability used in swine diet formulation are metabolizable energy (ME), true ileal digestibility for amino acids, and bio-availability of minerals and vitamins. The ME value of an ingredient refers to the proportion of the dietary energy absorbed from the gastrointestinal tract minus gaseous and urinary energy losses. True ileal digestibility (standardized true digestibility coefficient) of amino acids refers to the proportion of the dietary amino acid absorbed from the gastrointestinal tract by the time the digesta reaches the terminal ileum, with corrections made for endogenous losses. The bio-availability of minerals and vitamins refers to the proportion of dietary mineral and vitamins which are absorbed and available for utilization (NRC, 1998).

The ideal protein concept defines the optimal dietary ratio among amino acids that corresponds to the amino acid requirements of the pig (NRC, 1998). In practical swine diets, the ratio has been commonly defined based on lysine requirements and available amino acids rather than total (Tuitoek et al., 1997). Diet formulation to ensure pig nutrient requirements based only on the mixture of cereal grains with soybean meal is not recommended. The reason is that the concentration of limiting amino acids in most of the ingredients is very low. Therefore, at the point that the required concentrations of limiting amino acids, such as lysine, methionine, and tryptophan, are achieved, the non-essential amino acids are in excess. However, the use of high quality protein sources, and

inclusion of crystalline amino acids in diet formulation can alleviate this problem (NRC, 1998).

Traditionally, swine diets have been formulated to maximize pig performance without regard for nutrient excretion. Therefore, several nutrients are included in the diet in excess, in order to account for the variability of nutrient content and availability. Nutrient oversupply increases the amount of nutrients excreted in urine and feces (Kornegay and Harper, 1997; NRC, 1998; Creech et al., 2004). It is also important to take into account that around 80% of the feed consumed by a market pig was consumed during the finishing period. Therefore, the reduction of nutrient over-supply during the finishing phase deserves special attention.

Nutrient excretion by growing-finishing pigs

Estimated values of nutrient excretion based on individually-fed pigs have been summarized by Kornegay and Harper (1997). Their summary suggested that 45 to 60% of the N consumed is excreted, 50 and 80% of the calcium (Ca) and P, and 70 to 95% of potassium (K), sodium (Na), manganese (Mg), copper (Cu), zinc (Zn), manganese (Mn), and iron (Fe) is excreted (Kornegay and Harper, 1997). More recently, it has been suggested that 70% of nitrogen intake is excreted (Kornegay and Verstegen, 2001).

Due to the high level of nutrient content in swine manure, it has been recognized as a valuable fertilizer (Kornegay and Harper, 1997; IFA, 2007) and, therefore the common fate is land application. However, nutrients applied in excess of crop requirements can increase the concentrations in the soil, cause

reductions in crop yields, and leach into water bodies (Kornegay and Harper, 1997; Creech et al., 2004; Velthof et al., 2007). Of the nutrients present in swine waste, N and P have generated great environmental concern, in addition to K, Cu and Zn, which are gaining more attention (NRC, 1998; Sutton and Richert, 2004).

Recently, the ASABE published estimated values for DM, N and P excretion, on a per pig basis. The excretion of DM, N and P was estimated using prediction models that take into account diet composition, feed intake, nutrient retention, and pig lean growth. The estimated excretion values for a growing-finishing pig managed in average conditions were 380 g of DM, 39.3 g of N, and 6.73 g of P (Carter et al., 2003). However, very little nutrient excretion data are available based on group-fed pigs in commercial conditions.

Manure management in intensive swine production is challenging due to the large volume produced and limited crop land in the vicinity for land application. The increasing concern about nutrients overloaded into the environment has emphasized the need to reduce the amount of nutrients excreted and the implementations of nutrient recycle systems that reduce environmental impact (Kornegay and Harper, 1997). The reduction of nutrient overfeeding will reduce the amount of nutrients excreted, and the concentration of nutrients in swine waste (Kornegay and Harper, 1997; Creech et al., 2004).

However, accurate measurements of nutrient excretion and gaseous emissions from group-fed pigs under commercial conditions are needed to establish base lines to identify best management practices and evaluate the environmental impact of swine production.

Waste disposal through manure land application

In intensive swine production systems, waste treatment and disposal have become a significant environmental issue. Mainly, due to the common practice of applying swine waste on to cropping land as an organic fertilizer (Kornegay and Harper, 1997; Sauer et al., 2003; Wang et al., 2004). Application of manure to the soil can contribute to enhance soil fertility, structure, and water holding capacity (Choudhary et al., 1996).

Soil fertility is a main factor to sustain agricultural production and food security (Aulakh and Sandhu, 2007). Maintenance of soil productivity is a function of the judicious use of organic and inorganic sources of nutrients to balance nutrient availability in soil solution, reduce carbon (C) depletion from soil, increase C sequestration rates (Aulakh and Sandhu, 2007), and avoid build up of mineral concentrations in soil (Fairchild and Malzer, 2007).

Swine manure and effluent are excellent sources of N to be used in crop fertilization programs (Choudhary et al., 1996). The efficiency of N utilization in soil is affected by the adequacy of water in soil. Soil moisture and temperature influence N mineralization, denitrification, and leaching (Fairchild and Malzer, 2007). Thus, it is recommended to apply swine manure or effluent close to planting dates, and avoid proximity to expected precipitation events (Choudhary et al., 1996). Manure land application during high precipitation periods or with high irrigation levels induces N loss through leaching and denitrification (Aulakh and Sandhu, 2007; Fairchild and Malzer, 2007). Also, manure application to

frozen soil constitutes a high risk of nitrate and other soluble nutrients leaching (Choudhary et al., 1996).

In addition to N losses through leaching, N is lost as ammonia emissions to the atmosphere during land application (Sharpe and Harper, 2002; Velthof et al., 2007). In the European Union, approximately 19% of N excreted in swine operations is lost as ammonia during manure land application (Velthof et al., 2007). In the US, it has been reported that the ammonium N in the effluent that is lost as ammonia N during land application before reaching the soil surface area can vary from 1 (Wu et al., 2003a) to 12% (Sharpe and Harper, 2002), and the total N lost into the atmosphere after land application goes up to 35% of effluent total N concentration (Sharpe and Harper, 2002). In the UK, dilute slurry (less than 2% DM) is used in crop land irrigation. Ammonia emission during irrigation represents 1 to 2.5% of the ammonium N concentration of the slurry; after irrigation is completed, the total ammonia N lost is approximately 10% of total ammonium N in the slurry (Misselbrook et al., 2004). It is important to consider that N losses during effluent application can be affected by effluent flow rate, temperature, wind speed, and concentration of ammonium N in effluent (Wu et al., 2003b).

It is also true that swine waste products are commonly applied to the soil only based on N loading rates, without taking into account the concentration of other nutrients in the waste. This practice can increase the risk of over-loading the soil with nutrients, and with it, the risk of polluting water (Kornegay and Harper, 1997).

In New Zealand, the application of swine effluent is regulated to 150 to 200 kg of N per hectare per year. The amount of N leaching following this loading rate application of swine effluent is insignificant. However, P and K have accumulated, causing an imbalance of nutrients in the soil (Wang et al., 2004).

It has been reported that natural concentrations of P in US soil commonly range from 26 to 57%, in contrast with 49 to 80%, as is basis, of total P measured in similar soils after 10 years of manure application (Sharpley et al., 2004). In addition to P accumulation in soil, the P reaction products changed from approximately 49% of inorganic P in the form of Al and Fe complexes to 49% in the forms of Ca-P complexes. These Ca-P complexes are not water soluble, thus, this portion of P in soil will not be available for plant uptake (Sharpley et al., 2004). Other reports suggest soil accumulations of Cu and Zn after 4 and 10 years of swine effluent application, in association with leaching of Cu into lower levels of soil. However, the accumulation levels were low enough to not represent any phytotoxic risk, even to Cu and Zn sensitive crops (Novak et al., 2004). Also, a Canadian report suggests accumulation of K, and a reduction of removable Ca and Mg, in cereal cropping soil after 5 to 7 years of swine manure application (Qian et al., 2005).

When manure has been applied based on crop P removal rate, runoff losses were approximately 2.8% of total P applied, with 50% of P lost as soluble P and 50% lost as sediment-bound forms (Sauer et al., 2003). Even though no significant P leaching was measured under this management practice, these results corresponded to a single application. Therefore, evaluations of long-term

applications are needed to clear up the potentiality of P, as well as other minerals, accumulation in soil and leaching over time.

The best strategy to reduce nutrient losses from land application will be splitting manure applications in combination with appropriate irrigation schedules (Aulakh and Sandhu, 2007). To estimate the best rate of manure application two major approaches are used: 1) a predictive approach that takes into account nutrient availability in soil through soil testing or remote images in conjunction with crop potential for nutrient uptake (Lemunyon and Kuenstler, 2002, Fairchild and Malzer, 2007) and 2) an 'in time' crop need strategy where manure application will be a function of using specific sensors to detect crop needs (Fairchild and Malzer, 2007). In addition to these strategies, crop rotation can help to preserve soil integrity, and reduce the risk of nutrient leaching to underground water reservoirs (Lemunyon and Kuenstler, 2002). The future of manure land application will depend on the ability of the producer to manage application rate and frequency based on spatial and temporal availability of nutrients in soil with crop needs (Fairchild and Malzer, 2007).

Influence of C:N ratio on N release during organic matter decay

The practical importance of the C:N ratio in swine waste becomes obvious when the changes that takes place in the soil after residual application are taken into account. The C:N ratio in a stabilized soil ranges between 8:1 and 15:1. The application of any organic material with a C:N ratio below 20 will provide additional free N to the soil solution. The free N in soil solution will be available

for plant uptake (Brady and Weil, 1999) and leaching into underground water. If the rate of land application of swine waste residual is high and the C:N ratio is low, it can increase the risk of N leaching into underground water.

Impact of nutrients loaded into the soil on water quality

Nutrients applied in excess of crop requirements can accumulate in soil. Water soluble forms of nutrients are incorporated into soil solution when soil moisture is high. Nutrients accumulated in soluble forms are easily mobilized in solution through soil horizons. The mobilization of nutrients in soil solution from superficial horizons to lower soil levels is known as nutrient leaching (Choudhary et al., 1996; IFA, 2007). Thus, high precipitation and manure application to frozen soil can increase nutrients leaching into underground water (Choudhary et al., 1996).

Nitrogen incorporated to soil in the form of nitrate is water soluble, and therefore, it is mobile in soil solution (IFA, 2007). If soil moisture is high and N leaches away from crop rooting zones, nitrogen value as fertilizer is lost, and it can leach into water bodies (Choudhary et al., 1996; IFA, 2007). As a consequence, high N loads into terrestrial and aquatic ecosystems have increased N deposition and eutrophication of water reservoirs (De Vries et al., 2007; IFA 2007). Also, nitrogen lost as ammonia can contribute to nitrogen leaching. Ammonia can be deposited into soil via acid rain, contributing to soil acidification. Ammonia in soil is nitrified to water soluble nitrates that can leach into underground water (Galloway et al., 2003).

Eutrophication of water bodies is causing a global concern about loss of biodiversity and its impact on human health. This process has been defined as the "accumulation of nutrients in aquatic and terrestrial ecosystems that can lead to an undesired increase in biomass production and a shift in species composition" (IFA, 2007).

Increased N and P load into water bodies has been recognized as one of several mechanisms linked to eutrophication all over the world (Glibert, 2007; IFA, 2007). Algae blooms are associated with increased levels of a nutrient that was limited in the natural ecosystem. The increase in frequency, magnitude, and duration of algae blooms in enriched-water ecosystems suggest that eutrophication is a consequence of increased nutrient concentrations in the ecosystem (Glibert, 2007).

Nutrient enrichment of water bodies can drive harmful algae blooms. Harmful algae are those that produce toxins that are accumulated in shellfish and fish that later are consumed by humans, causing health problems. Also, some harmful algae toxins can directly affect shellfish or fish, or disturb the ecosystem in a detrimental way, such as the development of hypoxia or anoxia when the blooms decay (Glibert, 2007). Nutrient enrichment and reduction of oxygen in water sources markedly decrease drinking water quality (Khalil and Richards, 2007; IFA, 2007).

Nitrate accumulation in drinking water has been associated with health problems such as methemoglobinemia. Nitrates in water are transformed to nitrites by human intestinal bacteria, which are potent oxidants. Nitrites oxidize

ferrous iron of the hemoglobin molecule into ferric iron, decreasing blood oxygen and carbon dioxide carrying capacity. Patients with methemoglobinemia are cyanotic and non responsive to oxygen therapy; therefore, in severe conditions this disorder can lead to patient death (Hill, 1996; Brunato et al., 2003).

Stream water samples collected within the Tipton Creek watershed in Iowa, from the vicinity of a concentrated swine operation had detectable P concentration. Even though P concentration was not high enough to compromise water quality, the effects of runoff on P export to the watershed were simulated, to estimate the environmental risk that manure P application could have in this watershed (Sauer et al., 2003). Precipitation records from previous years were used to estimate the impact of 4 runoff events under similar management conditions five years later. The simulation was conducted assuming a 25% increase in swine production in the area. The result of the simulation suggested a 40% increase in total P exported to the watershed under the assumed conditions (Sauer et al., 2003). Also, a tendency of K (Qian at al., 2005) and Cu (Novak et al., 2004) leaching has been reported after long-term manure application in other areas.

The contribution of small amounts of limiting nutrients in specific nutrient restricted ecosystems can cause a dramatic shift in biodiversity (Glibert, 2007). However, it is not feasible to estimate the magnitude of the environmental disturbance attributable to intensive swine production. However, one of the biggest challenges that the swine industry is facing at the present time is balancing production with the reduction in environmental impact.

Impact of emissions from swine production on air quality

The concentration of atmospheric reactive N is increasing. The general concern about the contribution of N emitted from human activities (anthropogenic N) into the atmosphere is growing (Cleveland, 2007). The most abundant form of reactive N in the atmosphere is ammonia (Aneja et al., 2007) which has been associated with dust and ammonium salts formation (IFA, 2007).

Dust monitoring is based on particulate matter (PM) size. The nomenclature includes PM10 as particle matter which size is smaller that 10μm, and PM2.5 for particle matter smaller that 2.5μm (IFA, 2007).

Ammonium, nitrate, and sulphate concentrations in PM_{10} have a seasonal behavior. The lowest concentrations of ammonia and nitrate in PM_{10} are measured when temperature is higher, and concentrations increase with low temperatures (during winter) (Alebic-Juretic, 2007). Opposite behavior is observed for sulphate concentration in PM_{10} with concentration increasing by 10% during summer in comparison with its concentration registered during winter (Alebic-Juretic, 2007).

The association of this seasonal behavior of ammonia and nitrate concentrations measured in rural areas with specific agricultural practices is very poor (Fagerli et al., 2007). The temporal variation in emission from agricultural practices, such as land manure application, is affected by soil surface temperature, moisture, and wind flow (Fagerli et al., 2007).

Increased atmospheric dust formation has been associated with an increased incidence of respiratory problems in humans. The respiratory tract is primarily a place where dust interacts with the human body. Dust particles enter carried by the air inhaled during breathing. They reach the mucosa and alveoli, inducing irritation of the airways (Iversen et al., 2000). It has been documented as a growing health concern of swine operation neighbors. The concern is mainly based on the incidence of irritation of the respiratory tract within their population. This respiratory problem seems to be consistent with symptoms associated to respiratory problems of confined-environment-swine workers (Thu, 2002).

However, the effects of dust exposure on human health have been better documented in confinement environments characterized by the presence of dust, endotoxins, and ammonia (Iversen et al., 2000; Thu, 2002; Von Essen and Romberger, 2003). The respiratory problems associated with exposure in swine confinement facilities include asthma-like syndrome, exacerbation of underlying asthma, chronic bronchitis, and mucous membrane irritation syndrome (Iversen et al., 2000; Von Essen and Romberger, 2003). These problems could result from irritation of the airways in combination with other disease mechanisms, which in all cases resulted in loss of lung function (Iversen et al., 2000).

In order to minimize the effects on human health, it is well recognized the need to emphasize research in dust particle matter (Predicala and Maghirang, 2004) and gases emission monitoring (Ni, 1999, Ni et al., 2000; Hebert et al., 2000; Aneja et al., 2007) in addition to the identification of best management

practices to reduce swine dust production and emissions (Ni, 1999; Ni et al., 2000; Hebert et al., 2000; Thu, 2002).

Regulatory policies to preserve air and water integrity

The Environmental Protection Agency has identified concentrated animal feeding operations (CAFOs) as a priority sector for supervision and regulation. Intensive swine production operations are identified as CAFOs within the EPA regulation (EPA, 2006). CAFOs are categorized as pollutant point sources, and since 2003, all CAFOs with potential to discharge are required to apply for a National Pollutant Discharge Elimination System (NPDES) discharge permit (EPA, 2006). The application for the NPDES discharge permit requires the submission of information about the discharge. This information should include: specification of the discharge, and the implemented comprehensive nutrient management plan; including specifications of the waste treatment system design (EPA, 2006).

The implementation of comprehensive nutrient management plans in intensive operations is not only required to meet Environmental Protection Agency regulations (EPA, 2006). It is also required to meet the USDA Natural Resource Conservation Service (USDA-NRCS) guidelines for concentrated animal feeding operations (Henry et al., 2003).

The implementation of comprehensive nutrient management plans requires the identification of a combination of management practices that can be efficiently adopted by each production system. Thus, production management

practices in the swine industry and their effects on nutrients loaded into the environment are gaining a lot of attention as subjects of regulation, at the state and federal level, to protect natural resources.

The selection of the management practices to be adopted in specific production conditions can be a complex task. Therefore, tools have been developed to support producers in their selection process. In all cases, the selection tools have been the result from interdisciplinary collaborative work combining animal scientists, natural resource scientists, engineers, economists, production leaders, and policy advisers. An example of these tools is the Comprehensive Animal Nutrient Management System, developed as a collaborative effort of Washington State University and University of Idaho (Chen et al., 2003). Another available resource is the NRCS Customer Service Toolkit, developed by University of South Carolina and the NRCS (Henry et al., 2003).

The environmental regulations that can affect the future of intensive swine production are not limited to those that regulate water quality issues. The Clean Water Act regulates waste discharge, including manure land application. However, the Clean Water Act does not regulate gases emitted into the air, such as ammonia and hydrogen sulfide (EPA, 2006). Therefore, to preserve air integrity, the EPA has three air quality regulatory acts. These acts are the Clean Air Act (CAA), Comprehensive Environmental Response Compensation and Liability Act (CERCLA), and Emergency Planning and Community Right-To-Know Act (EPCRA). Currently, these acts are being reviewed to address gaseous emissions from CAFOs. The implementation of regulations on

ammonia and hydrogen sulfide emission from CAFOs will impact swine production. In the near future, emissions of ammonia and hydrogen sulfide above 100 lb/day or 250 tons/year will be subject to penalties established within these acts.

However, more research is required to identify the best management practices to reduce ammonia and hydrogen sulfide emissions (Kornegay and Harper, 1997; Sutton and Richert, 2004). It is also required the standardization of an appropriate air monitoring system to enhance the decision making process in regards to implementation of new regulatory policies (Velthof et al., 2007; Aneja et al., 2007).

Dietary manipulation to reduce environmental impact of swine production

Environmental impact of swine production can be minimized with an optimal combination of management practices to reduce nutrient excretion from swine production, in addition to the implementation of balanced fertilization programs (Velthof et al., 2007). Dietary manipulation has been proposed as a practical and feasible approach to reduce nutrient excretion, especially during the finishing phase (Kornegay and Harper, 1997; Sutton and Richert, 2004; Velthof et al., 2007).

Approximately 80% of the feed consumed by a finished pig is consumed during the finishing phase. Therefore, special attention needs to be placed on nutrients excreted during finishing. Dietary manipulation has been proposed to

reduce nutrient excretion in finishing pigs. This approach includes avoiding or reducing nutrients over fed, the use of highly digestible sources of nutrients, and the inclusion of dietary supplements to enhance nutrient utilization (Kornegay and Harper, 1997, Sutton and Richert, 2004).

Dietary manipulations to reduce nitrogen excretion

In the growing and finishing phases, opportunities exist to reduce nutrient excretion through the inclusion of high quality protein sources, the reduction of over-feeding non-limiting amino acids by the reduction of dietary protein levels, and balancing diets with addition of crystalline amino acids (Sutton and Richert, 2004).

Use of high quality protein sources

Traditionally, swine diets have been formulated to supply adequate amounts of essential amino acids that met or exceeded pig requirements, in addition to amounts of non-essential amino acids, or of amino groups for non-essential amino acid synthesis (NRC, 1998). A basic concept in swine diet formulation is the ideal protein. The ideal protein represents the optimal pattern among essential amino acids which supply pig needs. In the case of grower and finisher pigs, the pigs needs refer to the amino acids requirements for protein accretion and maintenance (NRC, 1998).

The inclusion of high quality protein sources in diet formulation will allow pigs to meet their requirements at lower dietary protein levels (NRC, 1998; Sutton and

Richert, 2004). High quality protein sources have been defined as a feed commodity, feedstuff, or mixture of them which have an amino acid pattern similar to the pig requirement (NRC, 1998) and a high biological value (Sutton and Richert, 2004).

Regularly, proteins with high biological value are rich in one or more limiting amino acids, such as lysine, methionine, threonine and tryptophan. It is impossible to formulate an amino acid balanced diet using only natural feed ingredients. Therefore, moderate supplementation of diets with crystalline amino acids is considered a strategy to formulate balanced diets that meet amino acids requirements with reduced protein concentration (NRC, 1998).

Although the concept of biological value is well understood, diet formulation based on this concept is not feasible. Diet formulation based on biological value will require a known biological value of each amino acid in the ingredient to be used. Therefore, to optimize diet formulation on ideal amino acid basis, swine diets have been formulated based on true digestible amino acid values rather than total amino acid concentrations (Tuitoek et al., 1997).

Reduction of dietary protein levels with addition of crystalline AA and N excretion

The protein content in swine diets is the result of diet formulation based on pig nutrient requirements for a specific weight, physiological condition, and expected growth performance. Typically, grower and finisher diets are formulated using corn and soybean meal as basal ingredients and fortified with vitamins and minerals. Diet formulation using the basal ingredients as unique

amino acid sources leads to the over-feeding of amino acids, and a high protein content diet. Feeding diets with high protein content results in high N intake and excretion. Urinary N is an important portion of the N excreted. It is the product of the breakdown of absorbed amino acids that exceeds metabolic demand of the pig. Therefore, growing-finishing diets should be formulated to meet amino acid requirements and to avoid amino acid and protein over-feeding (Sutton and Richert, 2004).

Previous reports of N balance in growing-finishing pigs suggest that 55 (Kornegay and Harper, 1997) to 70% of nitrogen intake is excreted (Kornegay and Verstegen, 2001). Therefore, the reduction of dietary CP in amino acid supplemented diets has been proposed to reduce N excretion and ammonia emissions (Kornegay and Harper, 1997; Kornegay and Verstegen, 2001; Otto et al., 2003; Sutton and Richert, 2004; Portejoie et al., 2004; Panetta el at., 2006; Htoo et al., 2007).

The magnitude of response in reduction of N excretion obtained from different studies is dependent on the protein level used as the reference value in the control diet and the amino acid supplementation criteria employed. Commonly, the CP and amino acid concentration in the diets employed as control diets meet or exceed the NRC requirements. However, amino acid supplementation has been performed to meet the amino acid profile of the control diet (Canh et al., 1998; Portejuie et al., 2004; Figueroa-Velazco, 2004) or the ideal amino acid pattern (Kephart and Sherritt, 1990; Figueroa 2002, 2003; Kerr et al., 2003a, 2003b; Panetta et al., 2006; Htoo et al., 2007).

In the development of low protein diets, the effects of reducing dietary CP on N intake and retention have been studied. The reduction in protein levels in finishing diets from 16.5 to 12.5% linearly decreased N intake from 62 to 47 g/pig/d, and increased N retention as a percentage of intake from 39 to 48% (Canh et al., 1998). In grower diets, a reduction in CP concentration from 18.2 to 13.6% resulted in a linear reduction in N intake from 40 to 30 g/pig/d and a linear increase in N retained as percentage of the intake from 53 to 60% (Deng et al., 2007b).

Further reductions in dietary CP from 15 to 6% linearly decreased N intake from 43 to 26 g/pig/day, increased N retention as percentage of the intake from 56 to 74%, and N retained as percentage of N absorbed from 70 to 86% (Otto et al., 2003). In this study, it was also suggested that a reduction of dietary CP by 3% units could reduce N excretion by approximately by 20% (Otto et al., 2003).

Reduction in CP concentration in finisher diets by 4 to 6% units, maintaining similar levels of limiting amino acids to the control diet, have demonstrated a reduction in N excretion from 21 to 44%, respectively (Portejoie et al., 2004). Although N excretion was diminished by approximately 7% per each percentage unit reduction in dietary CP, it could be possible to obtain greater reductions in N excretion using a similar reduction in dietary CP. In this study, the protein concentration of the control diet was 4% units higher than the requirement established by the NRC (1998).

Other evaluations of reduced protein diets reported that decreasing dietary CP from 18.2 to 16.5, 15.5, 14.5 and 13.6% reduced fecal N excretion by 7 to

17%, urinary N excretion by 19 to 45%, and total N excretion by 15 to 45%, respectively, for 2 to 5% units reduction in CP in the diet. For every one percentage unit reduction in dietary CP, N excretion was decreased by 7.6% (Deng et al., 2007b), in agreement with previous results (Portejoie et al., 2004). Further reductions in dietary protein in grower diets, from 19 to 12%, reduced N excretion by 58% without affecting retained N as percentage of intake (Le Bellego et al., 2001).

However, reductions in N digestibility have been reported as a linear effect of reducing dietary protein concentration using growing diets with 19, 16, 14 and 12%. The apparent digestibility coefficient of N in the 19% CP diet was 91.5% and sequentially decreased to 89% in the 12% CP diet (Le Bellego et al., 2001). In agreement with this report, the reduction in dietary CP concentration from 18.2 to 13.6% in finishing diets linearly decreased N digestibility from 84 to 82% (Deng et al., 2007b).

The reduction in N digestibility in reduced CP diets is more evident when diets are formulated with the inclusion of ingredients with lower digestibility than corn and soybean meal. As an example, a reduction of 3% units in dietary protein, with addition of crystalline amino acids, in a grower diet with 8% inclusion of barley reduced N digestibility by 3%. In spite of the reduction in N digestibility, the 3% units reduction in dietary protein decreased N excretion by 29 (normal barley) to 32% (low-phytate barley) (Htoo et al., 2007).

The effects of reduced dietary CP diets on N excretion have also been evaluated in diets with addition of fermentable fiber. The reduction of CP

concentration in grower diets by 3% units with addition of crystalline amino acids on an ideal basis decreased urinary N excretion by 28% and total N excreted by 18% (6% per each percentage unit of CP that was reduced; Zervas and Zijlstra, 2002a). The inclusion of 15% soy hulls in the diet decreased urinary N excretion by 5%, and the inclusion of 20% sugar beet pulp decreased urinary N by 9%. These levels of fermentable fiber, 15 and 20% inclusion of soy hulls and sugar beet pulp, increased fecal N excretion by 4 and 6.5%, respectively. However, the inclusion of fermentable fiber did not affect total N excretion (Zervas and Zijlstra, 2002a).

Another study was conducted with the objective to evaluate the effects of reduced CP in the diet and oat-hull fiber on N excretion. Three protein levels (19.7, 16.9, and 13.8% CP) and two fiber levels (5 and 3.6% CF) were evaluated in grower diets. Urinary, fecal, and total N excretion linearly decreased with the reduction in dietary protein concentration. When N excretion from pigs fed the highest protein level was contrasted with N excretion from pigs fed the lowest protein level, the 6% units reduction in dietary CP reduced urinary N excretion from 18 g/pig/d to 10 g/pig/d (48% reduction). Also, fecal N excretion reduced from 8 to 6 g/pig/d (23% reduction), and total N excretion reduced from 26 to 16 g/pig/d (40% reduction). When N excretion was expressed as percentage of N intake, urinary and total N linearly decreased with the reduction in protein concentration in the diet. However, fecal N excretion as percentage of N intake was not affected by dietary CP concentration (Zervas and Zijlstra, 2002b). The inclusion of fiber in the diet affected N intake. The intake of N was higher in the

diet with 5% of CF in relation to the N intake of the diet with 3.6% CF. Also, N excretion was 9% higher in pigs fed the diet with 5% CF in relation with N excreted by pigs fed the diet with 3.6% CF (Zervas and Zijlstra, 2002b).

Effect of reduced protein diets on pig growth performance

Diet formulation on an ideal protein basis represents a practical approach to supply the required amino acids in swine diets. It has been suggested that in corn-soybean meal diets with addition of crystalline amino acids on an ideal basis, dietary protein can be reduced up to 22%, which represents approximately a 3% units reduction, without affecting pig growth performance (Tuitoek et al., 1997).

The reduction of dietary protein by 1 to 3% units in corn-soybean meal diets fed to grower and finisher gilts did not affect average daily gain, average daily feed intake, and gain to feed ratio of gilts. However, a further reduction in CP to 4% units tended to decrease average daily gain and the feed:gain ratio was increased (Tuitoek et al., 1997).

The negative effects of further reductions in dietary protein concentration on pig growth performance have been consistently reported. The reduction of dietary protein by 4 or more percentage units with addition of crystalline essential amino acids on an ideal basis decreases daily gain, final weight, and increases feed:gain ratio (Tuitoek et al., 1997; Gomez et al., 2002; Figueroa et al., 2002, 2003; Figueroa-Velasco et al., 2004; Panetta et al., 2006). It is not clear why reductions in dietary protein over 4% units have negative effects on pig growth.

On the other hand, a reduction in dietary CP by 4% units, with addition of crystalline amino acids, to meet similar concentration of lysine, methionine, threonine and tryptophan to the control diet increases feed intake, and no detrimental effect is observed in average daily gain and feed conversion (Figueroa-Velasco et al., 2004).

It is possible that the optimum amino acid balance changes over time, especially the ratio of threonine and sulfur amino acids to lysine (Tuitoek et al., 1997). Another possible explanation could be the reduction in total N supply when protein concentration in the diet is reduced over 4% units. In this case diminished pig growth could be the consequence of limited total N supply (Tuitoek et al., 1997). Also, previous reports suggest that N utilization in reduced protein diets can be enhanced by the addition of glutamate (Kephart and Sherrit, 1990, Kerr and Easter, 1995) and glycine (Kerr and Easter, 1995). However, these data leave open the possibility that certain amounts of non-essential amino acids, or their metabolic precursors, need to be supplied via feed, to optimize N utilization in grower and finisher pigs (Tuitoek et al., 1997).

Another theory is the preferential absorption of free amino acids which drives a reduction in utilization of amino acids from intact proteins when pigs are fed once a day. However, this theory is not valid after it was demonstrated that increased feeding frequency and free access to feed to do not enhance amino acid utilization. Therefore, the reduction in N retention observed in pigs fed reduced protein diets may be due to the reduction in N intake (Le Bellego et al., 2001).

Effect of reduced protein diets on carcass characteristics

Carcasses of pigs fed reduced protein diets by more than 4% units with amino acid supplementation on an ideal basis and without reduction of ME levels have increased fat (Kerr et al., 1995; Tuitoek et al., 1997; Le Bellego et al., 2001). However, the reduction in ME levels in reduced protein diets eliminate this negative effect on carcass characteristics (Gomez et al., 2002; Figueroa et al., 2002, 2003).

Reductions in dietary protein by 4% units in grower and finisher diets, supplemented with lysine, methionine, threonine and tryptophan to have equivalent concentrations in relation with traditional corn-soybean meal diets, do not affect backfat, longuissimus muscle area, lean meat gain, and percent lean meat (Figueroa-Velasco et al., 2004). When the 4% units reduction in the grower and finisher diets was accompanied with a 3% reduction in dietary ME, the effects on pig growth and carcass traits were dependent on pig sex. The 3% reduction in dietary ME decreased backfat thickness in gilts, and increased longissimus muscle area in barrows (Figueroa-Velasco et al., 2004).

Effect of reduced ME in reduced protein diets

Diets with reduced protein and addition of crystalline amino acids have higher NE values than traditional diets with similar GE. Reduced protein diets increase ME retention by increasing fat deposition (Figueroa-Velasco et al., 2004). The reduction in dietary CP by 6.5% units in grower diets decreased pig heat

production. The reduction in heat production seems to be due to a reduction in the thermal effect of feed. The reduction in heat production is accompanied by an increase in total energy gain, mainly due to the increase in fat deposition (Le Bellego et al., 2001). The ME system for diet formulation is not sensitive to this change in energy utilization. Therefore, the NE system may be more appropriate to formulate diets taking in to account the increase in NE driven by the reduction in protein concentration in the diets (Le Bellego., 2001).

The reduction in crude protein reduces non-essential amino acid supplied by traditional corn-soybean meal diets. The consumption of reduced protein diets reduced deamination, urea synthesis, and N excretion (Figueroa-Velasco et al., 2004). A previous report estimated that urinary energy lost decreases by 6.8 kcal per each gram of urinary N that is reduced, and 0.9 kcal per each gram reduced in protein intake. These values were estimated using a diet which CP digestibility coefficient was 93%, and therefore, they change depending on the digestibility of dietary protein fed (Le Bellego et al., 2001).

Dietary manipulations to reduce phosphorus excretion

The reduction of P excretion is particularly important in those areas where concentrated swine operations are located. Swine waste disposal is based in crop land application. In most areas, swine manure application rate is limited based on N concentration. However, evidence of accumulation of P in the soil is positioning P as the limiting nutrient for swine manure application. The accumulation of P in soil has been associated with the risk of soil and water

pollution by increasing P levels through runoff of water with a high level of P, and long term swine manure application on crop land.

Phosphorus is a key nutrient in skeletal development; it also plays an important role in energetic metabolism. Phosphorous deficiency in pigs can induce a reduction in growth rate, feed intake, and reproductive performance (NRC, 1998). Therefore, swine diets are formulated to guarantee that available P levels are high enough to cover or exceed pig requirements. The availability of dietary P is dependent on the amount of available P supplied by each of the ingredients used. The major components of swine diets are cereal grains and oilseeds meals. Therefore, it is important to consider the main factors that affect the content of available P in grains and oilseeds. These are the content of phytate-P, the content of non-phytate-P, and the level of active endogenous phytase (Eeckhout and De Paepe, 1994). Therefore, dietary manipulations to reduce P excretion include: reduction of dietary P levels, enhancement of dietary P bioavailability with the inclusion of supplemental phytase, and formulation of diets balanced on an available P basis with a Ca:tP ratio close to 1.2:1.

Reduction of dietary phosphorus levels

The inability of the pig to efficiently utilize the P from grains has driven the common practice of supplementing the diets with inorganic P sources that can guarantee the supply of available P to meet or exceed pig requirements. As a result, over-feeding P is a common practice in commercial operations. In these

conditions, most of the phytate-P is excreted in the feces (Cromwell et al., 1995), in addition with the portion of the inorganic P that was not absorbed.

Phosphorus excretion has been decreased by the reduction of dietary P. The higher reductions in P excretion result from the combination of the reduction of dietary P level below pig requirement (Qian et al., 1996). Several studies support that a reduction of dietary P by 0.1 % unit results in a decrease of P excretion between 21 and 25 % (Cromwell et al., 1995; Qian et al., 1996; Harper el al., 1997; Liu et al., 1998).

Inclusion of supplemental phytase

The P present in grains is in form of phytin, also known as phytic acid and commonly referred to as phytate. Phytate is a mixture of Ca-Mg salts of inositol hexaphosphoric acid. The P in this form is bound in an inositol ring forming myo-inositol hexaphosphate. The concentration of P in phytate is 282 g/kg (Selle et al., 2000). However, phytate-P is not available due to the inability of the swine gastrointestinal tract to produce the appropriate enzyme (phytase) for phytate digestion (Cromwell et al., 1995; Harper el al., 1997; Kornegay and Harper, 1997).

This enzyme is myo-inositol hexakisphosphate phosphohydrolase, which is commonly refered to as phytase. Phytase is capable of hydrolyzing phytate into inorganic P (orthophosphates) and intermediary products starting with penta-inositol phosphate to mono-inositol phosphate (Vats, 2005). The phytase activity is measured in phytase units (FTU), which are commonly abbreviated as FYT.

One phytase unit is defined as the amount of enzyme that liberates 1 μmol of inorganic P per minute from 5.1 m*M* of sodium phytate at 37 ^{o}C and pH 5.5 (Engelen et al., 1994).

The ingredients more commonly used in swine diet formulation in the U.S are corn and soybean-meal. However, in other countries such as Canada, Belgium and the Netherlands, ingredients such as wheat and barley are important. Additionally, in the near future, distiller dried grains with solubles may be an important ingredient in swine diet formulation. It is also important to consider that total P in corn ranges from 0.25 to 0.35%, and 68% of it is in the form of phytate, with an endogenous phytase activity that can vary from 0 to 46 FYT. In soybean meal, the total P content can range from 0.59 to 0.73%, with 53% of it as phytate P, and an average phytase activity of 0 to 20 FYT. Ingredients, such as wheat and barley, have a total P content that can vary from 0.31 to 0.39%, with 55 to 78% as phytate-P, and a phytase activity that ranges from 915 to 1,581 FYT for barley, and 1,475 to 2,039 FTY for wheat. Corn distiller grains have been reported to have 0.9% total-P, with only 21% of it in the form of phytate-P, and a phytase activity of approximately 385 FYT. Even though there is evidence of phytase activity in grains, this activity is moderate to low (Eeckhout and De Paepe, 1994).

Also, the pelleting process has a dramatic negative effect on phytase activity. A Belgian study reported a reduction of phytase activity in wheat fine bran of 44% due to the pelleting process (Eeckhout and De Paepe, 1994). This is also true for microbial phytase that had been added to the diets. Brady et al. (2002)

measured phytase activity in barley-wheat-soybean meal based diets without exogenous phytase (produced by *Peniophora lycii*) inclusion prior to and after pelleting. The phytase activity prior to the pelleting process was estimated at 530 FYT/kg. However, when phytase activity was measured after pelleting, the activity was reduced to 39 to 45 FYT/kg. They also measured the phytase activity in diets supplemented with 750 FYT/kg of diet and after pelleting the feed, the phytase activity was as low as 27% of the expected value (Brady et al., 2002).

Exogenous phytase has been added to swine diets to enhance P availability, and reduce inorganic P supplementation and P excretion (Cromwell et al., 1995; Harper el al., 1997; Kornegay and Harper, 1997). The reduction of P levels in the diets during the grower and finishing phases by 0.1 and 0.05% units, respectively, resulted in an overall reduction of daily gain by 18%, feed intake by 15%, and feed efficiency by 3%. However, the addition of phytase (250 to 500 FYT/kg; Natuphos 5000® BASF Corp. Mount Olive, NJ) to these low P diets restored daily gain, feed intake, and feed conversion to levels similar to that observed for pigs fed diets with adequate levels of P. Phytase supplementation to low P diets resulted in a linear improvement in P digestibility, with an overall enhancement of 33% (Harper et al., 1997). Based on pig performance, phosphorus digestibility, and bone strength data, it has been suggested that the addition of 500 FYT/kg into grower and finisher diets results in P release equivalent of 0.87 to 0.96 g of P from dicalcium-monocalcium phosphate supplements (Harper et al., 1997).

The improvement in pig performance due to phytase supplementation is not only dependent on the concentration and digestibility of dietary P. Pig performance is also affected by the type of phytase supplemented. The phytase can be derived from different strains of bacteria, yeast, and fungi. However, the most commonly used for commercial production are *Aspergillus niger* and *Aspergillus ficuum* (Vats, 2005). Phytase from *Aspergillus niger* has a moderate effectiveness to increase the utilization of phytase-P in swine diets. The inclusion of *Aspergillus niger* derived phytase has very little effect when dietary P is reduced by more than 0.1% unit. However, when dietary P reduction has been less than 0.1%, the addition of *Aspergillus niger* derived phytase have not enhanced pig growth performance. Therefore, the *Aspergillus niger* phytase has been classified as a low activity phytase (Cromwell et al., 1995).

The reduction in P excretion has been the result from the inclusion of different levels of supplemental phytase in swine diets. The data from 25 different studies with phytase supplementation were used to determine the relationship of the level of phytase supplemented and the level of the reduction in total P excreted by growth-finishing pigs. As a result, a decrease of 31% in P excretion can be expected from the inclusion of 500 FYT/kg (Natuphos 5000® BASF Corp. Mount Olive, NJ) in swine diets (Kornegay and Harper, 1997). This predicted value is in agreement with P excretion values measured in a further study where pigs were fed a reduced P diet (0.1% unit reduction) with supplemented phytase (500 FYT/kg of diet; Natuphos 5000® BASF Corp. Mount Olive, NJ). In this case, P excretion was reduced by 35% (Liu et al., 1998).

Effect of the Ca:tP ratio

Phosphorus is a very active nutrient. It can interact with other nutrients, such as Ca, and form insoluble complexes. One of the complexes that can be formed is calcium phytate. The formation of this complex can negatively affect phytase activity and phosphorus utilization. Therefore, any factors that reduce available P need to be taken into account.

Phosphorus excretion has been decreased by the addition of phytase to swine diets and increased by increasing level of dietary P. Supplementation of low P diets with phytase increased P absorption and reduced the amount of P excreted in feces (Qian et al., 1996; Liu et al., 1998). Higher reductions in P excretion result from supplementation of phytase above 500 FYT per kg of diet, and the reduction of dietary P below 0.1% unit, while the Ca:tP ratio is 1.2:1 (Qian et al., 1996; Liu et al., 1998).

When dietary Ca levels in low P diets are maintained at the NRC (1998) requirements, the efficacy of phytase to increase available P is reduced, and formation of calcium phytate increased (Liu et al., 1998). Average daily gain, feed efficiency, and P utilization were increased by reducing the Ca:tP ratio from 1.5:1 to 1.2:1 in reduced P finishing diets. In both diets, P was reduced by 0.1% unit below the NRC (1998) requirements and 500 phytase units per kg of feed were added. Also, pig growth performance of pigs fed a diet with a Ca:tP of 1.2:1 was similar to the growth performance of pigs fed a diet with a 1:1 ratio, when

phytase was added. This response could be due to the increase in P digestibility by more than 9% when phytase was added (Liu et al., 1998).

Another experiment performed in Ireland demonstrated that a reduction of dietary P by 0.15% units, with addition of 750 phytase units per kg of feed, where Ca:tP ratio exceeded the value recommended by the NRC (>1.2:1) resulted in a reduction of feed intake, daily gain, and feed efficiency (Brady et al., 2002). When diets were formulated to have a similar reduction in dietary P and the Ca:P ratio was reduced to 1.15:1, phytase addition resulted in an increase in pig feed intake, average daily gain, and P digestibility (Brady et al., 2002). These results are in agreement with previous reports for weanling pigs where the activity of supplemental phytase (700 or 1050 FYT/kg of diet) was decreased as the Ca:P ratio increase from 1.2:1 to 2:1. The negative effect of a wide Ca:P ratio was more dramatic when dietary P was reduced by 0.1 % unit (Qian et al., 1996).

Qian et al. (1996) and Lui et al. (1998) summarized three possible mechanisms that have been proposed by other researchers that can explain the detrimental effect of a wide Ca:P ratio in pigs diets. The first mechanism is the formation of the calcium-phytate complex. The second is an increase in the luminal pH that could result in a decrease in phytase activity, and the third, is competitive binding of Ca to the phytase active sites.

Dietary manipulations to reduce mineral excretion

Scientific evidence associated with mineral build up in the soil has driven a particular concern about mineral concentration in swine manure, and the effects

of long term manure application on cropping areas. A summary from digestibility experiments suggest that 70 to 95% of the mineral intake is excreted by growing and finishing pigs (Kornegay and Harper, 1997). This high level of mineral excretion requires immediate attention. The reduction in mineral excretion from growing and finishing pigs can also be achieved through dietary manipulations. The dietary manipulations include reducing dietary mineral levels and increasing mineral availability (Creech et al., 2004).

Reducing mineral levels in the diet

Over-feeding trace minerals is a regular practice in swine diet formulation. High levels of minerals in swine diets results in high levels of minerals excreted. It has being reported that 70 to 95% of mineral intake is excreted (Kornegay and Harper, 1997). Therefore, formulation of swine diets with mineral levels close to pig requirements would also lead to a reduction in mineral excretion and mineral concentration in the waste (Creech et al., 2004).

On the other hand, high levels of some minerals can negatively affect the availability of others. This is the case for Fe and Mn. If the levels of inclusion of these minerals in the diet are reduced to levels closer to pig requirements it will also serve to reduce the required levels of inclusion of Zn and Cu (Creech et al., 2004). High levels of dietary Zn and Cu result in high levels of these nutrients excreted (NRC, 1998) with a reduction in their retention as percentage of the intake (Kornegay and Harper, 1997).

An experiment was conducted to evaluate the effect of trace mineral concentration in the diet, and the mineral source employed on pigs growth performance and trace mineral excretion. Fecal mineral excretion was estimated using group fed pigs to collect fecal grab samples. The results suggested that reductions in mineral intake will translate into proportional reductions in their excretion. The reduction of dietary Cu level by 66% and dietary Zn, Fe and Mn by 75% in grower-finisher diets (41 d of age to slaughter) had no effect on pig growth performance during this phase. Trace mineral fecal concentration was reduced by approximately 50% when the above reductions in dietary Cu, Zn, Fe, and Mn were done. When 50% of the trace minerals supplemented to the reduced mineral diets were included as chelated forms, Cu in feces tended to decrease, but Zn, Mn, and Fe fecal concentration remained similar to the pigs fed the reduced mineral diets formulated with inorganic mineral sources (Creech et al., 2004).

Also, the removal of the micro-mineral premix from finisher diets has been evaluated. The removal of the trace mineral premix from finishing diets 28 d prior to slaughter reduced fecal Ca, Cu, Fe, Mn, and Zn by 35 to 74% during the withdrawal period. The removal of trace mineral supplementation 28 d prior to slaughter did not have negative effects on pig growth performance, and carcass traits. However, pork mineral concentration was reduced. It also did not affect Cu/Zn superoxide dismutase or glutathione peroxidase activity in muscular tissue (Shaw et al., 2002). The absence of negative effects on growth performance is

in agreement with prior studies where the mineral premix was removed from the diet 30 days before slaughter (McGlone, 2000).

In other studies, the trace mineral premix has been totally removed over the whole growing-finishing period. The removal of the trace mineral premix during the whole period caused a reduction in pig growth. However, when phytase was added at 500 FYT/kg of the diet the negative effect on growth was not observed (Shelton et al., 2004; Shelton et al., 2005).

Increasing mineral availability

Some studies have indicated that the use of nontraditional organic mineral sources improve mineral availability in the diet. The increase in mineral availability can help to reduce mineral supplementation. The reduction of dietary mineral concentration may reduce mineral intake and excretion (Creech et al., 2004).

Others have proposed the addition of phytase to increase mineral availability in the diets. The hydrolysis of phytate and its phosphorylated derivatives result in the loss of the ability of phytate to chelate other minerals (Vats, 2005). Commonly, the utilization of microbial phytase in swine diets has been commonly evaluated to enhance P availability. However, phytase addition in swine diets can also increase the availability of Ca and Cu, and decrease excretion (Kornegay and Harper, 1997).

Monitoring emissions from swine production facilities

Management decisions within the swine industry are mainly driven by economic and regulatory factors. Emission of gases, such as ammonia and hydrogen sulfide, odor, and dust are pollutants from animal husbandry that could impact air quality (Ni et al., 2000). The public concern about the impact that swine production operations can have on air quality at the facility location and vicinity have reinforced the need of developing guidelines and regulations to reduce the risk of polluting the air.

Understanding gas emission as part of the production system is a key factor in the development of management strategies oriented to minimize the risk of polluting the air and reduction of environmental hazards. Swine manure is stored in the production buildings prior to being loaded into the treatment system. In commercial conditions, swine manure can be stored during short periods of time and diluted with water in shallow pit buildings or during longer time and without dilution in deep pit buildings. Manure stored within the building is the main source of gas released into the building and emitted into the environment (Ni et al., 2000).

It is also important to establish the difference between gas released and emitted. Gas release refers to the gas mobilization from the immediate surface of the liquid manure into the free air stream in the house (Ni et al., 2000). Gas emission refers to the process of mobilization of gas from the house into the outdoor atmosphere (Ni et al., 2000).

In 2006, the National Air Emission Monitoring Study (NAEMS) was established as part of a voluntary Compliance Agreement between the EPA and the pork industry. The objective of the NAEMS is to monitor emissions from swine facilities and collect emission data that can be used in the design of emission regulations. Additionally, the NAEMS may promote a national standard for emission monitoring methods (NAEMS, 2007). In agreement with the NAEMS objectives, the products of the Conference on Environmental Health Impacts of Concentrated Animal Feeding Operations, emphasized the need of monitoring emissions from concentrated swine feeding operations (Bunton et al., 2007).

Monitoring emissions from the facility require a cost effective selection of instruments to obtain an accurate measurement, in addition to a sampling design which included passive sampling, spot checking and laboratory testing for air quality. The results produced can be used to develop emission models that take into account the components in the air and concentration of the end products of their chemical transformation. Following the development of emission models, the models need to be validated through the comparison of the predicted values with direct measurements from monitoring systems. The data base generated from the monitoring systems, in addition to the prediction models developed, can serve as baseline emission used by regulatory agencies (Bunton et al., 2007).

Due to the limited scientific data available for gas emission from swine production systems is important to focus future research to produce data that can be used to select the best management practice to reduce the impact of swine

production on air quality in specific production conditions. This can be a time consuming complex task, mainly due to the need of controlling air sampling and equipment calibration.

Ammonia emission from swine housing

Ammonia released from swine facilities is produced from microbial and enzymatic degradation of nitrogenous compounds in swine waste, such as proteins and amino acids. Ammonia concentration in well-ventilated swine buildings normally ranges from 0 to 20 ppm. Although, ammonia in swine buildings usually does not exceed 40 ppm, ammonia in high concentrations is considered a noxious gas that can represent an environmental hazard for labor and pigs in intensive swine operations (Heber et al., 2000).

Ammonia volatilization starts with the degradation of urinary urea by fecal urease. Separation of urine and feces reduces ammonia release by 99% (Panetta et al., 2005). During storage, manure is exposed to urease activity. Therefore, storage time is an important factor in ammonia release from swine manure. In laboratory conditions, the rate of ammonia volatilization during the first 24 h of slurry storage represents the rapid conversion of urea to ammonia by urease. As storage time increases, ammonium concentration in the slurry increases, suggesting that the rate of ammonium production in the slurry is higher than the rate of formation of volatile compounds (Panetta et al., 2005).

Ammonia production results from a combination of ammonium concentration and slurry pH. Swine slurry pH is neutral to alkaline, with a high buffering

capacity (Panetta et al., 2005). Liquid swine manure has a high buffer capacity which is a function of the dynamic dissociation of bicarbonate and ammonium in solution (Sommer and Husted, 1995). Ammonia released at the manure surface is influenced by the dynamic changes in pH that take place as a function of carbon dioxide and ammonia release (Ni et al., 2000). In the initial stages of manure storage, slurry pH at the surface increases over time (Panetta et al., 2005) due to higher loss of carbon dioxide than loss of ammonia. The initial faster loss of carbon dioxide is explained by a lower solubility in relation with ammonia (Ni et al., 2005). Carbon dioxide losses increase slurry pH and ammonia losses decrease pH (Sommer and Husted, 1995). Therefore, in initial stages of liquid manure storage, ammonium concentration in slurry and pH increases close to 8 (Panetta et al., 2005). After this initial storage period, ammonia release increases and pH decreases falling back to neutrality (Sommer and Husted, 1995). Based on the relationship between pH and ammonia losses, liquid manure pH has been proposed as an indicator of free ammonia and ammonium partitioning in liquid manure (Ni et al., 2005).

In laboratory conditions, a reduction in slurry pH from 8.85 to 6.59 during 96 h of incubation (storage time) reduced ammonium concentration in slurry by 9% and ammonia release by 11%. The reduction of pH from 8.85 to 5.30 reduced slurry ammonium concentration by 21% and ammonia release by 23% (Panetta el al., 2005).

A review of 30 articles about mechanistic models of ammonia release suggests that ammonia release from swine manure is based on convective mass

transfer across the liquid-gaseous interface at the manure surface level. Ammonia convective mass transfer is a function of air velocity at the surface of the manure, and air and manure temperature (Ni, 1999).

Ammonia in the liquid phase of manure can exist in the forms of ammonium ions in solution and free ammonia gas. Ammonia dynamics in manure can be driven by the concentration gradient. Ammonium can be dissociated into ammonia and a hydrogen ion, and ammonia can bind with free hydrogen to form ammonium again. Through convective mass transfer, ammonia at the liquid manure surface is diffused into the air (Figure II.1). The diffusion of ammonia to the surface air is affected by ammonia concentration in the air, air flow rate, and air temperature (Ni, 1999).

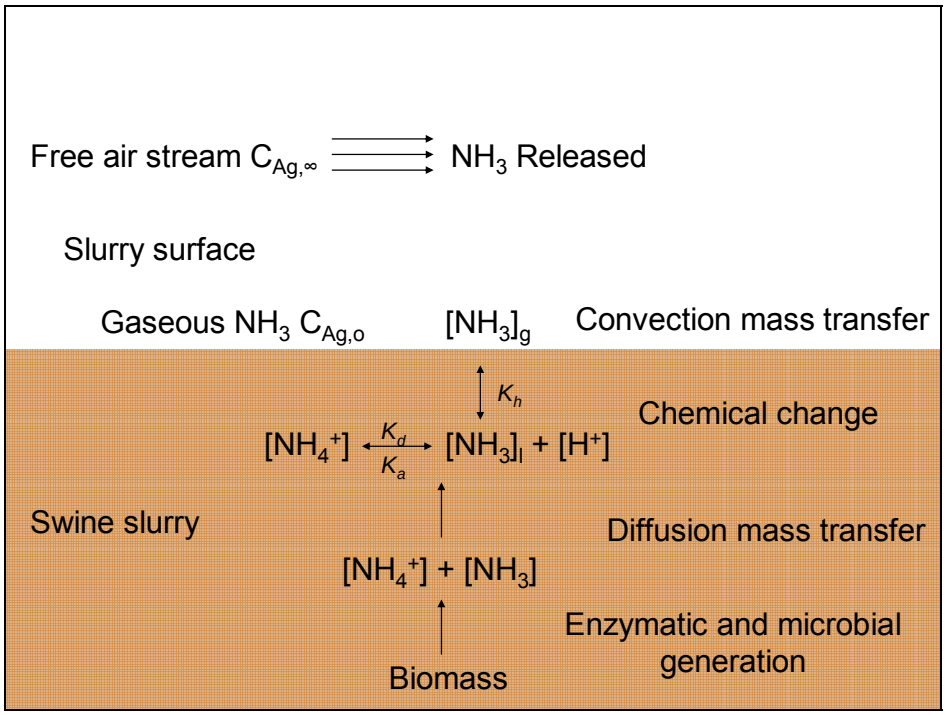


Figure II.1. Mechanism of ammonia formation and release from swine slurry (adapted from Ni, 1999). $[NH_3]_g$: free ammonia in gaseous phase at slurry surface; $[NH_3]_l$: free ammonia in liquid phase; $C_{Ag,o}$: mass concentration of free ammonia in gaseous phase at slurry surface; $C_{Ag,\infty}$: mass concentration of ammonia in free air stream; K_a: dissociation constant; K_b: dissociation constant; K_h: Henry's constant.

The free ammonium in gaseous phase at slurry surface is either expressed in mole concentration, $[NH_3]_g$, or in mass concentration, $C_{Ag,o}$.

In deep pit buildings, ammonia emission rates range from 5 to 130 g/d/AU (AU = 500 kg live weight), and 60% of the ammonia released and emitted comes from the manure stored in the pit. This has been tested measuring ammonia

release rates in empty buildings and comparing those release rates with those produced by the same buildings occupied at full capacity (Ni et al., 2000).

Temperature is an important factor affecting ammonia release from manure. The conversion of organic nitrogenous compounds in manure to ammonium is favored by warm temperatures. In laboratory conditions, ammonium concentration in swine slurry increased by 2.7 mg/m^3 or 0.06 g/L for every 1˚C increase in temperature over 35˚C. During storage, increased temperatures in manure and slurry increases ammonium concentration and ammonia volatilization. Ammonia volatilization decreases when ammonium concentration in slurry is reduced (Panetta et al., 2005).

In deep pit systems, when temperature at the headspace of the pit increases, the temperature of the surface manure also raises, accelerating ammonia release from manure, and with it, increasing ammonia concentration in the building. The increase in temperature by 6˚C (from 21 to 27˚C) at the headspace of the pit from an empty finisher building of 1,000 head capacity raised the ammonia release rate by 80% (from 93 to 167 g/h). This release rate (167 g/h) is equivalent to 66% of the release rate of ammonia from the same finisher building at full occupancy. The increase in ammonia concentration in the building occurred in less than ten minutes after the temperature was increased (Ni et al., 2000). Based on the previous reports, pit temperature control is a potential strategy to reduce ammonia release from swine manure and slurry.

Although ventilation systems are primarily designed to dissipate heat from swine housing, ventilation helps to remove ammonia from the buildings (Heber et al., 2000). For ammonia removal from the building, ventilation rate is an important factor. Ventilation provides an effective reduction in ammonia concentration at manure surface level by removing ammonia. Higher ventilation rates result in decreased ammonia concentration inside the buildings and increased emission rates from the buildings to the environment (Ni et al., 2000).

Disturbance of slurry by stirring modifies the slurry liquid-gas interface and increases slurry uniformity. The modifications induced in the slurry liquid-gas interface favored ammonium formation and volatilization (approximately by 5%) without causing depletion of the ammonium N pool (Panetta et al., 2005).

Management strategies to reduce ammonia emissions from swine buildings

It is well recognize the importance of reduced ammonia emissions from confined animal feeding operations as a contribution of a global strategy to minimize the negative effects of increased levels of reactive nitrogen in the atmosphere (Aneja et al., 2007). Therefore, different strategies have been proposed to reduce ammonia emissions from swine buildings, such as dietary manipulation (Canh et al., 1997) and the use of pit additives (Heber et al., 2000, Panetta et al., 2005).

Dietary manipulation to reduce ammonia emissions from swine buildings

Dietary manipulation has been proposed as an effective strategy to reduce simultaneously nitrogen excretion and ammonia emissions. The dietary manipulations evaluated include reductions in dietary CP with addition of crystalline amino acids (Canh et al., 1997; Velthof et al., 2005; Panetta et al., 2006), increases in dietary fiber (Canh et al., 1997), inclusion of acidifying salts (Velthof et al., 2005), and yucca extract (Panetta et al., 2006).

The reduction of dietary CP by 8% units with addition of crystalline amino acids decreased ammonia emission by 63% (Portejoie et al., 2004). Another report suggested a reduction in ammonia emission by 54% when dietary CP was reduced by 4% units (Velthof et al., 2005). These results are in agreement with a report that suggests that reductions in dietary CP by 0.4% unit to 3.1% unit results in a reduction of ammonia emission from 13 to 58% (Panetta et al., 2006).

The inclusion of acidifying salt (17% of $CaSO_4$) to an 18% CP grower diet reduced ammonia emission from manure by 8%. However, when the salt was added to a diet with a 4% units reduction in CP the ammonia emission from manure was not affected (Velthof et al., 2005). Additionally, in the same experiment, a 6% units increase in dietary concentration of dietary non starch polysaccharides (NSP) had no effect on ammonia emissions (Velthof et al., 2005).

Also, diet supplementation with yucca (*Yucca Shidigera Roezl ex Ortgies*) extract has been evaluated to reduce ammonia emissions from swine production. Two levels of yucca extract addition to a 17% CP grower diet were evaluated.

The two levels were 62.5 and 125 mg of yucca extract per kilogram of diet. After a four day adaptation period, ammonia emission was measured during 72 hours. The addition of yucca extract to grower diets did not affect ammonia and N concentration in manure, and ammonia emission (Panetta et al., 2006).

Use of pit additives to reduce ammonia emissions from swine buildings

Addition of yucca extract to the pit has been evaluated to reduce ammonia volatilization from swine waste. The addition of yucca to swine slurry in laboratory vessels decreased ammonia concentration in the headspace. Yucca acts as N binder reducing ammonia release without affecting ammonium concentration in the slurry (Panetta et al., 2005).

Monsanto EnviroChem (St. Louis, Mo.) developed a pit additive marketed as Alliance, composed of 24% water, 5% benzaldehyde, 9% neodol, 18% surfactants, 34% glyoxal, and 10% copper sulfate, with a pH 3.0. Alliance was developed to be applied into the pit in a dose of 300 to 350 ppm via spraying a 0.44% v/v solution at the pit headspace. This pit additive was tested in deep pit buildings, addition of alliance to the pit reduced ammonia emission by 24%. However, the application of Alliance to the pit added approximately 20% to the manure produce. Therefore, it is not clear if the reduction in ammonia emission is due to the additive by itself, or if the dilution of the manure could contribute to the reduction in ammonia emission. Also, Alliance mechanism of action is not very clear; it could be a reduction in microbial populations at the manure surface,

and/or a reduction in enzymatic activity for ammonia production (Heber et al., 2000).

Hydrogen sulfide emission from swine housing

Hydrogen sulfide is one of the gases emitted from swine facilities; it is produced during anaerobic fermentation of manure (Ni et al., 1999a; 1999b, 2002a and 2002b). It is considered the most dangerous gas among the manure fermentation products when it reaches acute concentrations (Ni et al., 2000). Therefore, an increment in concentration of hydrogen sulfide within a production building can be an environmental hazard for the labor. Release of hydrogen sulfide in swine houses has gained attention due to the potential to harm both pigs and human health. In humans, a concentration of 500 ppm of hydrogen sulfide in the air can cause dizziness, irritation of the respiratory tract, nausea and headache; and concentrations above 1000 ppm can cause respiratory paralysis and death (Field, 1980; cited by Ni et al., 1999a, 1999b, and 2002a).

Most available reports of hydrogen sulfide concentrations in swine housing have been produced from simple spot sampling sites and during a very short sampling period (Ni et al., 2002a). However, hydrogen sulfide concentration is often low in swine housing in relation with carbon dioxide and ammonia concentrations (Ni et al., 1999a, 1999b, 2002a and 2002b).

In deep pit systems, approximately 50% of the hydrogen sulfide is released from the manure stored in the pit (Ni et al., 2000). Hydrogen sulfide release and emission from swine housing is affected by all factors that can affect the

fermentation of manure, such as pig size, manure volume, composition, storage, temperature, disturbance, and air exchange (Ni et al., 2002a and 2002b).

Hydrogen sulfide emission is calculated by multiplying the airflow rate by the concentration of hydrogen sulfide in the air. Therefore, any factor that affects air flow or concentration will also affect the emission rate. Seasonal increment in temperature increases hydrogen sulfide release from manure, in addition to increasing building ventilation rate. The increase in hydrogen sulfide release, in addition to the increase in air flow, results in higher hydrogen sulfide emissions during the summer (Ni et al., 2000, Ni et al., 2002b).

An experiment was conducted to characterize hydrogen sulfide concentrations in mechanically-ventilated swine finisher buildings with deep pits during the summer time. The hydrogen sulfide concentration was measured continuously from March to September using multiple sampling sites in two finisher buildings of 1,000 head capacity. The average occupancy during the study was 700 head. The sampling sites were pit headspace (6 sampling points), pit fans (4 sampling points), and wall fans (5 sampling points). The average daily concentration of hydrogen sulfide in the buildings ranged from 180 to 232 ppb, and the daily mean concentration ranged from 18 to 1107 ppb (Ni et al., 2002a).

The highest hydrogen sulfide concentrations were observed when ventilation rates were low and the pigs were small (around 80 kg). In this case, the building ventilation was the main factor affecting the daily mean hydrogen sulfide concentration, and was also associated with diurnal changes in hydrogen sulfide

concentration. Also, the sampling location affected the hydrogen sulfide concentration measured (Ni et al., 1999a; 2002a).

Also, at the same time, hydrogen sulfide emission from the two buildings was measured during 4,544 sampling cycles. The building ventilation rate was calculated as the summation of air flow rates from pit fans and wall fans. The hydrogen sulfide emission during each sampling cycle was estimated as the product of the hydrogen sulfide concentration measured at the air sampling location multiplied by the summation of the flow rates at the different sampling sites. The mean hydrogen sulfide emission was 0.59 kg/day/building, 0.74 g/day/m^2 of pit surface, or 6.3 g/AU (AU = 500 kg of pig weight). However, the highest hydrogen sulfide emission rate (1.87 kg/day or 20 g/AU) was measured in association with the highest temperatures and building ventilation rates (Ni et al., 1999b; 2002b).

Based on the effects of the diurnal pattern, sampling location, temperature, and ventilation rate, it has been suggested that hydrogen sulfide concentration and emission rate from swine housing should be monitored using long term sampling periods and multiple sampling locations (Ni et al., 1999a, 1999b, 2002a and 2002b). In deep pit buildings, pig size has no effect on hydrogen sulfide concentration and emission, due to the large volume of manure stored in the pit, which minimizes the effect of fresh manure addition (Ni et al., 1999b and 2002b).

The dynamic of hydrogen sulfide release has not been well established. A burst release of hydrogen sulfide has been reported, as a unique behavior, with a duration that ranges from 2 to 6 hours (Ni et al., 1999b, 2000, and 2002b). The

burst release of hydrogen sulfide was defined as a sudden increase in hydrogen sulfide concentration over 100% of the concentration measured in the previous hour under relatively constant ventilation and temperature (Ni et al., 2000a and 2000b). The sudden increase in hydrogen sulfide concentration during the burst has been associated with the break up of gas bubbles at the surface of manure. Also, during manure disturbance, gas bubbles break up and hydrogen sulfide concentration increases. Based on these observations, hydrogen sulfide has been recognized to be concentrated in these gas bubbles (Ni et al., 2001).

During anaerobic fermentation of manure, hydrogen sulfide is produced and becomes part of the biogas complex dissolved in the liquid phase of manure. As hydrogen sulfide production increases, the liquid phase of manure becomes supersaturated with hydrogen sulfide, and micro-gas bubbles are formed. As hydrogen sulfide production progress the micro-gas bubbles start agglomerating and become bigger size bubbles with buoyant capacity to travel to manure surface. When these gas bubbles brake up at manure surface, the hydrogen sulfide is released, and the concentration rises suddenly. This mechanism has been proposed as the model of bubble release (Figure II.2, Ni et al., 2001).

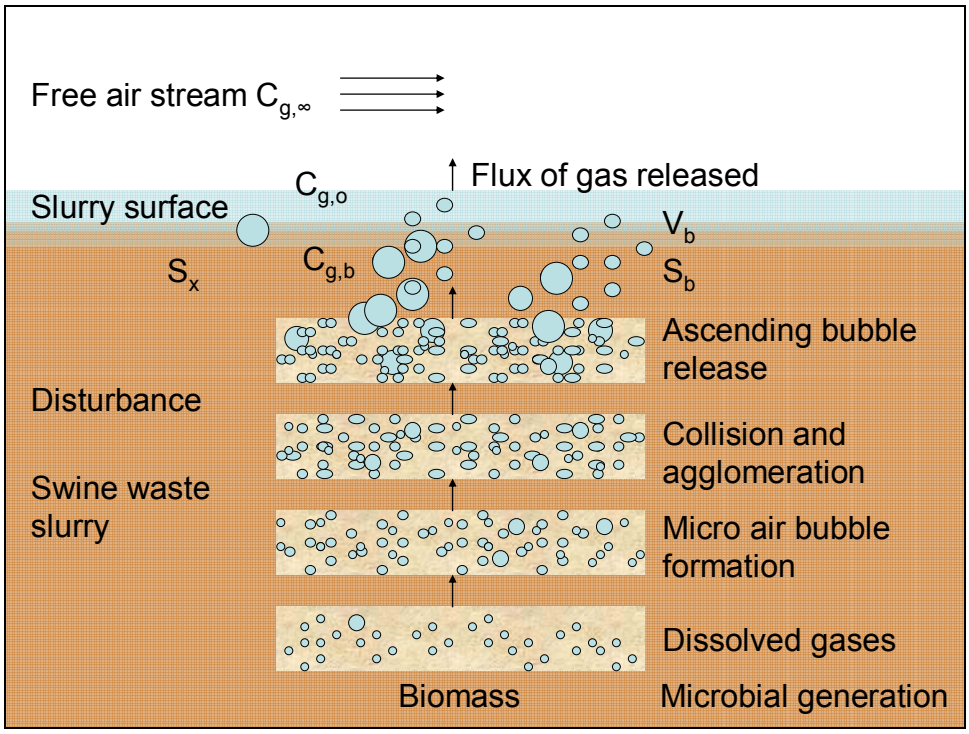


Figure II.2. Hydrogen sulfide model of bubble release (adapted from Ni et al., 2001). $C_{g,\infty}$: gas concentration in free air stream; $C_{g,o}$: gas concentration at slurry surface; $C_{g,b}$: gas concentration in bubbles; V_b: volume of bubbles; S_b: speed of ascending bubble movement; S_x: speed of bubble movement relative to liquid caused by slurry disturbance.

However, the burst in hydrogen sulfide release was initially detected in empty buildings with the deep pit only accounting for the hydrogen sulfide released from the stored manure (Ni et al., 1999b; 2000; 2002b). Taking into account that hydrogen sulfide release in an occupied building is expected to be higher; the burst in an occupied building may also be higher (Ni et al., 2000).

Dietary manipulation to reduce hydrogen sulfide emissions from swine buildings

Sulfur (S) concentration in grower diets has been evaluated to reduce hydrogen sulfide emission. Individually penned barrows have been used as model to study the effect of feeding grower pigs with diets containing 0.15, 0.24, and 0.34% of S on hydrogen sulfide emission. The reduction in dietary S by 0.09% unit below the NRC (1998) requirement did not change hydrogen sulfide emission. However, when dietary S increased by 0.1% unit hydrogen sulfide emission was increased (Clark et al., 2005).

Management practices to reduce hydrogen sulfide concentrations in swine buildings

Beside the evaluation of dietary manipulation to reduce hydrogen sulfide emission, research has been conducted to develop waste treatment strategies to reduce the release rate of toxic gases, such as hydrogen sulfide, in an effort to reduce environmental hazards for the labor force. Most of these studies have been conducted on a laboratory scale. Therefore, those management practices which reduced hydrogen sulfide concentration and/or emission rates at laboratory scale need to be tested in commercial conditions to confirm their effectiveness.

One of the management practices proposed to reduce increased concentrations of hydrogen sulfide inside the building is the use of low level air bubbling in manure storage. This strategy consisted of bubbling 5 to 10 ml of air per minute through stored swine manure slurry. This low level air bubbling in

manure will reduce the incidence of burst events and the amount of hydrogen sulfide released during slurry removal (Clark et al., 2005).

In commercial buildings with deep pits, fresh manure in continuously added to aged manure that is stored in the pit. A laboratory study was conducted to evaluate the effects of manure solid contents and initial manure age on the release of hydrogen sulfide. Manure from two different ages (1 and 4 weeks of accumulation) was collected from a commercial swine farm in Indiana. The manure collected was tested at two different concentrations, as collected and diluted with water to 50% the original concentration. The test was performed using laboratory reactors with at least 4 replications for each treatment. Manure was added 4 times during the test period, and hydrogen sulfide release rates were calculated by multiplying the gas concentration by the air flow rates. Hydrogen sulfide emission rates were affected by the interaction of initial age and manure concentration. When the initial age of manure was one week, the hydrogen sulfide released from undiluted manure was greater than the hydrogen sulfide released from the diluted manure (105 vs.98 μ/h). However, when manure was aged (initial age: four weeks), diluted manure released almost two times the hydrogen sulfide realized by the initially 4 weeks old concentrated manure (146 vs. 75 μ/h). Also, manure addition resulted in high peaks of hydrogen sulfide release (Ni et al., 2000).

Hydrogen sulfide removal from swine housing facilities is controlled by the house ventilation rate. The ventilation rate within any swine house is controlled by a ventilation system which operates based on controlling internal temperature

to a specific setting. Any factors that influence the external temperature, and therefore the rate of air flow from the room, will also affect the concentration of hydrogen sulfide inside the room (Ni et al., 1999a and 2002a). Critically high concentrations of hydrogen sulfide in swine buildings are associated with low ventilation rates (Ni et al., 2000).

During winter time, cooler slurry temperatures decrease the rate of anaerobic fermentation of the slurry; which decreases the rate of production of hydrogen sulfide. Also, during winter time, the ventilation of the rooms decreases and with it the removal of hydrogen sulfide from the rooms. The reduction in air flow results in the increase of hydrogen sulfide concentration in the room (Ni et al., 19991 and 2002a).

Effect of manure removal on gas emissions

Concentration of ammonia and hydrogen sulfide within the production buildings can represent hazardous condition for the labor force and pigs, and also deteriorate equipment and building infrastructure. Therefore, in order to reduce the negative impact of gas accumulation, especially accumulation of hydrogen sulfide and ammonia in buildings with shallow pit systems, an increase in the flushing frequency has been proposed (Lim et al., 2004).

Flushing frequency in shallow pits has been studied in combination with recharge using tap water or second lagoon recycle water. The flushing strategies characterized included daily flush and 7, 14 and 42 days of static pit. The study was conducted using growing-finishing pigs (80 to 114 kg) fed a

conventional corn-soybean meal diet. Flushing and static pit recharge with lagoon effluent resulted in lower ammonia and hydrogen sulfide emissions than tap water recharge pits. Also, higher pit flushing frequency reduced ammonia and hydrogen sulfide emissions (Table II.1, Lim et al., 2004).

Daily flushing of the pit reduced ammonia emission by 45 and 42%, respectively, in relation with 7 and 14 day flushing frequencies. Pit recharge reduced ammonia emission by 51 to 62% in relation with 7 and 14 day flushing frequencies. Pit recharge with recycled water every 7 day decreased hydrogen sulfide emission up to 40%. However, increased frequency of removal of manure increased burst emissions during the flushing time. Daily flushing of pit recharged with secondary lagoon recycle water produced hydrogen sulfide burst emissions from 7,171 up to 28,235 μg/m^3 (Lim et al., 2004).

Table II.1. Ammonia and hydrogen sulfide emission rates from finisher buildings with shallow pits with different flushing frequencies and recharge water.

Flushing frequency, d	1	7	14	7	14	42
Recharge water	none	none	none	Recycle	Recycle	Recycle
Measurement period, d	42	42	82	4	11	36
NH_3 emission rate, g/d	59	109	103	43	54	56
NH_3 emission rate, g/d/AU	15	27	25	10	12	11
H_2S emission rate, g/d	1.8	1.1	1.8	0.7	1.5	7.4
H_2S emission rate, g/d/AU	0.40	0.27	0.41	0.16	0.34	1.42

AU = 500 kg of live pig mass
From: Lim et al., 2004

Mass balance approach

The mass balance approach has been used to provide a comprehensive description of the origin and fate of nutrients in association with a given system.

The use of mass balance estimation requires an accurate identification of all system components, inputs and outputs (Eigenberg et al., 1998).

The mass balance approach has been used to track nutrients, such as N and P, from feedlot cattle operations and describe those nutrient losses (Eigenberg et al., 1998). Also, mass balance has been implemented in manure handling, treatment practice evaluation (Larney et al., 2006), and land application (Maguire et al., 2007). Estimation of nutrient mass balance in a system requires the estimation of nutrient mass, in all sources of nutrients entering, and exiting the system (Larney et al., 2006, Maguire et al., 2007).

Also, mass balance has been implemented as the basis of development of computer software tools in comprehensive nutrient management planning. The software tools are developed to support the selection of the best management practices to be implemented in specific production conditions (Chen et al., 2003, Henry et al., 2003). These software summarized information from regional, national or global simulators for nutrient management. Although, the computer software tools can be helpful for decision makers, the selection process can be limited to their use. A selection process based only on the use of a software tool can lead to misleading conclusion due to the heterogeneity of the production systems (Redding et al., 2007).

Limitations in excretion and emission data

The evaluation of nutrient excretion, gaseous emissions and nutrient flow in the finisher system are indispensables to identify appropriate strategies to reduce

nutrient wastage, ammonia, and hydrogen sulfide emissions from commercial facilities. The available excretion data are limited and have been mostly produced from balance studies, with individually-fed pigs, housed in metabolism crates, using the total fecal and urine collection methods (Kerr and Easter, 1995; Cant et al., 1997; Cant et al., 1998a; Zervas and Zijlstra, 2002a; Zervas and Zijlstra, 2002b; Otto et al., 2003; Potejoie et al., 2004; Panetta et al., 2005; Powers et al., 2006; Deng et al., 2007; Htoo et al., 2007). Another small portion of data have been produced with pigs housed in groups of 2 to 4 pigs per pen, using external markers and fecal grab samples to estimate fecal nutrient concentration (Qian et al., 1996; Harper et al., 1997; Creech et al., 2004; Figueroa-Velasco et al., 2004; Panetta et al., 2006).

Evaluation of reduced nutrient diets have produced controversial results. At the present time, the extent to which the dietary protein level can be reduced with group-fed pigs is still unclear. Also, the effects of reductions in dietary mineral supplementation, with phytase addition, and the inclusion of mineral chelates and proteinates on nutrient excretion are important subjects for future research.

Monitoring ammonia and hydrogen sulphide emission from production systems is a key factor in the development of management strategies to reduce these emissions. However, most of the data available have been produced from deep pit buildings (Heber et al., 2000; Ni et al., 2000; Ni et al., 2002a, Ni et al., 2002b). The shallow pit system is predominant in the High Planes area; however, the data available to model ammonia and hydrogen sulfide emission is very limited. Also, most of the data which have evaluated emissions from swine

slurry have been conducted on a laboratory scale (Ni et al., 1999a; Ni et al., 2000; Predicala and Maghirang, 2004; Panetta et al., 2005; Clark et al., 2005).

The implementation of production strategies which have been tested only on a very small scale or in laboratory conditions is not acceptable. In the actual conditions, it is required to concentrate efforts in the production of nutrient excretion and emission data from group-fed pigs. Pigs should be housed in a setting that allows the collection of representative waste samples. In more ideal conditions, data should be produced evaluating simultaneously nutrient excretion and gaseous emission for long periods of time. Based on the limitations identified in the available literature and the need to produce excretion and emission data from group-housed pigs, we initiated a series of three experiments which will be described in detail in Chapters III to VII.

CHAPTER III

GENERAL EXPERIMAENTAL PROCEDURES

A series of three experiments was conducted with the objectives of evaluating the effects of dietary manipulation on nutrient excretion from growing-finishing pigs, to estimate baseline nutrient excretion during the finishing period, and to study nutrient flow through the growing-finishing phase. Experiments 1 and 2 were conducted with the objectives of determining the effects of reducing dietary protein and P on pig growth performance, nutrient excretion, carcass characteristics and bone strength and to establish baseline excretion for DM, N and P. Experiment 1 was conducted to evaluate the effects of reducing dietary crude protein by 2% units and P by 0.1% in contrast to a traditional fortified corn-soybean meal diet, and Experiment 2 was conducted similar to Experiment 1 with the exception that the diet evaluated had a reduction in dietary protein of 4% units. Experiment 3 was designed to evaluate the effects of reducing dietary CP by 3% units, P by 0.1% unit, with addition of phytase, and sequential reduction in trace mineral supplementation from 50 to 100%, over 4 dietary phases. Additionally in Experiment 3, the mass balance approach was used to evaluate nutrient flow through a finisher facility expressed on a finished pig basis. Crystalline amino acids were added to all reduced protein diets on a true ileal

digestible basis. A more detailed description of the experimental units, diets, and statistical analysis, are found in the Material and Methods section of the individual chapter, dedicated to each experiment.

Animal housing

All procedures were approved by the OSU Institutional Animal Care and Use Committee. The pigs were housed in an environmentally-controlled building. The building had four identical rooms. Each room was equipped with identical electronic ventilation and temperature controls (Figure III.1.B), a shallow pit, and pull plug system (Figure III.1.C). Temperature was controlled and humidity was monitored to confirm standard conditions in all rooms. Each room measured 5.5 m x 4.5 m. The room was divided in a 0.6 m x 5.5 m corridor and a pen area of 2 m x 5.5 m on each side of the corridor. In Experiments 1 and 2, the pen area at each side of the corridor was divided in three pens of similar size (2 m x 1.8 m). Thus, each room had a total of 6 pens, with 2 pigs per pen, and a pig space of 1.8 m^2. Each pen was equipped with a two hole feeder and a water nipple. In Experiment 3, the pen area on each side of the corridor was not divided, thus each room had two pens of 2 m x 5.5 m. In the pen on the north side of each room 10 barrows were allocated, and 9 gilts in the south pen, with a pig space of 1.1 m^2.

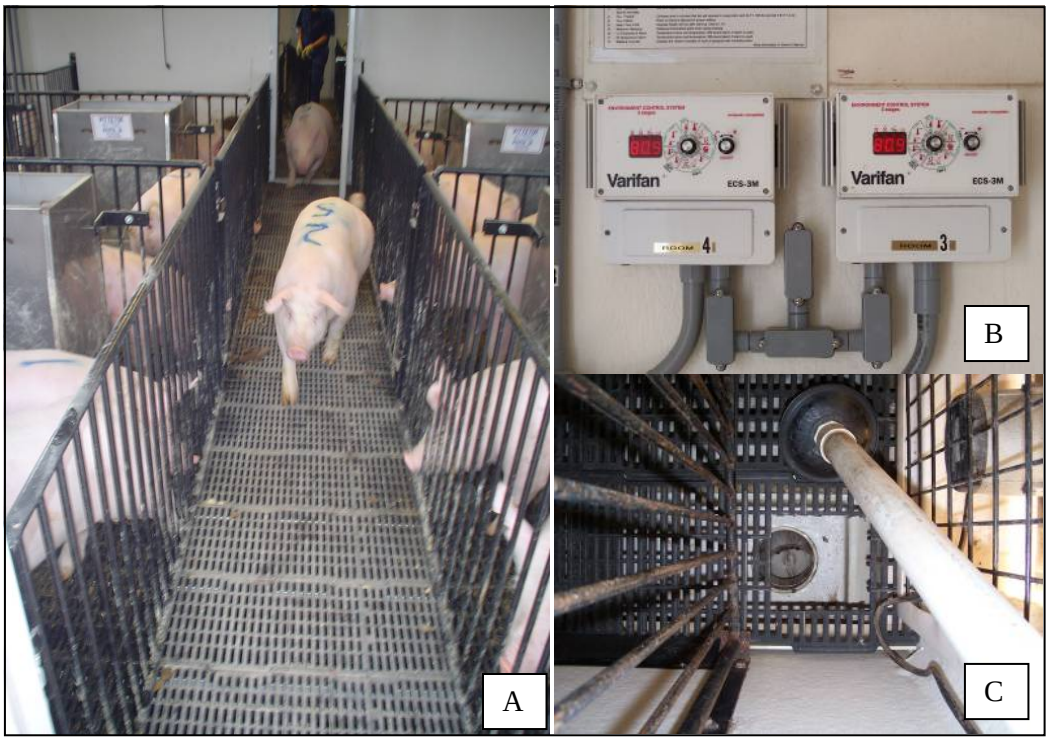


Figure III.1. Pig housing: A) Internal view of one room within the environmentally controlled building. B) Individual temperature setting panel of rooms 3 and 4. C) Close up of the pull plug system in each room.

Pig growth performance

Individual pig weights and pen feed consumption were measured weekly. Pigs were moved from pens and transferred to a scale, where animals were weighed and housed in holding pens until the slurry sampling was completed.

At the beginning of each week, the feed in each feeder was weighed, and returned to the feeder, with additional feed added as needed during the week to guarantee ad libitum consumption. At the end of the week, the remaining feed in the feeder was weighed; thus, the weekly feed intake was determined. Each week, at the time that feed was added or removed from the feeder, a feed sample was taken in order to collect diet samples representative of the feed

consumed each week. The samples were submitted to the laboratory for DM, N, P, C, Ca, K, Mg, Na, Fe, Zn, Cu, and Mn analysis.

Pigs had free access to water and water intake was monitored by room via an individual water meter installed in the tap water line. The water meters measured water disappearance from each room per week. Water samples were collected and submitted to the Soil, Water and Forage Analytical Laboratory (SWFAL), at Oklahoma State University, for determination of the mineral background. The weekly measurements of water intake in addition to the mineral concentration in water were used to estimate the contribution of water to mineral intake.

Pig weight and feed intake was used to calculate average body weight (BW), average daily gain (ADG), average daily feed intake (ADFI), and gain to feed ratio (G:F). Weekly measurements of feed and water intake, analyzed diet nutrient concentration, and water mineral concentration were used to estimate nutrient intake by week.

Pit content measurements

At the beginning of each week during the entire finishing period, pits were filled with equivalent amounts of water, and the volume of the pit contents was measured in each room. Prior to sampling, all remaining manure on the floor was scraped into the pit (Figure III.2A). At the same time, a submergible pump was placed inside the pit drainage channel (Figure III.2B), approximately 70 cm from the drain plug. The pump was connected to a polyethylene hose, long enough to reach all the corners of each room. After the pump was placed into

the pit and the end of the hose in the opposite corner, the pump was used to mix the slurry for 20 min. While the slurry was flowing through the hose, the slurry was used to rinse the floor slats, to ensure that all remaining material was washed into the pit. In addition, the bottom of the pit was scraped to ensure complete mixing. After 20 min mixing, the drain plug was pulled and a continuous sample was collected as the slurry was exiting the building. The slurry sample was collected in a 20 L container, and a mixer was placed inside the container to homogenize the slurry (Figure III.2C). At this time, pH was measured using a portable pH meter (Accumet AP62, Fisher Scientific), and EC and temperature were measured using a portable conductivity meter (YSI 30 Conductivity/Salinity Meter, YSI Incorporated).

After these measurements, a suction pump was used to transfer the sample to three 500 ml bottles (Figure III.2C). One slurry bottle was stored as is, and the remaining two were acidified to a pH between 2 and 3. The slurry samples were transported to the laboratory for DM, N, P, C, Ca, K, Mg, Na, Fe, Zn, Cu, and Mn analysis.

Figure III.2. Pit content sampling: A) Scraping manure on the floor and adding into the pit, B) Mixing pit content with the aid of a recycling submergible pump, C) Homogenizing slurry sample, D) Transferring slurry samples to 500 ml bottles.

Feed and slurry analyses

Feed and slurry samples were analyzed weekly for DM, N, and P. Feed samples were ground through a 1 mm screen using a Willey Mill (Standard Model 3; Arthur H. Thomas Co., Philadelphia, PA). Dry matter and P content of feed and slurry was determined using a gravimetric method. Dry matter was

determined 2.5g of sample required for the quinolinium molybdophosphate method (AOAC, 1998) placed in quartz crucibles, and then dried at 100^{o}C for 24 h. After removal from the oven, feed samples were placed into a dissecator and allowed to stabilize at room temperature before being weighed (AOAC, 1998). Following weighing, P determination was started using the dry samples from the DM determination and the quinolinium molybdophosphate method (AOAC, 1998).

The non-acidified slurry samples were immediately analyzed for DM and P analysis using similar procedures as the feed samples with the following modifications. Slurry sample was agitated and immediately a 5 mL aliquot was transferred to a quartz crucible. The slurry aliquot was weighed (range 5 to 6 g) and from this point DM and P procedures were performed without further modifications.

Nitrogen concentration of feed and slurry was determined by the automated Kjeldahl procedure (AOAC, 1998) using a FOSS Tecator 2020 Digestor and a FOSS Tecator 2400 Kjeltec Analyzer (FOSS Tecator, Hoganas, Sweden). For N concentration determination in the feed, the sample digestion procedure was modified by weighing 0.5 g of feed, placed into a Kjeldahl digestion tube, and adding only one tablet of digestion catalyzer (3.5 g K_2SO_4 + 0.35 g Se, Fisher tab ST-35, Kjeldahl tablets). For slurry N concentration determination, the acidified slurry samples were used. The acidified slurry sample was agitated; then a 5 mL aliquot was immediately transferred to a Kjeldahl digestion tube, and one tablet of digestion catalyzer was added. From this point, the Kjeldahl procedure was

performed without modifications. All DM, N, and P analysis were performed in duplicate for both feed and slurry samples.

Using the feed samples collected each week, a representative composite feed sample was prepared for each feeding phase of the two diets. A total of 6 composite samples (2 diets x 3 dietary phases) were prepared for Experiments 1 and 2, and a total of 8 composite samples were prepared (2 diets x 4 dietary phases) for Experiment 3. The composite feed samples and duplicate slurry samples were transferred to the Soil, Water and Forage Analytical Laboratory at Oklahoma State University, where samples were analyzed for DM, and N by LECO, and P, C, Ca, K, Mg, Na, Fe, Zn, Cu, and Mn by digestion with concentrated nitric acid and hydrogen peroxide and analyzed by inductively coupled plasma (ICP) emission spectroscopy. Additionally, slurry samples were analyzed for NH_4-N (AOAC, 1998) and water soluble P (WSP) (AOAC, 1998).

Nutrient excretion

The weekly pit volume measurements and the nutrient concentration in slurry for each week were used to calculate nutrient excretion. It is important to note that not all nutrients contained in the slurry were from fecal or urinary contribution. Slurry nutrient concentration also accounted for the nutrient contribution via feed and water wastage. The determined nutrient excretion values were expressed on a per pig per day basis, as a percentage of intake, and on a per finished pig basis.

Nutrient excretion was produced by the following equation: Nutrient excretion, g = slurry volume, L x slurry [nutrient], g/L. Weekly values over 16 weeks were added together and then divided by the numbers of pigs in the room, to estimate cumulative excretion on a per finished pig basis. To express nutrient excretion on a per pig per day basis, the cumulative excretion per finished pig was divided by the duration of the finishing period in days. Finally, to express nutrient excretion as percentage of the intake, nutrient intake was estimated using daily feed intake and the nutrient concentration in feed. The amount of nutrient recovered in the slurry was expressed as a percentage in relation with nutrient intake.

Carcass evaluation

At a target weight (Exp. 1 and 2, 108 kg; Exp.3, 118 kg), pigs were identified by tattoo and transported to a commercial processing plant. Pigs were slaughtered, scalded, scraped, eviscerated, and hot carcass weight (HCW) was recorded. Carcasses were allowed to chill for at least 16 h prior to evaluation. All measurements were taken using direct measurements on the chilled carcass. Carcasses were separated down the midline and backfat depth was measured at the 1st, 10th, last rib, and last lumbar vertebra. On the right side, carcasses were ribbed between the 10th and the 11th rib to measure loin muscle area (LMA) and fat depth. The LMA was traced, and the muscle area determined from the tracing. The traced muscle area was measured with the aid of a Kurta XLP 1212, board and pen (Mutoh America Inc. Kurta XLP 1212 (oard and pen). 3007

East Chamers, Phoenix, Arizona). The Kurta XLP 1212 was connected to a PC where the software (Ribeje-v 2.0, Critical Vision Inc. Rieje v. 2.0 software. Atlanta, Georgia) was installed. The muscle area was transferred to the PC and measured with the Ribeje v 2.0 software. The fat depth over the loin was measured directly over the loin at a point ¾ of the distance from the midline. The standard fat-free lean (SFFL) was estimated using the standard procedure for ribbed carcasses described by Burson (2001), using the following equation: SFFL, lb = 8.588 + (0.465 x HCW, lb) – (21.896 x 10^{th} rib fat depth, mm) + (3.005 x 10^{th} rib loin muscle area, sq. inches) (NPPC, 2001).

Bone strength determination

In the Experiment 1 and 3, the front feet were removed from the carcass. In Experiment 2, the front and back feet were removed from the carcass. All feet were stored frozen (-20^{o}C). At a later date, the feet were allowed to thaw. Each pair of front feet were placed in a disposable aluminum pan and placed in an autoclave in batches of 6 pairs per run (Figure III.3A and B). The autoclave was set to operate at a pressure of 250 psi, and the feet were cooked using the gravity cycle set to 1 min conditioning time, followed by 7 min sterilizing time, and a 10 min drying time. The sterilizing temperature was set to 121^{o}C, with a maximum temperature of 122^{o}C and a minimum temperature of 120^{o}C. When the cycle was over, the feet were removed. After autoclave the metacarpals (MC) were manually removed cleaned of exogenous tissue (Figure III.3C), and stored at -20^{o}C. A similar procedure was followed with the back feet to remove

metatarsals (MT). The day before breaking the bones, the MC and MT were removed from the freezer and allowed to thaw overnight. Bone breaking strength analysis was conducted using an Instron testing instrument (Model 4502, Instron Corporation) equipped with a 10 kg load cell (Figure III.3D). For the metacarpals, the high extension limit was set to 25 mm and for metatarsals at 45 mm. Bone breaking strength was measured in kg of force necessary to fracture the bone.

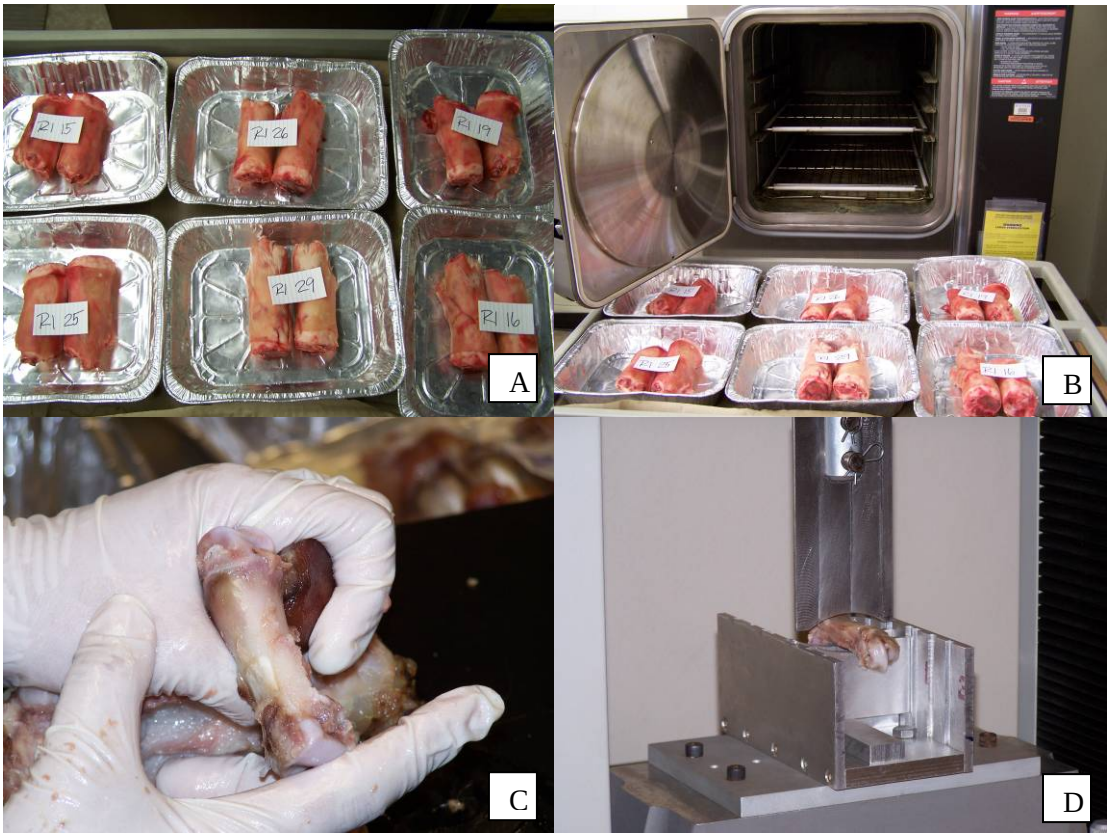


Figure III.3. Bone strength measurement: A) One batch of front feet, B) Batch of feet ready to be placed into the autoclave, C) Metacarpals removed after cooking the feet, D) Metacarpals placed in the base of the Instron instrument.

Statistical analysis

The data were analyzed as a Randomized Complete Block design. The model included the effects of block, dietary treatment, and the interaction block by dietary treatment served as the experimental error. The room served as experimental unit. Orthogonal contrasts were performed to compare the response to the dietary treatments.

CHAPTER IV

EXPERIMENT 1

EFFECT OF REDUCING DIETARY CRUDE PROTEIN BY 2% UNITS AND PHOSPHORUS BY 0.1% UNIT ON NUTRIENT EXCRETION OF PIGS DURING THE ENTIRE GROWING-FINISHING PERIOD

Abstracts

A total of 48 Yorkshire barrows (34.5 kg BW) was used to determine the effect of reducing dietary CP and P on DM, N, and P excretion during the finishing period. Pigs were blocked by BW and allotted randomly to two dietary treatments. Pigs were housed in 4 identical rooms (12 pigs/room, 2 rooms/trt) in an environmentally-controlled building, with a shallow pit, pull-plug system. The control was a fortified corn-soybean meal-based diet (18, 16, and 14% CP; 0.50, 0.45, and 0.40% P for Phases 1, 2, and 3, respectively). The experimental diet was a low nutrient excretion (LNE) diet similar to the control with the exception that CP was reduced by 2% units, P by 0.1% units, and Lys HCl was added. Diets were formulated on a true digestible Lys basis (0.84, 0.71, and 0.57%). Pig weight, feed intake, pit volume, and pH were recorded weekly. Feed and slurry samples were collected for DM, N, P, Ca, K, Mg, Na, S, Fe, Zn, Cu, and Mn analysis. Slurry DM, pH, and NH_4-N concentration were not affected ($P > 0.10$)

by treatment. However, slurry N concentration tended to decrease ($P < 0.10$) and P concentration decreased ($P< 0.01$) when pigs were fed LNE. Final weight, F:G, and finishing period duration were similar ($P > 0.10$) with both diets. Also, hot carcass weight, backfat, longissimus muscle area, carcass yield, and fat-free lean percentage were similar for both treatments. Daily DM intake was not affected ($P > 0.10$) by diet. However, daily N, P, Ca, k, Fe, and Mn intake tended ($P < 0.15$) to decrease for pigs fed the LNE diet. The daily intake of the other minerals measured was similar ($P > 0.10$) for both diets. Daily DM excreted was similar ($P > 0.10$) for both treatments. However, N, NH_4-N, and P excretion decreased ($P < 0.05$) for pigs fed LNE. Daily mineral excretion was not affected by the dietary treatment ($P > 0.01$), with the exception of Mg excretion, which was reduced ($P < 0.01$) with LNE. Daily DM and P excretion, as a percentage of intake, were similar ($P > 0.10$), but N excretion tended to decrease ($P < 0.10$) for pigs fed LNE. Mineral excretion, as percentage of intake, were not affected ($P > 0.10$) by the dietary treatment. However, cumulative N and P excreted during the finishing period was similar ($P > 0.10$) for both diets. The LNE diet reduced daily N and P excretion by 20% and 24%, respectively. However, cumulative N and P excretion was not affect by feeding LNE, and had very little effect on mineral excretion during the finishing period.

Introduction

In commercial operations, it has become a challenge to develop comprehensive nutrient management plans that take into account nutrient

excretion and wastage. In the past, swine diets were formulated to maximize pig performance without regards for nutrient excretion. In the future, swine diets will need to be formulated to reduce nutrient excretion without negative effects on pig growth performance.

Estimated values of nutrient excretion have been summarized by Kornegay and Harper (1997) who indicated that growing-finishing pigs fed traditional corn-soybean meal diets commonly excrete 45 to 60% of the N consumed, 50 and 80% of the Ca and P, and 70 to 95% of K, Na, Mg, Cu, Zn, Mn, and Fe (Kornegay and Harper, 1997).

Approximately 80% of the feed that a finished pig consumes is consumed during the growing and finishing phases. Therefore, special attention needs to be placed on nutrients excreted during these phases. The dietary manipulation approach to reduce nutrient excretion in finishing pigs will include avoiding or reducing over-feeding of nutrients (Kornegay and Harper, 1997; Sutton and Richert, 2004). Dietary manipulation is a practical and feasible approach to reduce nutrient excretion, especially during growing-finishing.

In growing and finishing phases, opportunities exist to reduce N excretion through the reduction of dietary protein levels and balancing diets with addition of crystalline AA (Sutton and Richert, 2004). Also, dietary P concentration can be reduced below NRC requirements when supplemental phytase is added to the diets (Cromwell et al., 1995; Qian et al., 1996; Harper el al., 1997; Liu et al., 1998).

However, most of the information available regarding nutrient excretion has been produced using individually-fed growing and finishing pigs. Based on the limited information available, an experiment was conducted with the objective to determine the effect of reducing dietary CP by 2% units and P by 0.1% unit on pig growth performance, carcass traits, bone strength, slurry characteristics and nutrient excretion during the entire finishing period.

Materials and methods

Pig allotment

A group of 48 Yorkshire barrows with an initial average body weight of 34.5 kg were allotted to one of two dietary treatments in a randomized complete block design with initial weight as the blocking criterion (with post-allotment assessment to stratify ancestry). Two blocks were used, with one experimental unit per treatment within each block. The experimental unit was a room with 6 pens and 2 pigs per pen. The room was previously described in Chapter III.

Dietary treatments

The two dietary treatments evaluated were a conventional corn and soybean meal diet, fortified with vitamins and minerals, used as the control diet (Control), and a low nutrient excretion diet (LNE). The control diet was formulated to be fed in 3 dietary phases (18, 16, and 14% CP; 0.50, 0.45, and 0.40% P, Phases 1 to 3, respectively). The LNE diet was similar to the control, with the exceptions that

CP was reduced by 2% units, crystalline amino acids were added on an ideal basis, and P was reduced by 0.1%. The reduction in dietary CP was achieved by the reduction in the inclusion of soybean meal. Both diets were formulated on a true digestible Lys (0.84, 0.71, 0.57%, Phases 1 to 3 respectively). The true digestible Thr:Lys ratio was 63:100 in Phase 1, and 65:100 in phases 2 and 3; true digestible Met:Lys ratio was 27:100 in all Phases; and true digestible Trp:Lys ratio was 18:100 in Phases 1 and 2, and 19:100 in Phase 3. The reduction in dietary P was achieved by reducing the inclusion of dicalcium phosphate. Also, limestone inclusion was diminished to maintain a Ca:tP ratio of 1.2:1. Diet formulation and calculated composition are presented in Table IV.1.

Other procedures

The methodology employed to evaluate pig growth performance, pit content, feed and slurry analysis, nutrient excretion, carcass evaluation, bone strength and statistical analysis, was previously described as general experimental procedures, in Chapter III.

Results

Analyzed crude protein and phosphorus composition of the diets.

Dietary CP and P concentration in all diets were analyzed. Note that in all diets the expected and analyzed CP and P values were similar. It is also important to note that the reduction in dietary CP by 2% units in the LNE diet was

achieved in all dietary phases (Table IV.1). This was also true for the reduction in dietary P by 0.1% unit in the LNE diet (Table IV.1).

Growth performance and nutrient intake

All the results are reported on a per pig basis. The initial weight of all pigs was 34.5 kg ($P > 0.10$) and they were fed to a target weight of 108 kg ($P > 0.10$, Table IV.2). The reduction in dietary CP by 2% units and P by 0.1% unit did not affect ($P > 0.10$) the duration of the finishing period, ADG, ADFI, and F:G ratio when pigs were fed the LNE diet (Table IV.2). Also, the reduction in CP by 2% units and P by 0.1% unit did not affect ($P > 0.10$) daily intake of DM, C, N, Ca, K, Mg, Na, Fe, Zn, Cu and Mn (Table IV.2). However, the 0.1% unit reduction in dietary P tended ($P < 0.10$) to reduce P intake (Table IV.2).

Carcass characteristics and bone breaking strength

The hot carcass weight, carcass yield, and backfat depth at the 10^{th} rib were similar ($P > 0.10$) for both diets (Table IV.3). Also, the longissimus muscle area, carcass yield, fat-free lean percentage, and metacarpal breaking strength were not affected ($P > 0.10$) by dietary treatment (Table IV.3).

Slurry characteristics

Slurry volume, temperature (Figure IV.1), EC (Figure IV.2), pH (Figure IV.3), and nutrient concentrations (Figures IV.4 to 7), measured on a weekly basis was summarized and used to calculate average values for the entire finishing period.

Note that nutrient concentrations in slurry increased over time as pigs grew (Figures IV.4 to 7). Slurry volume, temperature, EC, and pH (Table IV.4) was similar ($P > 0.10$) for both dietary treatments. Also, slurry concentration of DM, NH_4-N, Ca, K, Mg, Na, Zn, and Mn were not affected ($P > 0.10$) by dietary treatment (Table IV.5). However, N concentration in the slurry tended to be reduced ($P < 0.10$) by 15% when pigs were fed the LNE diet (Table IV.5). Also, Fe and Cu concentration in slurry tended to be reduced ($P < 0.10$) by feeding LNE (Table IV.5). Additionally, the C:N ratio ($P < 0.11$) tended to increase in the slurry from pigs fed the LNE diet (Table IV.5). The reduction in dietary P by 0.1% unit tended to reduce ($P < 0.10$) slurry P concentration by 21% (Table IV.5).

Nutrient excretion

Excretion results are presented on a per pig basis. Daily DM, C, Ca, K, Fe, Zn, and Mn excretion were not affected ($P > 0.10$) by dietary treatment (Table IV.6). However, when pigs were fed the LNE diet, daily N, NH_4-N, P ($P < 0.05$), and Mg ($P < 0.01$) excretion decreased. When daily excretion was expressed as percentage of the intake, N excretion tended to decrease ($P < 0.10$). However, the excretion of other nutrients was not affected ($P > 0.10$) by treatment (Table IV.6). Cumulative N and P excretion were not affected ($P > 0.10$) by diet (Table IV.6). However, taking into account the importance of reducing cumulative excretion, the numerical differences obtained in cumulative N and P excretion should be considered.

Summary

In summary, a 2% units reduction in dietary CP, in addition to a 0.1% unit reduction in P in grower-finisher diets decreased daily N excretion by 21%, ammonium N in waste by 29%, and daily P excretion by 24%; without negative effects on pig growth performance and carcass characteristics.

Implications

The reduction of N and P intake though dietary manipulation in growing-finishing pigs is a feasible strategy to reduce daily and cumulative N and P excretion without detrimental effects on pig growth performance for the entire finishing period. Also, the reduction in N concentration in the manure produced during the finishing phase can be an important contribution to reduce the amount of N lost as ammonia.

Table IV.1. Composition of experimental diets, as-fed basis (Exp. 1).

Dietary phase	1 (35-56 kg)		2 (56-87 kg)		3 (87-108 kg)	
Ingredient, %	Control	LNE	Control	LNE	Control	LNE
Corn	68.98	74.77	74.44	80.28	83.37	89.11
Soybean meal, 48%	25.84	20.24	20.68	15.04	14.91	9.33
L-Lysine		0.17		0.18		0.17
L-Theonine		0.03		0.03		0.01
L-Tryptophan						0.01
Soybean oil	3.00	3.00	3.00	3.00		
Dicalcium phosphate	0.68	0.26	0.52	0.11	0.33	
Limestone	0.95	0.98	0.82	0.81	0.84	0.82
Salt	0.25	0.25	0.25	0.25	0.25	0.25
Vitamin mix[a]	0.15	0.15	0.15	0.15	0.15	0.15
Trace mineral mix[b]	0.10	0.10	0.10	0.10	0.10	0.10
Antibiotic[c]	0.05	0.05	0.05	0.05	0.05	0.05
Calculated values:						
ME, kcal/kg	3484	3490	3497	3502	3355	3359
CP, %	18.00	16.00	16.00	14.00	14.00	12.00
Total lysine, %	0.96	0.94	0.82	0.80	0.67	0.65
True dig. lysine, %	0.84	0.84	0.71	0.71	0.57	0.57
True Thr:Lys	63	63	65	65	65	65
True Met:Lys	27	27	27	27	27	27
True Trp:Lys	18	18	18	18	19	19
Ca, %	0.60	0.50	0.50	0.39	0.45	0.35
P, %	0.50	0.40	0.45	0.35	0.40	0.31
Available P, %	0.19	0.11	0.16	0.08	0.12	0.05
K, %	0.78	0.68	0.69	0.59	0.60	0.49
Mg, %	0.19	0.17	0.17	0.16	0.16	0.15
Fe, mg/kg	226	187	207	167	185	152
Zn, mg/kg	136	134	134	132	133	131
Cu, mg/kg	18.3	17.3	17.4	16.4	16.5	15.6
Mn, mg/kg	52.0	44.6	48.0	40.6	44.0	37.7
Analyzed values:						
CP, %	18.15	15.58	15.72	13.32	14.29	12.27
P, %	0.49	0.39	0.43	0.34	0.42	0.32

Control: corn-soybean meal diet. LNE: 2% units reduced CP and 0.1% unit reduced P diet.

[a] Provided 6,607.9 IU/kg of vitamin A; 991.2 IU/kg of vitamin D, 26.4 IU/kg of vitamin E, 2.6 mg/kg of vitamin K, 33.0 mg/kg of Niacin, 6.0 mg/kg of Riboflavin, 19.8 mg/kg of Panthothenic Acid, and 25.8 µg/kg of vitamin B_{12}

[b] Provided 11.01 mg/kg of Cu, 110.13 mg/kg of Fe, 26.43 mg/kg of Mn, and 110.13 mg/kg of Zn

[c] Provided 40 mg of Tylosin per kilogram of diet.

Table IV.2. Effect of reduced dietary crude protein and phosphorus on pig growth performance and nutrient intake (Exp. 1)[a]

	Dietary treatment[b]		SE	P <
	Control	LNE		
Growth performance				
Initial wt, kg	34.3	34.7	0.21	0.45
Final wt, kg	108	108	0.67	0.98
Days to slaughter	104	108	2.48	0.50
ADG, kg	0.726	0.702	0.03	0.63
ADFI, kg	2.09	2.00	0.05	0.42
F:G	2.83	2.86	0.01	0.13
Nutrient intake		g/d		
DM	1,846	1,762	42.9	0.40
C	865	805	20.2	0.28
N	52.0	42.4	1.32	0.12
P	9.2	6.8	0.22	0.08
Ca	11.4	9.0	0.31	0.12
K	15.0	12.0	0.38	0.12
Mg	2.70	2.36	0.07	0.18
Na	2.48	2.37	0.05	0.34
		mg/d		
Fe	447	350	12.7	0.12
Zn	296	280	7.42	0.30
Cu	35.0	30.5	1.06	0.21
Mn	99.5	79.0	2.47	0.11

[a]Least square means for 2 rooms (12 pigs per room) per treatment.
[b]Control: traditional corn-soybean meal diet. LNE: 2% units reduced CP and 0.1% unit reduced P diet.

Table IV.3. Effect of reduced dietary crude protein and phosphorus on carcass characteristics and metacarpal breaking strength (Exp.1) [a]

	Dietary treatment[b]			
	Control	LNE	SE	P <
Live wt, kg	112.8	110.3	1.63	0.47
Hot carcass wt, kg	87.6	85.6	1.11	0.43
10^{th} rib fat depth, cm	2.08	2.07	0.01	0.50
LMA, sq cm	39.1	38.3	0.22	0.25
Carcass yield, %	77.7	77.7	0.10	0.74
Fat-free lean, %	51.1	51.0	0.15	0.74
Metacarpal strength, kgf	160	141	6.80	0.29

[a]Least square means for 2 rooms (12 pigs per room) per treatment.
[b]Control: corn-soybean meal diet. LNE: 2% units reduced CP and 0.1% unit reduced P diet.

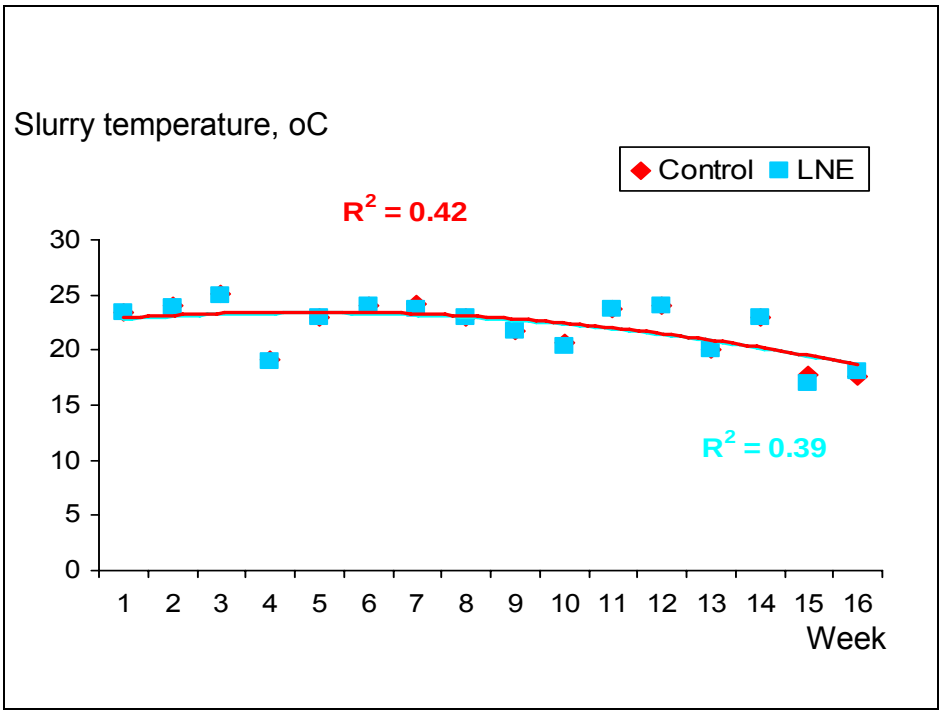


Figure IV.1. Slurry temperature plotted versus week for pigs fed control or LNE diet (Exp. 1). [a]Least square means for 2 rooms (12 pigs per room) per treatment.

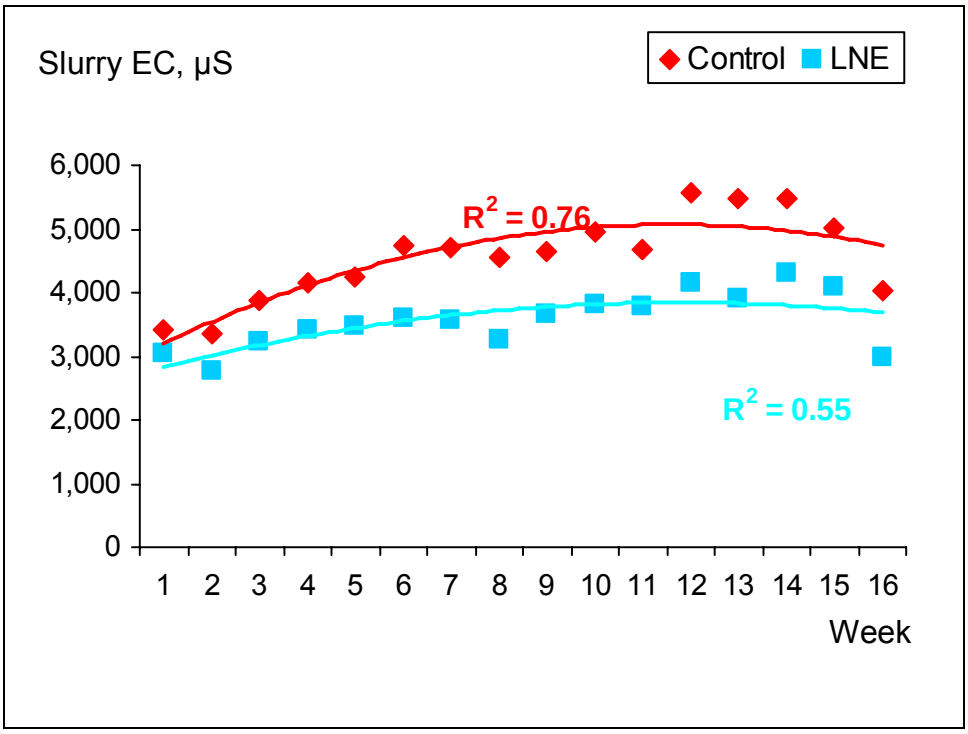


Figure IV.2. Slurry EC plotted versus week for pigs fed control or LNE diet (Exp. 1). [a]Least square means for 2 rooms (12 pigs per room) per treatment.

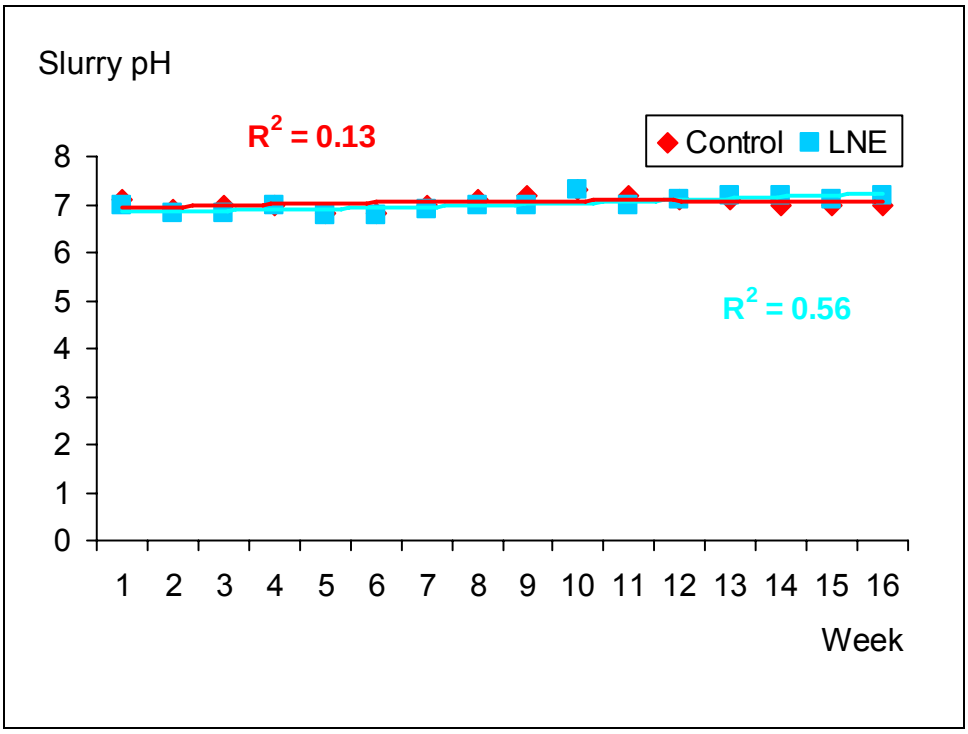


Figure IV.3. Slurry pH plotted versus week for pigs fed control or LNE diet (Exp. 1). [a]Least square means for 2 rooms (12 pigs per room) per treatment.

Table IV.4. Effect of reduced dietary crude protein and phosphorus on slurry volume, temperature, EC, and pH (Exp. 1)[a]

	Dietary treatment[b]			
	Control	LNE	SE	P <
Volume, L/pig/d	11.0	12.5	0.67	0.35
Temperature, ^{o}C	22.5	22.2	0.13	0.40
EC, µS	4,584	3,582	3.14	0.27
pH	7.04	7.02	0.01	0.63

[a]Least square means for 2 rooms (12 pigs per room) per treatment.
[b]Control: corn-soybean meal diet. LNE: 2% units reduced CP and 0.1% unit reduced P diet.

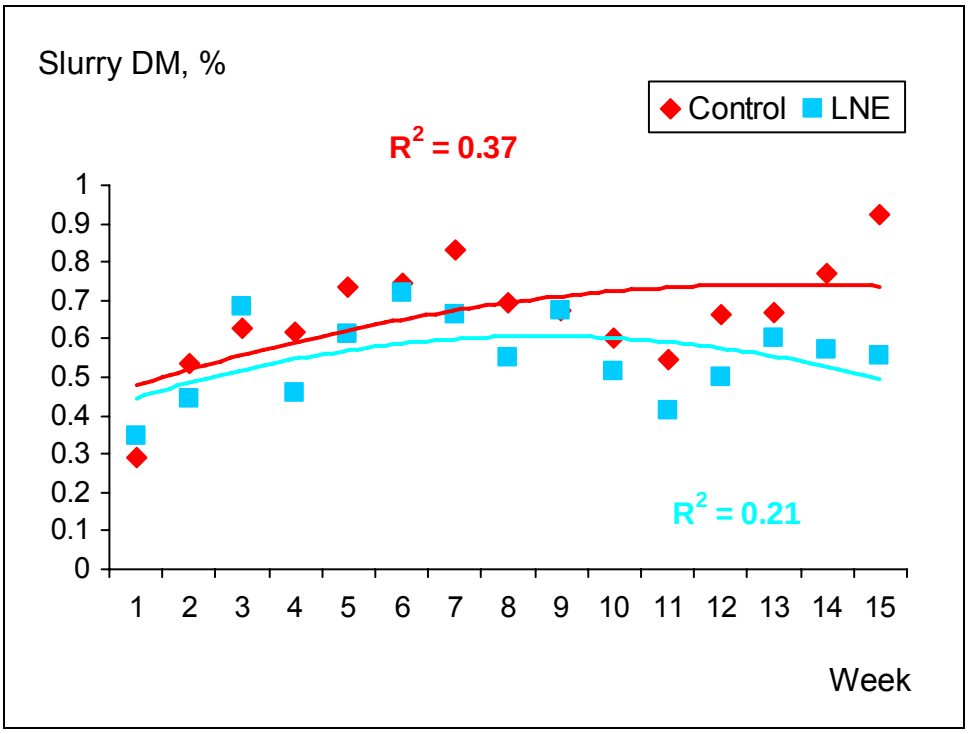


Figure IV.4. Slurry DM concentration plotted versus week for pigs fed control or LNE diet (Exp. 1). [a]Least square means for 2 rooms (12 pigs per room) per treatment.

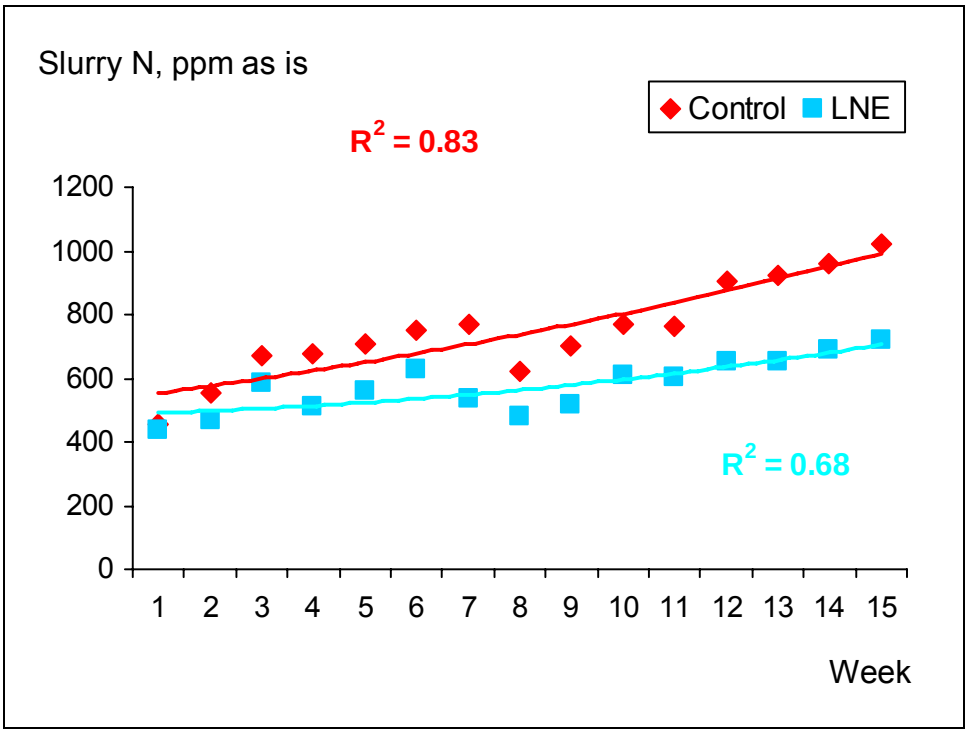


Figure IV.5. Slurry N concentration plotted versus week for pigs fed control or LNE diet (Exp. 1). [a]Least square means for 2 rooms (12 pigs per room) per treatment.

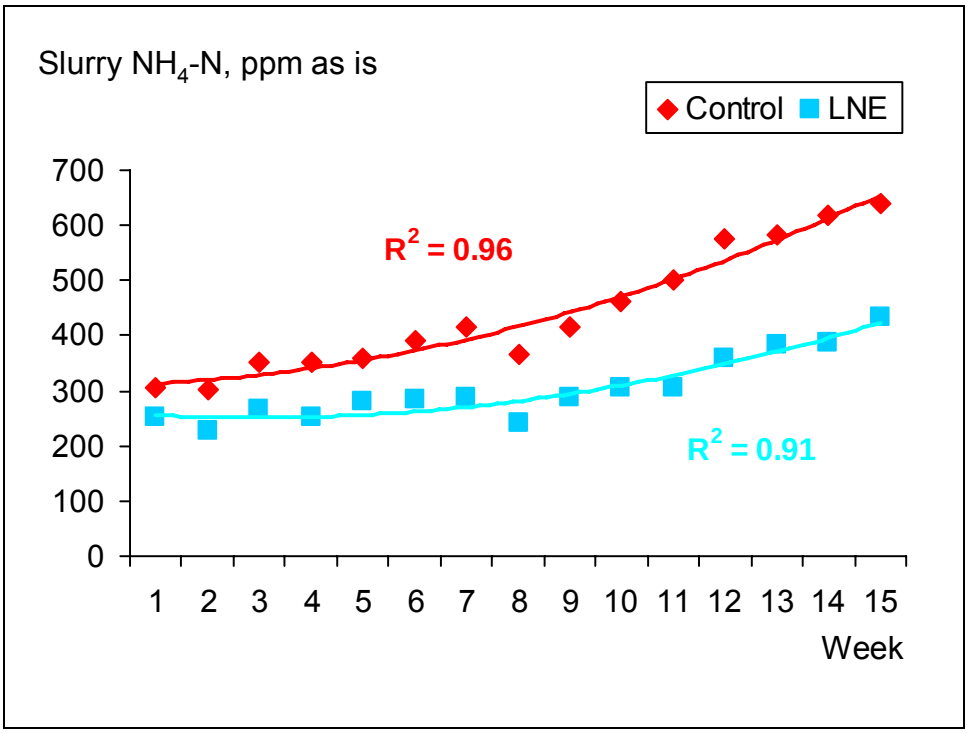


Figure IV.6. Slurry NH_4-N concentration plotted versus week for pigs fed control or LNE diet (Exp. 1). [a]Least square means for 2 rooms (12 pigs per room) per treatment.

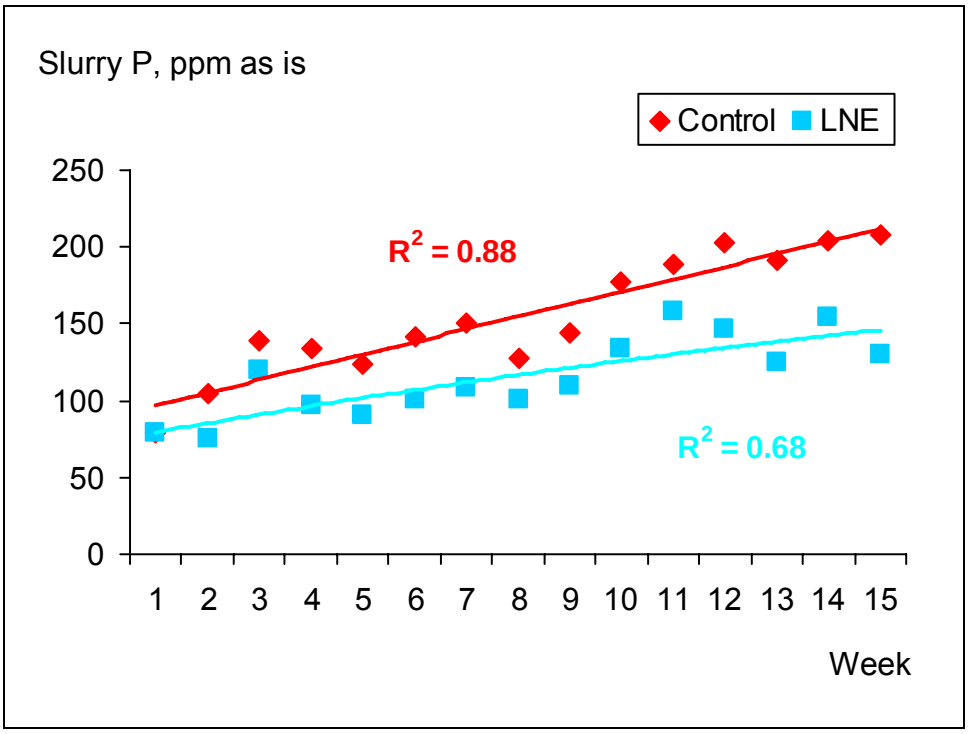


Figure IV.7. Slurry P concentration plotted versus week for pigs fed control or LNE diet (Exp. 1). [a]Least square means for 2 rooms (12 pigs per room) per treatment.

Table IV.5. Effect of reduced dietary crude protein and phosphorus on slurry nutrient concentration, DM basis (Exp. 1)[a]

	Dietary treatment[b]			
Nutrient	Control	LNE	SE	P <
DM, %	1.85	2.06	0.16	0.44
	%, DM basis			
C	38.8	41.7	0.07	0.31
N	10.4	8.5	0.53	0.09
NH_4-N	6.03	4.42	0.37	0.20
P	2.19	1.71	0.03	0.01
Ca	2.83	2.68	0.06	0.32
K	4.88	4.04	0.27	0.27
Mg	0.97	0.92	0.03	0.42
Na	1.33	1.40	0.03	0.35
	ppm, DM basis			
Fe	182.5	143.1	3.66	0.08
Zn	120.7	107.6	1.92	0.13
Cu	20.5	17.6	0.25	0.08
Mn	36.7	32.3	0.70	0.14
C:N ratio	4.87	6.27	0.36	0.11

[a]Least square means for 2 rooms (12 pigs per room) per treatment.
[b]Control: corn-soybean meal diet. LNE: 2% units reduced CP and 0.1% unit reduced P diet.

Table IV.6. Effect of reduced dietary crude protein and phosphorus on daily and cumulative nutrient excretion (Exp. 1)[a]

	Dietary treatment[b]			
	Control	LNE	SE	P <
Daily excretion		g/pig		
DM	303	297	14.7	0.79
C	115	120	2.60	0.32
N	32.3	25.6	0.90	0.04
NH_4-N	18.8	13.3	0.75	0.04
P	6.63	5.14	0.19	0.03
Ca	8.61	7.72	0.14	0.14
K	15.2	12.1	0.21	0.06
Mg	2.99	2.73	0.01	0.01
Na	4.19	4.22	0.21	0.95
		mg/pig		
Fe	566	421	10.6	0.07
Zn	377	325	7.20	0.12
Cu	61.0	50.0	2.36	0.19
Mn	113	96	0.01	0.11
		as % of intake		
DM	16.5	16.8	0.78	0.79
C	13.4	14.9	0.75	0.38
N	62.1	60.3	0.21	0.10
P	72.6	75.2	3.26	0.67
Ca	75.8	86.0	4.41	0.28
K	102	100	0.67	0.43
Mg	111	116	2.73	0.42
Na	170	178	11.4	0.69
Fe	127	120	5.17	0.53
Zn	128	118	5.47	0.42
Cu	176	164	11.8	0.61
Mn	114	122	4.59	0.43
Cumulative excretion		kg/pig		
DM	31.7	31.9	3.21	0.96
C	12.0	12.9	0.82	0.52
N	3.36	2.76	0.25	0.22
P	0.71	0.54	0.07	0.22

[a]Least square means for 2 rooms (12 pigs per room) per treatment.
[b]Control: corn-soybean meal diet. LNE: 2% units reduced CP and 0.1% unit reduced P diet.

CHAPTER V

EXPERIMENT 2

EFFECT OF REDUCING DIETARY CRUDE PROTEIN BY 4% UNITS AND PHOSPHORUS BY 0.1% UNIT ON NUTRIENT EXCRETION OF PIGS DURING AN ENTIRE GROWING-FINISHING PERIOD

Abstract

A total of 48 Yorkshire pigs (30.2 kg BW) was used to determine the effects of reducing dietary CP and P on DM, N, P, and mineral excretion during a 112-d finishing period. Pigs were stratified by sex, blocked by body weight, and allotted randomly to two dietary treatments. Pigs were housed in an environmentally-controlled building divided into 4 identical rooms (12 pigs/room, 2 rooms/trt) with each having a shallow pit, pull plug system. A fortified corn-soybean meal-based diet served as the control (18, 16, and 14% CP; 0.50, 0.45, and 0.40% P for phases 1, 2, and 3, respectively). The experimental diet (LNE) was similar to the control diet with the exception that CP was reduced by 4% units and P by 0.1% unit. Both diets were formulated on true digestible Lys (0.83, 0.71, and 0.58%), and Thr, Met, and Trp were added to LNE on an ideal basis. Pigs and feeders were weighed weekly, and pit volume, pH and EC were measured. Weekly feed and pit samples were collected for DM, N, P, Ca, K, Mg, Na, Fe, Zn, Cu, and Mn

analysis. Days on test increased ($P < 0.05$) for pigs fed LNE, but final weight and DMI were not affected ($P > 0.10$). The hot carcass weight, backfat depth, and carcass yield were not affected ($P > 0.10$) by diet. However, the longissimus muscle area tended ($P < 0.10$) to be reduced and fat-free lean percentage decreased ($P < 0.03$) when pigs were fed LNE. Daily N and P intake were reduced ($P < 0.01$) for pigs fed LNE. Daily mineral intake was similar ($P > 0.10$) for Na, Cu, and Mn; however, the daily intakes of Ca, K, Mg, Zn, and Fe were reduced ($P < 0.05$) for pigs fed LNE. The average concentration of DM in the pit was similar ($P > 0.10$), but N and P concentration, were reduced ($P < 0.05$) when pigs were fed LNE. Pit pH tended to decrease ($P < 0.08$) with LNE. Daily DM excreted was similar ($P > 0.01$) for both diets. However, pigs fed LNE had a marked decrease ($P < 0.05$) in N, NH_4-N and P excreted. Excretion as percentage of the intake was similar ($P > 0.10$) for DM and P, but N intake tended to be reduced ($P < 0.10$) for pigs fed LNE. When pigs were fed LNE, cumulative N and P excreted for the entire 112-d period tended to be reduced ($P < 0.10$) by 1.59 and 0.139 kg/pig. Although mineral intake, in some instances, was reduced for pigs fed LNE, daily mineral excretion was not affected ($P > 0.10$) by diet, with the exception of K and Mn, which tended to be reduced ($P < 0.10$) when LNE was fed. Based on these results, the LNE diet reduced daily and cumulative N and P excreted by 40 and 25%, respectively, with little effect on mineral excretion over the course of a 112-d period.

Introduction

The growing concern about air and water quality has fueled an increasing interest to develop production strategies within the swine industry to reduce nutrient excretion. The nutrients of major concern are N and P, therefore, avoiding the tradition of over-feeding of N and P to growing-finishing pigs can be an effective strategy to reduce N and P excretion. It has been suggested that around 70% of the N (Kornegay and Verstegen, 2001) and 60% of the P (Kornegay and Harper, 1997) consumed by growing-finishing pigs are excreted.

The reduction in dietary protein levels with addition of crystalline AA is an effective mean to decrease N excretion (Kerr and Easter, 1995, Sutton and Richert, 2004, Deng et al., 2007a, Deng et al., 2007b). The available data about the extent to which the dietary protein level can be reduced is conflicting and very limited with group-fed pigs. Most reports indicate that reductions beyond 4% units have detrimental effects on growth traits and carcass quality (Figueroa et al., 2002, Figueroa et al., 2003, Figueroa-Velasco et al., 2004). However, it has been reported that a 4% unit reduction in dietary protein results in a reduction in N excretion of 30 to 40%, without negative effects on pig growth performance (Kerr et al., 2003a, Kerr et al., 2003, Otto et al., 2003).

The reduction in dietary P levels has been well recognized to be an effective method to reduce P excretion. Several studies support a reduction in dietary P by 0.1% unit results in a decrease in P excretion between 21 and 25% (Cromwell et al., 1995; Qian et al., 1996; Harper el al., 1997; Liu et al., 1998). However, P excretion data measured with group-fed pigs is not available.

The reduction in dietary protein and P levels in the diets result from the reduction of inclusion of ingredients such as soybean meal (0.34% Ca, 2% K, and 0.3% Mg), dicalcium phosphate (24% Ca, 2% K, 8% Mg, 0.8% Fe, and 0.1% Mn), and limestone (36% Ca, 0.1% K, 0.2% Mg, 0.35% Fe, and 0.02%Mn). Therefore, the reduction in inclusion of those ingredients results in reduced dietary levels of minerals supplied.

In Experiment 1, a 2% units reduction in dietary CP, in addition to a 0.1% unit reduction in P in grower-finisher diets decreased daily N excretion by 21%, ammonium N in waste by 29%, and daily P excretion by 24%, without negative effects on pigs growth performance. However, the LNE diet had little effect on mineral excretion.

Based on the need for accessible data, a second experiment was conducted to determine the effect of a further reduction in dietary CP by 4% units and P by 0.1% units on pig performance, nutrient excretion during an entire finishing period, carcass characteristics, and pig bone strength.

Materials and Methods

Pig allotment

A group of 48 Yorkshire pigs, 36 barrows and 12 gilts with an average initial body weight of 30.2 kg were allotted to one of the two dietary treatments in a randomized completed block design. The initial weight and sex were used as blocking criterion (with post-allotment assessment to stratify ancestry). The

experimental design included two blocks, with one experimental unit per treatment within each block. A room with 12 pigs served as the experimental unit. In block one, the experimental unit was a room with 12 barrows. In block two, the experimental unit was a room with 6 barrows and 6 gilts. Room setting was previously described in Chapter III.

Dietary treatments

The two dietary treatments evaluated were a control diet similar to that used in Experiment 1, and a LNE diet similar to the control with the exception that part of the soybean meal was removed and crystalline lysine, threonine, methionine and tryptophan were added to meet pig amino acid requirements with a reduction of dietary CP by 4% units, plus a reduction in the addition levels of limestone and dicalcium phosphate to achieve a 0.1% unit reduction in P. Both diets were formulated to be fed in 3 dietary phases with similar values for true digestible Lysin each phase (0.83, 0.71, and 0.58 %, respectively). The true digestible Thr:Lys ratio was 63:100 in Phase 1, and 65:100 in phases 2 and 3; true digestible Met:Lys ratio was 27:100 in all Phases; and true digestible Trp:Lys ratio was 18:100 in Phases 1 and 2, and 19:100 in Phase 3. The reduction in dietary P was achieved by reducing the inclusion of dicalcium phosphate. Also, limestone inclusion was diminished to maintain a Ca:tP ratio of 1.2:1. Diet formulation and calculated composition are presented in Table V.1.

Other procedures

The methodology employed to evaluate pig growth performance, pit content, feed and slurry analysis, nutrient excretion, carcass evaluation, bone strength and statistical analysis, was previously described as general experimental procedures, in Chapter III.

Results

Analyzed crude protein and phosphorus composition of the diets.

The target CP and P concentrations for the control and LNE diet were achieved in all dietary phases. Note the reduction in dietary CP by 4% units in the LNE diet over the three dietary phases (Table V.1). This was also true for the 0.1% unit reduction in dietary P in the LNE diet (Table V.1).

Growth performance and nutrient intake

All pigs started with an average weight of 30.2 kg ($P > 0.10$) and were slaughtered at a target weight of 108 kg ($P > 0.10$). Pigs fed the LNE diet had an increase ($P < 0.05$) in the duration of the finishing period (Table V.2). The ADFI and DM intake were not affected ($P > 0.10$) by dietary treatment. The 4% units reduction in dietary CP and 0.1% unit reduction in dietary P decreased ($P < 0.02$) the daily intakes of N, P, Ca, K, Mg, Zn, and Fe. However, Na, Cu, and Mn daily intake were not affected ($P > 0.10$) by the dietary treatment (Table V.2).

Carcass characteristics and bone breaking strength

The hot carcass weight, carcass yield, and backfat depth at the 10th rib were not affected ($P > 0.10$) by dietary treatment (Table V.3). However, the longissimus muscle area tended ($P < 0.10$) to be smaller when pigs were fed the LNE diet. Also, the fat-free lean percentage was reduced ($P < 0.03$) by the LNE diet (Table V.3). The metacarpal breaking strength tended to be reduced ($P < 0.12$) when pigs were fed the LNE diet. However, metatarsal and metacarpal-metatarsal breaking strength was not affected ($P > 0.10$) by the 0.1% unit reduction of dietary P in the LNE diet (Table V.4).

Slurry characteristics

Slurry volume, temperature (Figure V.1), EC (Figure V.2), pH (Figure V.3), and nutrient concentrations (Figures V.4 to 7), measured on a weekly basis was summarized and used to calculate average values for the entire finishing period. Note that nutrient concentrations in slurry increased over time as pigs grew (Figures V.4 to 7). Slurry volume, measured on a per pig basis, and slurry temperature were similar ($P > 0.10$) for all rooms across the 16-wk period (Table V.5). However, slurry EC was reduced ($P < 0.02$) and the pH tended to be reduced ($P < 0.07$) for pigs fed the LNE diet. The DM and C concentration in the slurry was similar ($P > 0.10$) for both dietary treatments (Table V.6). However, the 4% units reduction in dietary CP and 0.1% reduction in dietary P decreased ($P < 0.02$) slurry N, NH_4-N, and P concentrations, on a DM basis, by 41, 56, and 23%, respectively. Even though the C:N ratio was statistically similar ($P > 0.10$), a

numeric increase was observed in the slurry from pigs fed the LNE (Table V.6). The 4% units reduction in dietary CP and 0.1% unit in dietary P tended to decrease ($P < 0.10$) slurry K, Mg, and Mn concentration. However, the LNE diet did not affected slurry ($P > 0.10$) Ca, Fe, Zn, and Cu concentration, and increased ($P < 0.05$) Na concentration (Table V.6).

Nutrient excretion

Daily DM was not affected ($P > 0.10$) by the reduction in dietary CP and P (Table V.7). However, daily C excretion tended to be ($P < 0.10$) decreased when pigs were fed LNE. Also, the 4% units reduction in dietary CP and 0.1% reduction in dietary P markedly decreased ($P < 0.03$) the amount of N (40% reduction), NH_4-N (56% reduction) and P (25% reduction) excreted. When excretion was expressed as a percentage of the intake, DM, C, N and P excretion were not affected ($P > 0.10$) by the reduction in dietary CP and P (Table V.7). Although, cumulative N and P excretion were similar ($P > 0.10$) for both diets, the cumulative excretion of N and P was numerically reduced by 1.59 and 0.139 kg/pig, respectively, when pigs were fed the diet with 4% unit reduced CP and 0.1% unit reduced P.

The reduction in dietary CP and P did not affect ($P > 0.10$) Ca, Mg, Na, Fe, Zn and Cu excretion. Daily K excretion tended ($P < 0.10$) to be decreased by feeding LNE. Only, Mn excretion was reduced ($P < 0.02$) with the experimental diet (Table V.7). When mineral excretion was expressed as percentage of the intake, mineral excretion was not affected by the dietary treatment, except for Ca

excretion which tended to be increased ($P < 0.08$) in pigs fed with the LNE diet. The reduction in dietary CP and P had very little effect on the total amount of minerals excreted over the entire growth-finishing period. Cumulative excretion of Ca, Mg, Na, and Fe, Zn and Cu were similar ($P > 0.10$) in both treatments groups. Only, cumulative excretion of K and Mn were decreased ($P < 0.05$) with the reduction in CP and P in the experimental diet (Table V.7).

Summary

A reduction of 4% unit of CP with addition of crystalline AA and 0.1% unit of P in grower-finisher diets decreased daily N and P excretion by 40 and 25%, and cumulative N and P excreted for the entire period by 1.36 and 0.14 kg/finished pig, respectively, during a 112-day finishing period. Reduction of the inclusion level of soybean meal, dicalcium phosphate, and limestone had little effect on mineral excretion over the growing-finishing period. The LNE diet only decreased daily K and Mn excretion, while the level of excretion of the other minerals was maintained. However, reduction of 4% unit of CP with addition of crystalline AA and 0.1% unit of P increased the duration of the finishing period by 7 days.

Implications

Based on these results, the reduction in N and P in grower and finisher diets markedly decreases N and P excretion. However, reduction of dietary CP by 4% in addition to with the 0.1% unit in P had adverse effects on pig growth

performance. The increased duration of the finishing period caused a dilution of the daily reductions in excretion over time.

Table V.I. Composition of experimental diets, as-fed basis (Exp. 2).

Dietary phase	1 (30-51 kg)		2 (51-85 kg)		3 (85-109 kg)	
Ingredient, %	Control	LNE	Control	LNE	Control	LNE
Corn	68.98	80.21	74.54	85.39	79.73	90.76
Soybean meal, 48%	25.84	14.51	20.68	9.33	15.54	4.20
L-Lysine		0.35		0.36		0.36
DL-Methionine		0.01		0.01		
L-Theonine		0.10		0.11		0.10
L-Tryptophan		0.03		0.03		0.04
Soybean oil	3.00	3.00	3.00	3.10	3.00	3.10
Dicalcium phosphate	0.68	0.40	0.52	0.24	0.36	0.08
Limestone	0.96	0.95	0.82	0.78	0.82	0.81
Salt	0.25	0.25	0.25	0.25	0.25	0.25
Vitamin mix [a]	0.15	0.15	0.15	0.15	0.15	0.15
Trace mineral mix [b]	0.10	0.10	0.10	0.10	0.10	0.10
Antibiotic [c]	0.05	0.05	0.05	0.05	0.05	0.05
Calculated values:						
ME, kcal/kg	3484	3482	3497	3496	3504	3503
CP, %	18.00	14.00	16.00	12.00	14.00	10.00
Lysine, %	0.96	0.92	0.82	0.79	0.68	0.65
True dig. Lysine, %	0.83	0.83	0.71	0.71	0.58	0.58
True Thr:Lys	63	63	65	65	65	65
True Met:Lys	27	27	27	27	27	27
True Trp:Lys	18	18	18	18	19	19
Ca, %	0.60	0.50	0.50	0.39	0.45	0.35
P, %	0.50	0.40	0.45	0.35	0.40	0.30
Available P, %	0.19	0.13	0.16	0.09	0.12	0.06
K, %	0.78	0.58	0.69	0.48	0.60	0.39
Mg, %	0.19	0.16	0.17	0.15	0.16	0.14
Fe, mg/kg	226	188	207	169	187	150
Zn, mg/kg	136	132	134	130	133	128
Cu, mg/kg	18.25	16.32	17.38	15.44	16.51	14.57
Mn, mg/kg	51.96	44.68	48.01	40.70	44.33	37.08
Analyzed values:						
CP, %	18.7	14.2	15.9	13.0	13.1	9.5
P, %	0.50	0.38	0.46	0.38	0.38	0.30

Control: corn-soybean meal diet. LNE: 4% units reduced CP and 0.1% unit reduced P diet

[a] Provided 6,607.9 IU/kg of vitamin A; 991.2 IU/kg of vitamin D, 26.4 IU/kg of vitamin E, 2.6 mg/kg of vitamin K, 33.0 mg/kg of Niacin, 6.0 mg/kg of Riboflavin, 19.8 mg/kg of Panthothenic Acid, and 25.8 µg/kg of vitamin B_{12}

[b] Provided 11.01 mg/kg of Cu, 110.13 mg/kg of Fe, 26.43 mg/kg of Mn, and 110.13 mg/kg of Zn

[c] Provided 40 mg of Tylosin per kilogram of diet.

Table V.2. Effect of reduced dietary crude protein and phosphorus on pig growth performance and nutrient intake (Exp. 2)[a].

	Dietary treatment[b]			
	Control	LNE	SE	P <
Growth performance				
Initial wt, kg	30.2	30.2	0.04	0.43
Final wt, kg	109.9	108.7	1.74	0.72
Days to slaughter	105	112	0.35	0.04
ADG, g	1,315.8	1,301.7	20.85	0.71
ADFI, kg	2.16	2.10	0.02	0.23
F:G	2.84	2.97	0.03	0.17
Nutrient intake		g/d		
DM	1,899.6	1,833.2	16.04	0.21
N	52.75	38.05	0.06	0.01
P	9.32	7.11	0.04	0.01
Ca	11.98	8.97	0.01	0.01
K	16.50	11.26	0.03	0.01
Mg	3.02	2.40	0.01	0.02
Na	2.19	2.24	0.04	0.49
		mg/d		
Fe	472	347	1.41	0.01
Zn	316	273	0.35	0.01
Cu	38.5	33.0	2.47	0.36
Mn	104	85	3.89	0.18

[a]Least square means for 2 rooms (12 pigs per room) per treatment.
[b]Control: corn-soybean meal diet. LNE: 4% units reduced CP and 0.1% unit reduced P diet.

Table V.3. Effect of reduced dietary crude protein and phosphorus on carcass characteristics and bone breaking strength (Exp.2) [a]

	Dietary treatment[b]			
	Control	LNE	SE	P <
Live wt, kg	109.9	108.7	1.74	0.72
Hot carcass wt, kg	87.5	86.4	1.85	0.74
10^{th} rib fat depth, cm	2.12	2.30	0.04	0.18
LMA, sq cm	44.2	38.7	0.57	0.09
Carcass yield, %	79.7	79.4	0.39	0.75
Fat-free lean, %	52.2	50.2	0.06	0.03
Metacarpal strength, kgf	152.1	136.8	2.06	0.12
Metatarsal strength, kgf	130.8	120.7	5.52	0.42
Metacarpal-metatarsal strength, kgf	140.2	130.1	5.44	0.41

[a]Least square means for 2 rooms (12 pigs per room) per treatment.
[b]Control: corn-soybean meal diet. LNE: 4% units reduced CP and 0.1% unit reduced P diet.

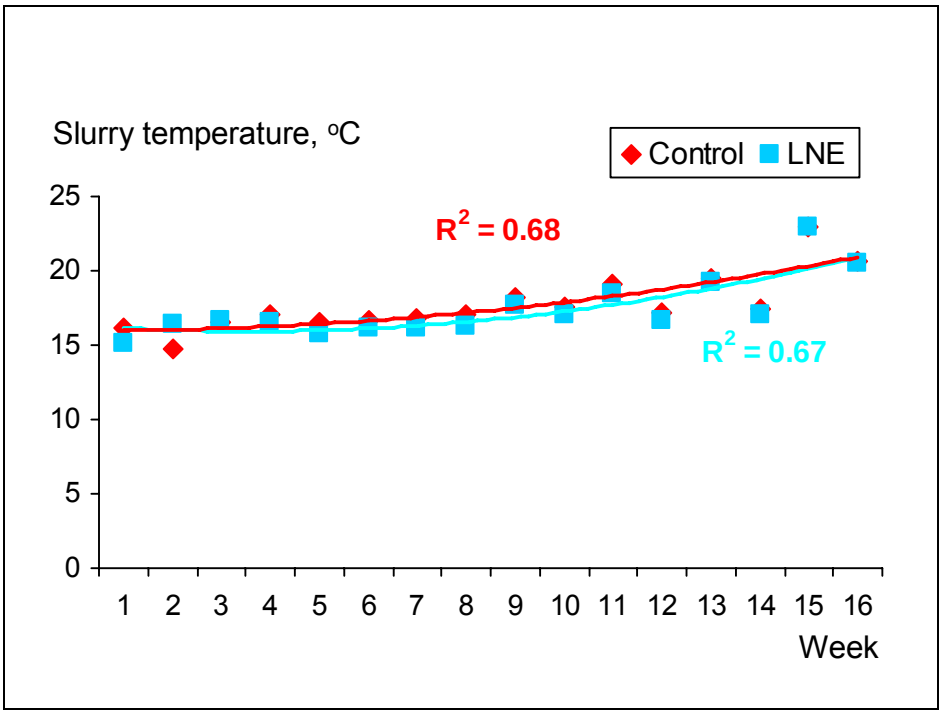


Figure V.1. Slurry temperature plotted versus week for pigs fed control or LNE diet (Exp. 2). [a]Least square means for 2 rooms (12 pigs per room) per treatment.

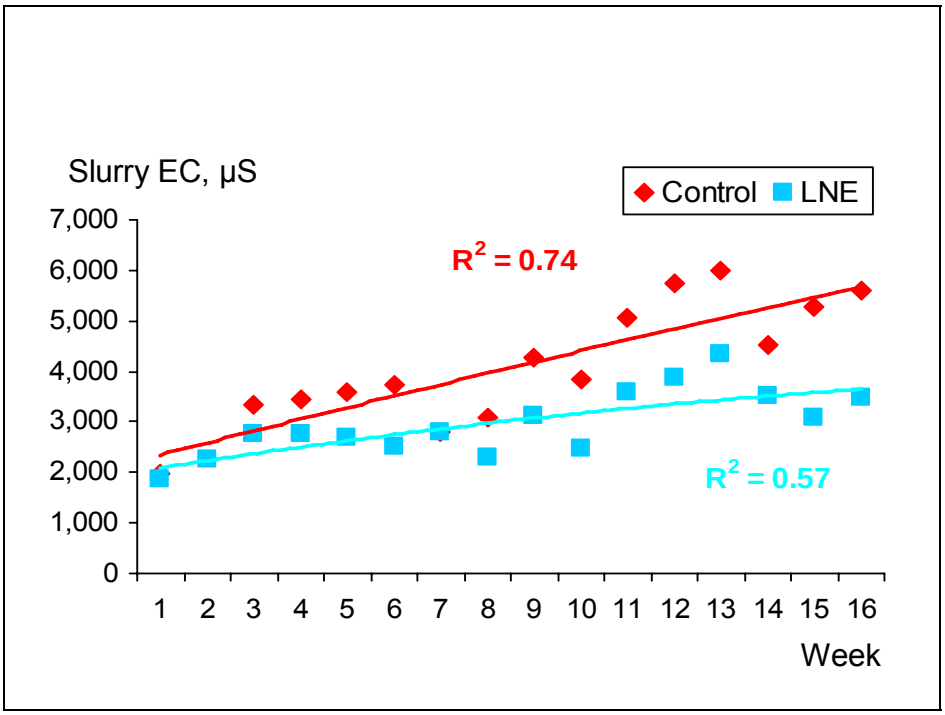


Figure V.2. Slurry EC plotted versus week for pigs fed control or LNE diet (Exp. 2). [a]Least square means for 2 rooms (12 pigs per room) per treatment.

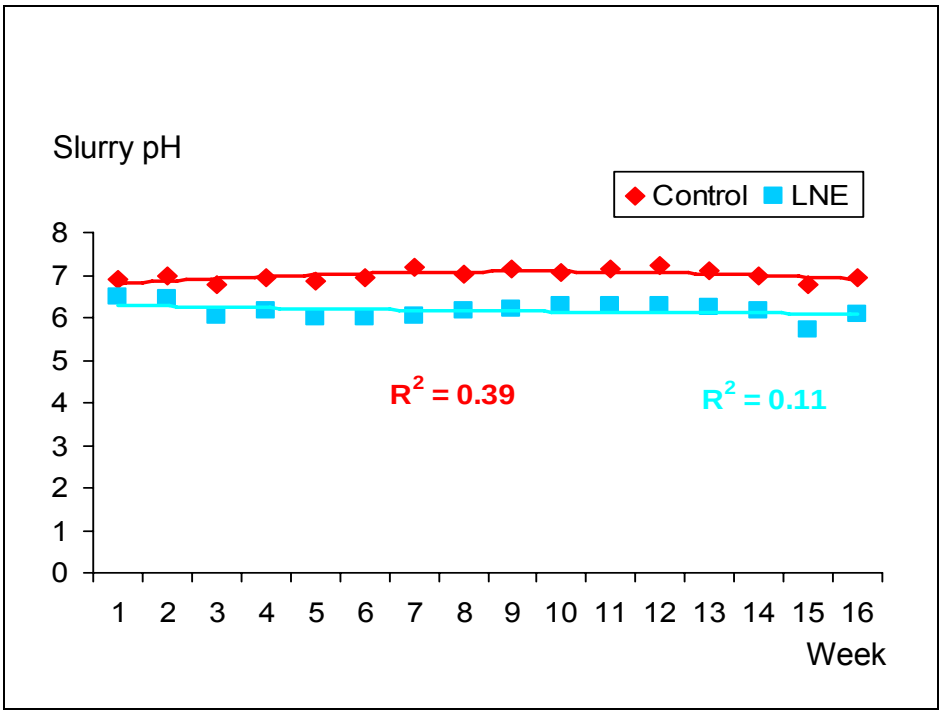


Figure V.3. Slurry pH plotted versus week for pigs fed control or LNE diet (Exp. 2). [a]Least square means for 2 rooms (12 pigs per room) per treatment.

Table V.4. Effect of reduced dietary nitrogen and phosphorus on slurry volume, temperature, EC, and pH (Exp. 2)[a].

	Dietary treatment[b]			
	Control	LNE	SE	PV
Volume, L/pig/d	9.53	11.30	1.25	0.50
Temperature, ^{o}C	17.53	17.26	0.11	0.34
EC, µS	4.81	3.01	0.05	0.02
pH	7.02	6.23	0.06	0.07

[a]Least square means for 2 rooms (12 pigs per room) per treatment.
[b]Control: corn-soybean meal diet. LNE: 4% units reduced CP and 0.1% unit reduced P diet.

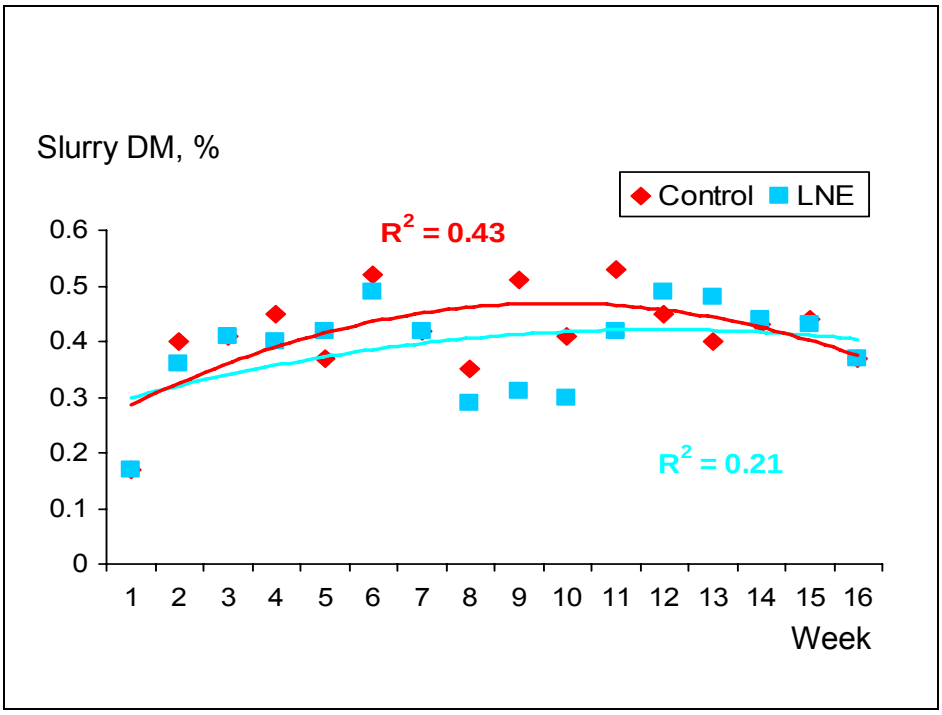


Figure V.4. Slurry DM concentration plotted versus week for pigs fed control or LNE diet (Exp. 2). [a]Least square means for 2 rooms (12 pigs per room) per treatment.

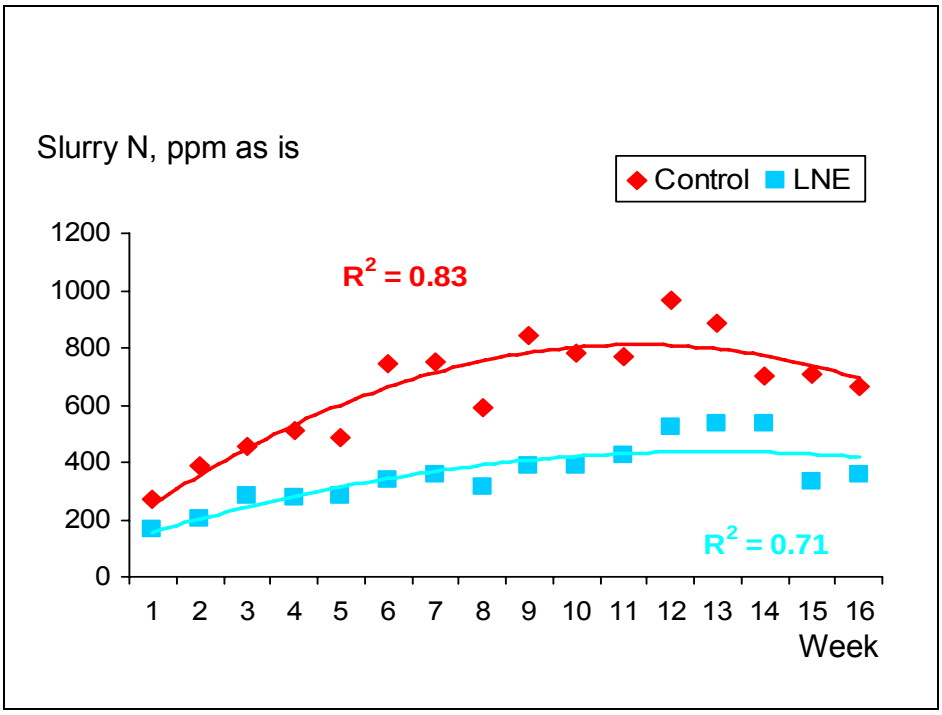


Figure V.5. Slurry N concentration plotted versus week for pigs fed control or LNE diet (Exp. 2). [a]Least square means for 2 rooms (12 pigs per room) per treatment.

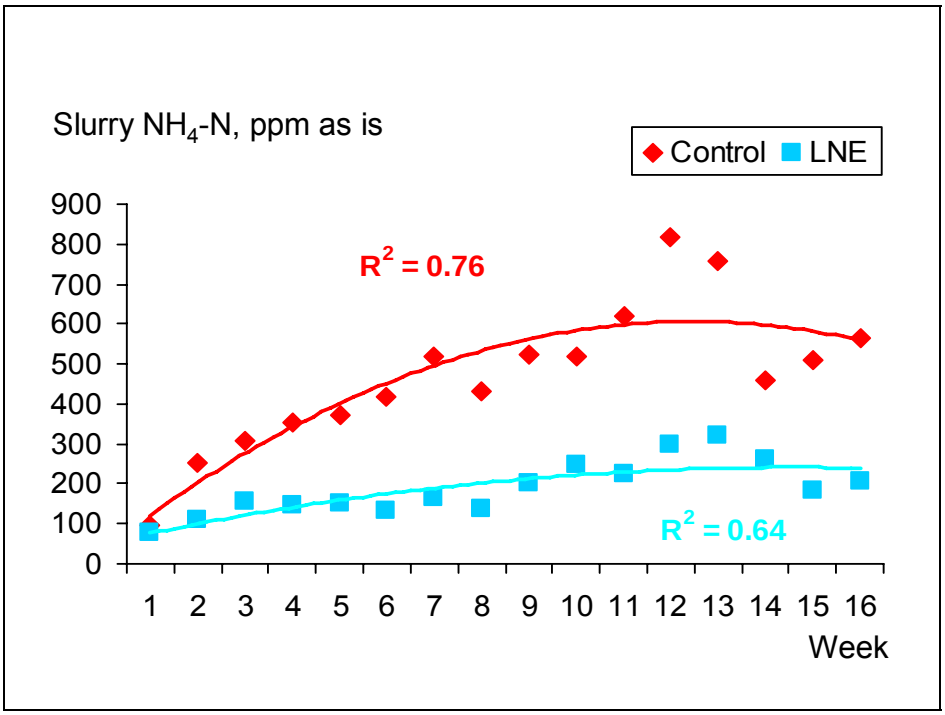


Figure V.6. Slurry NH_4-N concentration plotted versus week for pigs fed control or LNE diet (Exp. 2). [a]Least square means for 2 rooms (12 pigs per room) per treatment.

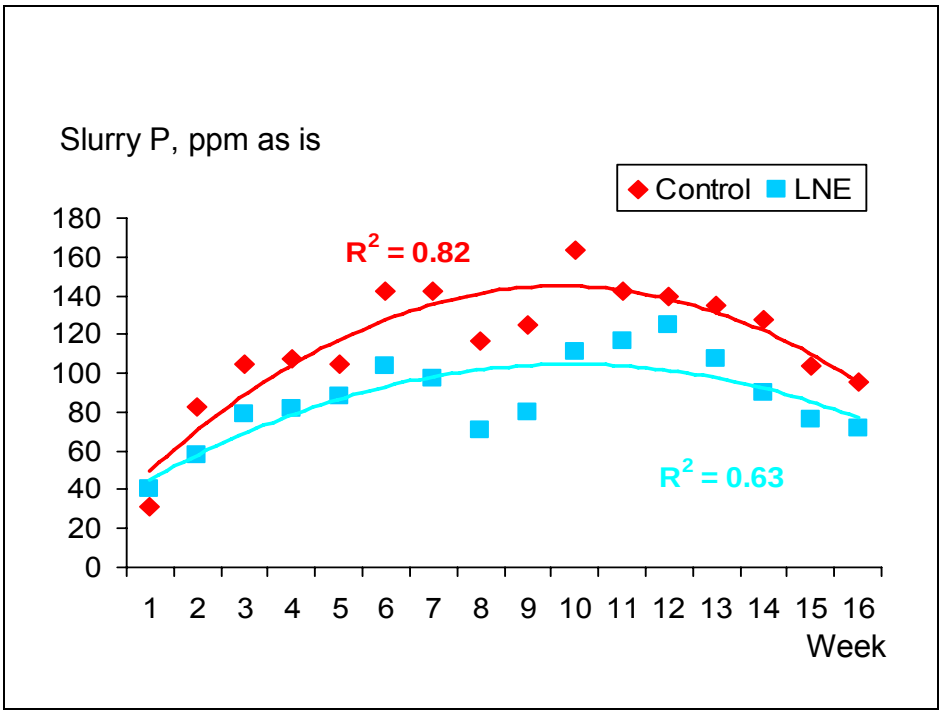


Figure V.7. Slurry P concentration plotted versus week for pigs fed control or LNE diet (Exp. 2). [a]Least square means for 2 rooms (12 pigs per room) per treatment.

Table V.5. Effect of reduced dietary crude protein and phosphorus on slurry nutrient concentration, DM basis (Exp. 2)[a].

	Dietary treatment[b]			
	Control	LNE	SE	P <
DM, %	0.58	0.53	0.02	0.26
	%, DM basis			
C	54.62	52.47	2.05	0.59
N	12.66	7.61	0.14	0.02
NH_4-N	8.4	3.7	0.40	0.02
P	2.47	1.90	0.01	0.02
Ca	2.92	2.83	0.02	0.16
K	5.76	3.96	0.20	0.10
Mg	1.28	1.16	0.01	0.07
Na	2.16	2.38	0.01	0.04
	ppm, DM basis			
Fe	162.5	157.5	12.72	0.83
Zn	103.5	93.5	3.53	0.30
Cu	15.5	13.5	0.71	0.30
Mn	37.0	32.5	0.35	0.07
C:N ratio	4.32	6.97	0.57	0.19

[a]Least square means for 2 rooms (12 pigs per room) per treatment.
[b]Control: corn-soybean meal diet. LNE: 4% units reduced CP and 0.1% unit reduced P diet.

Table V.6. Effect of reduced dietary nitrogen and phosphorus on daily and cumulative nutrient excretion, 112 days (Exp. 2)[a].

	Dietary treatment[b]			
	Control	LNE	SE	PV
Daily excretion	g/pig			
DM	273.8	269.2	6.78	0.72
C	149.1	140.2	2.99	0.09
N	34.74	20.64	0.23	0.02
NH_4-N	23.11	10.26	0.40	0.03
P	6.78	5.13	0.03	0.02
Ca	7.97	7.61	0.22	0.45
K	15.77	10.73	0.57	0.10
Mg	3.51	3.13	0.09	0.20
Na	5.89	6.38	0.02	0.36
	mg/pig			
Fe	445.1	419.0	23.87	0.58
Zn	284.8	250.4	4.86	0.12
Cu	43.7	32.2	1.45	0.20
Mn	101.7	87.5	0.23	0.02
	as % of intake			
DM,	14.4	14.7	0.25	0.60
C	17.2	16.5	0.38	0.43
N	65.7	53.9	2.10	0.16
P	72.6	71.9	1.66	0.82
Ca	66.5	84.7	1.79	0.08
K	95.5	94.8	6.15	0.95
Cumulative excretion	kg/pig			
DM	28.6	29.7	0.97	0.55
N	3.6	2.3	0.16	0.11
P	0.72	0.57	0.02	0.13
	g/pig			
Ca	10.0	10.1	0.53	0.91
K	19.6	14.1	0.94	0.05
Mg	4.4	4.1	0.13	0.31
Na	7.4	8.5	0.56	0.31
	mg/pig			
Fe	556	560	37.11	0.94
Zn	355	333	6.62	0.14
Cu	54	50	1.26	0.11
Mn	126	115	1.36	0.03

[a]Least square means for 2 rooms (12 pigs per room) per treatment.
[b]Control: corn-soybean meal diet. LNE: 4% units reduced CP and 0.1% unit reduced P diet.

CHAPTER VI

EXPERIMENT III

EFFECT OF REDUCING DIETARY PROTEIN, PHOSPHORUS, AND TRACE MINERALS ON NUTRIENT EXCRETION, GAS EMISSION, AND NUTRIENT MASS BALANCE DURING THE ENTIRE FINISHING PERIOD

Abstracts

Seventy-six crossbred pigs were used to evaluate the effects of reducing dietary CP, P, and trace minerals (TM) on DM, N, P, and mineral excretion, and on the mass balance of N and P during a 110-d finishing phase (28 to 118 kg BW). Pigs were stratified by sex, blocked by BW, and randomly allotted to two diets. Pigs were housed in an environmentally-controlled building with 4 identical rooms (19 pigs/room, 2 rooms/trt). Each room contained a shallow pit and exhaust air monitoring system. The control diet was a fortified corn-soybean meal diet (19.3, 17.2, 15.1 and 13.6% CP; 0.50, 0.46, 0.43, and 0.40% P) with 0.1% inclusion of TM premix for Phases 1 (28-54 kg), 2 (54-82 kg), 3 (82-100 kg) and 4 (100-118 kg). Diet 2 (LNE) was similar to the control with the exceptions that CP was reduced by 3% units, P by 0.1% units, phytase added (500 FYT/kg), and TM premix reduced by 50, 77, 83 and 100% for Phases 1 - 4, respectively. The TM premix supplied 11, 110, 26, and 110 ppm of Cu, Fe, Mn, and Zn. Diets were

formulated on true digestible lysisne (0.92, 0.79, 0.65, and 0.56%) and Lys, Met, Thr and Trp were added to LNE on an ideal basis. Pig weight, feed intake, pit volume, and slurry pH were measured weekly. Feed and slurry samples were collected weekly for DM, N, P, and mineral analyses. The estimation of mass balance, on a per pig basis, assumed that N and P entered the finisher via the feed and pigs, and exited via the slurry, exhaust air, and pigs. At day 0 and 110, 8 pigs and 6 pigs/room, respectively, were used to estimate initial and final body composition. Feed intake and composition were used to estimate N and P entering via feed. Slurry volume, composition, and NH_3-N emission were used to estimate N and P exiting via waste. Diet did not affect ($P > 0.10$) growth performance. Daily intakes of N and P decreased ($P < 0.05$) with LNE. Slurry concentrations of N and NH_4-N tended to decrease ($P < 0.10$) with LNE, while P and pH were reduced ($P < 0.05$). Daily DM, N, and P excretion were reduced ($P < 0.05$) for pigs fed LNE. Excretion of macro- and TM was reduced by more than 11 and 38%, respectively. Cumulative DM, N, and P excretion were reduced ($P < 0.05$) by 12, 31 and 34%, respectively with LNE. The amount of N and P initially entering via pigs was similar ($P > 0.10$). However, N and P entering via feed were reduced ($P < 0.03$) with LNE. Thus, LNE reduced ($P < 0.03$) total N and P entering by 18 and 22%, respectively. The amount of N and P exiting via the pigs was similar ($P > 0.10$) for both diets. However, N and P exiting via slurry, and NH_3-N emitted were reduced ($P < 0.05$) by feeding LNE. Thus, LNE reduced ($P < 0.05$) total N and P exiting by 18 and 21%, respectively. These results suggest a marked reduction in nutrient excretion for pigs fed LNE during the finishing

period. The proportion of N and P entering the finisher that exited via the pigs increased from 47 to 58% for N and 37 to 48% for P for pigs fed LNE compared with those fed the control.

Introduction

Currently, the increasing concern about the contribution of swine production to environmental pollution has enforced the consideration of more environmental regulations over waste discharge and gaseous emissions from intensive production operations. Intensive swine production is demanding the development of new strategies that can simultaneously reduce nutrient excretion and emissions. Also, it is important to evaluate nutrient flow within the production system, and the impact of management strategies on nutrient flow.

Results from the previous two experiments suggested that reduction of dietary N and P in growing-finishing diets is an effective dietary manipulation to reduce N and P excretion and ammonium in slurry. The 2% units reduction in dietary CP reduced daily N excretion by 21%, with no effect on pig growth performance. A further reduction in dietary CP by 4% units decreased N excretion by 40%, but negatively affects pig growth performance. The negative effect on pig growth could be due to the reduction in available P in addition with limited amino acids. The reduction in dietary P by 0.1% unit reduced P excretion by 24% in the two previous experiments. However, previous reports suggest that the reduction in P excretion can be increased by the addition of dietary phytase

(Cromwell et al., 1995; Harper el al., 1997; Kornegay and Harper, 1997; Liu et al., 1998) to the LNE diet.

In addition to the well recognized concern about N and P as environmental pollutants, mineral excretion as a risk of pollution is gaining attention. It has been reported that 70 to 95% of mineral intake is excreted (Kornegay and Harper, 1997). The reduction of mineral concentration in swine diets may decrease mineral concentration in the waste (Creech et al., 2004). However, there is no information available concerning the effects of combining reductions in dietary crude protein, phosphorus, and minerals, with phytase addition in group-fed finishing pigs. Also, it is important to evaluate the entire finishing period, and be able to describe the effects on nutrient flow through the finisher system.

Based on the need to evaluate these strategies placed together, an experiment was designed with the objective to determine the effects of reducing dietary CP by 3% units, P by 0.1% unit, with addition of phytase, and sequential reductions in trace mineral inclusion in growing-finishing diet on nutrient excretion, and emissions for the entire finishing period. In addition, the experiment was designed to estimate the mass balance of N and P for the entire finishing period.

Materials and methods

Pig allotment

A group of 76 crossbred pigs [Dx(YxL)] (40 barrows and 36 gilts) with an average initial body weight of 28 kg were allotted to one of two dietary treatments

in a randomized completed block design. The initial weight was used as blocking criterion and sex was stratified within experimental units (with post-allotment assessment to stratifyd ancestry). The experimental design included two blocks, with two experimental unit per treatment within each block. On day 0, two pigs per room were removed and used to determine initial whole body composition. Thus, the experimental unit was a room with 19 pigs.

Dietary treatments

Two dietary treatments were evaluated, a control diet similar to the one used in Experiment 1 and 2, with the exception that it was formulated to be fed in four phases (19.3, 17.2, 15.1 and 13.6% CP; 0.50, 0.46, 0.43, and 0.40% P) with 0.1% inclusion of TM premix for Phases 1 (28-54 kg), 2 (54-82 kg), 3 (82-100 kg) and 4 (100-118 kg). The low nutrient excretion (LNE) diet was similar to the control with the exceptions that CP was reduced by 3% units, P by 0.1% unit, phytase added (500 FYT/kg, as Ronozyme®P, DSM Nutritional Products), and TM premix reduced by 50, 77, 83 and 100% for Phases 1 - 4, respectively. The TM premix supplied 11, 110, 26, and 110 ppm of Cu, Fe, Mn, and Zn. Diets were formulated on true digestible lysisne (0.92, 0.79, 0.65, and 0.56%) with Ca:P ratio of 1.2:1, and Lys, Met, Thr and Trp were added to LNE on an ideal basis. Diet formulation, calculated composition, and CP and P analyzed values are presented in Table VI.1.

Other procedures

The methodology employed to evaluate pig growth performance, pit content, feed and slurry analysis, nutrient excretion, carcass evaluation, bone strength and statistical analysis, was previously described as general experimental procedures, in Chapter III.

Determination of initial and final body composition

At the start of the experiment (day 0), a stratified sample of 8 pigs (4 gilts and 4 barrows) was taken to determine initial body composition. As result, 8 pigs, representative of the initial groups assigned to the dietary treatments, were weighed, and transported to the OSU slaughter facility. The pigs were humanely slaughtered, and the viscera removed. The empty body and viscera were weighed separately, and store at -20^{o}C. The frozen empty bodies and viscera were ground, using a whole body grinder. Duplicate representative samples of the ground empty body and viscera were collected. Empty body and viscera samples were lyophilized and analyzed for DM, CP, P and ash.

Using the live weight and body composition of the pigs used for initial body composition, prediction equations to estimate initial composition regresed on initial weight were developed. The initial weight of all pigs in the experiment was used with the prediction equations to estimate initial body composition. The estimated initial body composition was used to calculate the amount of nutrients entering the finisher via the pig.

A similar procedure was performed on day 110, at the end of the growing-finishing period, to estimate final body composition. A sample of 6 pigs per room (3 gilts and 3 barrows) was taken and transported to the OSU slaughter facility. The pigs were humanely slaughtered, and head and viscera were removed. The empty bodies without head, and the head plus viscera were weighed, and stored at -20^{o}C. The frozen empty body and the head plus viscera were ground, and duplicate representative samples were collected. The samples were lyophilized and analyzed for DM, N, P, C, Ca, K, Mg, Na, Fe, Zn, Cu, and Mn. Nutrient retention was estimated by subtracting initial nutrient content in the pig from the final nutrient content. Nutrient accretion was estimated by dividing the amount of nutrient retained by the duration of the finishing period. Mass balance of N and P was estimated assuming that N and P entered the finisher via pig and feed, and exited the finisher via pig, slurry and air.

Ammonia and hydrogen sulfide emissions measurement

Emissions of ammonia and hydrogen sulfide, in addition to air flow from each room, were measured during the entire finishing period (110 days). Ammonia concentration was measured using an ammonia to nitric oxide converter. Nitric oxide was detected with a TEI Model 17C chemiluminescence analyzer (Thermo Electron Corporation, Waltham, MA). Hydrogen sulfide was measured using a pulsed fluorescence converter. Hydrogen sulfide was converted to sulfur oxide, followed by sulfur oxide detection with a sulfur oxide analyzer (TEI Model 450C-TL, Thermo Electron Corporation, Waltham, MA).

Each room was equipped with 2 variable speed exhaust fans (Figure VI.1A). Air flow from each fan was measured simultaneously with the measurement of the current passing through the fan control unit. Air flow was measured using a flowhood (8400 Flowhood kit, Shortridge Instruments, Scottsdale, AZ) at the time that pigs were removed from the room to be weighed. Using the current as the independent variable, air flow prediction equations for each fan were generated. Current at each fan control unit was continuously measured using current transducers (Hawkeye 822, Portland, OR), and air flow estimated with the prediction equations. Exhaust air samples were collected from the ducts attached to each fan before air entrance into the bio-filters (Figure VI.1C). At these sampling points, suction ports were inserted into the ducts (Figure VII.1D) and air samples were pulled from each fan (2 fans/room, 8 fans total), one at a time, and delivered into the analyzers (Figure VI.1F). Emissions from each room were measured in 20 min cycles every 80 min.

The exhaust air flow rate (ventilation air flow rate, m^3/s, Q_V) was estimated using the operation voltage of the wall fans at sampling time (Figure VI.1B). Each fan operation voltage was entered into the air flow prediction equation, which was generated from independent fan test performed during fan calibration, prior to the start of each feeding phase. Exhaust air flow rate of each fan, in addition to the mean ammonia and hydrogen sulfide concentration measured in inlet (Inlet gas concentration, ppm, C_i), and exhaust air (exhaust air gas concentration, ppm, C_e), were used to estimate gases generation (Q_G) and

emission (Q_E) rates, from each of the four rooms, using the following equations (Hebert et al., 2001):

Gas generation rate, mg/s, $Q_G = KQ_V (C_e - C_i)$

Gas emission rate, mg/s, $Q_E = KQ_V C_E$

Where K = factor to convert ppm to mg/m^3

Gas generation and emissions from each room were estimated by the addition of the individual contribution of each of the fans located within a room.

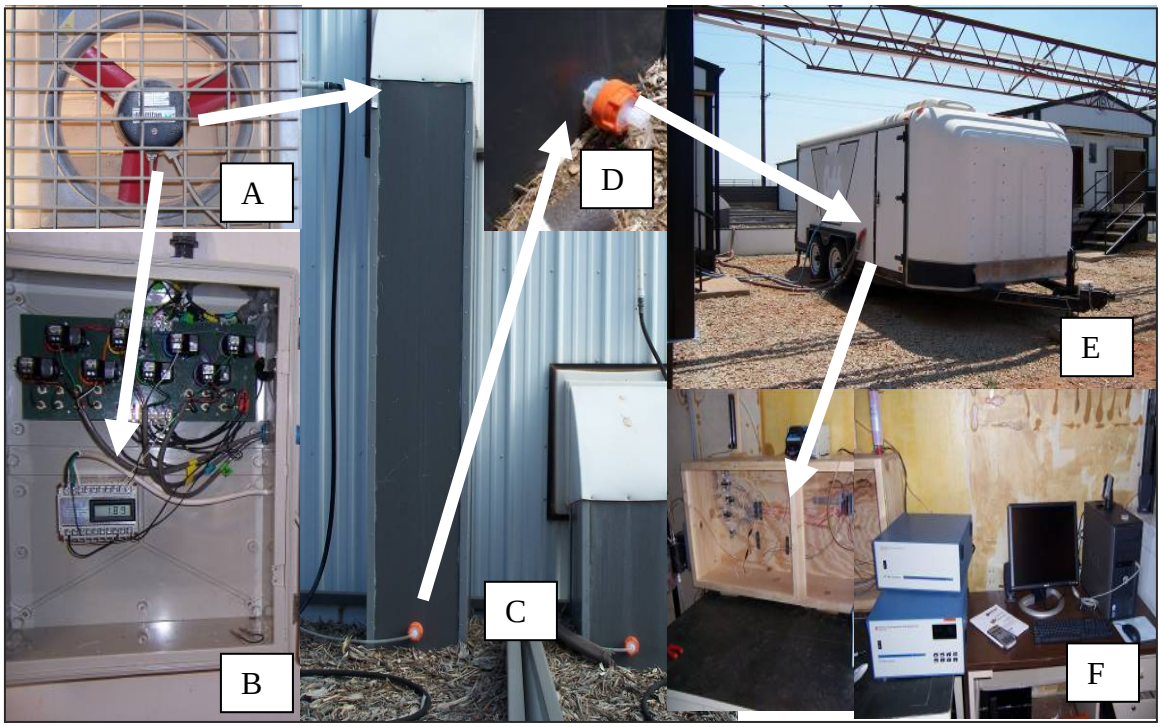


Figure VI.1. Exhaust air monitoring system. A) View of a wall fan, B) Voltage reader, C) Exhaust air ducts, D) Sampling ports at exhaust air ducts, E) Mobil instrumentation trailer for air monitoring, F) inside view of the instrumentation trailer.

Estimation of mass balance for the growing-finishing period

The mass balance approach was used to describe N and P flow within the finisher system. The mass balance of N and P was estimated on a per pig basis, assuming that N and P entered the finisher via the feed and pigs, and exited via the slurry, exhaust air, and pigs. To estimate the amount of N and P entering via feed, feed intake and composition were used. To estimate N and P entering via the pigs, 8 pigs were removed at starting of the growing phase (day 0), and used for determination of initial body composition. To estimate the amount of N and P exiting via the pigs, 6 pigs per room were removed at the end of the finishing phase (day 110), and used to estimate final body composition. The amount of N and P exiting the finisher via slurry was estimated using the weekly measurements of slurry volume and the analyzed N and P concentration in each week slurry sample. The amount of N exiting the finisher in exhaust air was estimated from the measured ammonia emissions. Thus, slurry volume and composition, in addition to ammonia emission were used to estimate N and P exiting via waste.

Results

Growth performance and nutrient intake

All pigs started with an average weight of 28 kg ($P > 0.10$) and were humanely slaughtered at a target weight of 118 kg ($P > 0.10$) (Table VI.2). The duration of the finishing period was similar ($P > 0.10$) for both treatment groups. The ADG, ADFI, and F:G ratio were not affected ($P > 0.10$) by diet. The 3% units

reduction in dietary CP, 0.1% unit reduction in dietary P, and the sequential reduction in trace mineral inclusion decreased ($P < 0.01$) daily N, P, Ca, K, Mg, Fe, Zn, Cu and Mn intake (Table VI.2). However, DM and Na intake were not affected ($P > 0.10$) by diet.

Carcass characteristics and bone breaking strength

The reduction in dietary CP by 3% units, P by 0.1% unit, addition of phytase, and sequential reduction of trace mineral inclusion did not affect ($P > 0.10$) hot carcass weight and backfat depth at the 10^{th}rib (Table IV.3). Also, longissimus muscle area, carcass yield, fat-free lean percentage (Table IV.3), and metatarsal breaking strength were not affected ($P > 0.10$) by dietary treatment (Table IV.3).

Body composition and nutrient accretion rate

Recall that at the beginning of the experiment a total of 8 pigs were used to estimate initial body composition. The initial body composition and body weight were used to generate prediction equations (Table IV. 4) to estimate initial content of water, CP, ash, fat, N and P in the pigs (Table IV. 4). All pigs started with similar ($P > 0.10$) initial body weight, thus, similar ($P > 0.10$) initial body composition was estimated (Table IV.5). The final body composition (water, CP, ash, fat, N and P) and water, CP, ash, fat, N and P accretion rates were not affected by diet (Table IV.5).

Slurry characteristics

Slurry volume, temperature (Figure V.1), EC (Figure V.2), pH (Figure V.3), and nutrient concentrations (Figures V.4 to 8), measured on a weekly basis was summarized and used to calculate average values for the entire finishing period. Note that nutrient concentrations in slurry increased over time as pigs grow (Figures V.4 to 8). Slurry volume, measured on a per pig basis, and temperature were similar ($P > 0.10$) for all rooms (Table VI.6). However, slurry EC was reduced ($P < 0.04$) and the pH tended to be reduced ($P < 0.10$) when pigs were fed the LNE diet. The slurry concentration of all nutrients measured was reduced ($P < 0.03$) when pig were fed the LNE, with exception of Na which tended ($P < 0.10$) to be reduced, in addition to K and Mg which were not affected ($P > 0.10$) by diet (Table VI.7). Additionally, water soluble phosphorus was reduced ($P < 0.05$) in the slurry from pigs fed LNE. The C:N ratio was increased ($P < 0.01$) by feeding the LNE diet (Table VI.7). Slurry N:tP ratio tended to be increased ($P < 0.10$) when pigs were fed LNE, and the WSP:tP ratio was not affected ($P > 0.10$) by diet.

Nutrient excretion

All excretion results are expressed on a per pig basis. Feeding LNE markedly decreased ($P < 0.03$) the daily excretion of DM, N, NH_4-N, P, Ca, K, Mg, Fe, Zn, Cu and Mn (Table VI.8). Daily DM excretion was reduced by 12%, N by 30%, P by 34%, macro-minerals by 23% and micro-minerals by 46%. When excretion was expressed as a percentage of intake, only N excretion tended ($P < 0.10$) to

be reduced by feeding LNE (Table VI.8). Also, cumulative DM, N and P excretion decreased ($P < 0.03$) when pigs were fed the LNE diet (Table VI.8).

Air flow, ammonia and hydrogen sulfide emissions

Air flow was similar ($P > 0.10$) across the four rooms (Table VI.9). The exhaust air ammonia concentration and ammonia emission rate were reduced ($P < 0.01$) when pigs were fed the LNE diet. The reduction in ammonia emission rate was by 56%. However, dietary treatment had no effect ($P > 0.10$) on hydrogen sulfide concentration and emission rate.

Nitrogen and phosphorus mass balance from the finisher

In the estimated mass balance for N and P, the total amount of N entering the finisher was very close to the total amount of N exiting the finisher, this was also true for the amount of P entering and exiting the finisher (Table VI.10). For the N mass balance the amount of N exiting the finisher exceeded the amount entering by 0.2 kg per finished pig. For the P mass balance, 0.08 and 0.05 kg of P leaving the finisher were not accounted in the control and LNE treated group, respectively (Table VI.10). The amount of N and P initially entering via pigs was similar ($P > 0.10$) for both treatments (Table VI.10). However, the amount of N and P entering via feed were reduced ($P < 0.03$) by feeding LNE diet. Therefore, the LNE diet reduced total N and P entering the finisher by 18 and 22%, respectively. The amount of N and P exiting via the pigs was similar ($P > 0.10$) for both diets. However, the amount of N and P exiting the finisher via slurry, and

NH_3-N emitted were reduced ($P < 0.05$) when pigs were fed LNE (Table VI.10). Therefore, the reduction in total N by 18% and total P by 21%, exiting the finisher was due to the reduction in the amounts of these nutrients entering via feed. The proportion of N and P entering the finisher via the pigs was increased and the proportion entering via feed was decreased by feeding LNE in relation to feeding the control diet. Also, the proportional distribution of N and P leaving the finisher was affected by dietary treatment. When pigs were fed LNE, the proportion of N and P leaving via the pigs was increased, the proportion leaving in slurry decreased, and also, the proportion of N leaving as ammonia N in exhaust air (Figures VI.1 and VI.2).

Summary

The reduction in dietary CP, P, and trace minerals, with addition of phytase to the diet markedly decreased daily and cumulative nutrient excretion for pigs fed LNE during the finishing period. Daily and cumulative DM excretion was reduced by 12%, N excretion by 31%, P excretion by 34%, macro-mineral excretion by more than 13%, and micro-mineral excretion up to 46%. Also, ammonia emission was reduced by 56%. Additionally, the LNE diet did not affect pig growth performance and carcass characteristics. The proportion of N and P entering the finisher that exited via the pigs increased from 47 to 58% for N and 37 to 48% for P for pigs fed LNE compared with those fed the control during the entire finishing period.

Implications

These results suggest that reductions in dietary CP, P and trace minerals in growing-finishing diets markedly decreased DM, N, P and other mineral excretion, and ammonia emission without affecting pig growth performance or fat-free lean gain. Therefore, dietary manipulation is an effective strategy to simultaneously reduce nutrient excretion, ammonia emissions, and the risk of exceeding the limits for ammonia emission established by future EPA regulations.

Table VI.1. Composition of experimental diets, as-fed basis (Exp. 3).

Dietary phase	1 (35-56 kg)		2 (56-87 kg)		3 (87-108 kg)		4 (87-108 kg)	
Ingredient, %	Control	LNE	Control	LNE	Control	LNE	Control	LNE
Corn	65.72	73.75	71.28	79.95	76.71	85.37	80.54	89.16
Soybean meal, 48%	29.11	20.57	23.67	15.00	18.30	9.73	14.58	6.12
L-lysine	-	0.30	-	0.28	-	0.27	-	0.27
DL-methionine	-	0.01	-	0.00	-	-	-	-
L-theonine	-	0.09	-	0.09	-	0.07	-	0.04
L-tryptophan	-	0.02	-	0.02	-	0.02	-	0.00
Soyean oil	3.00	3.00	3.00	3.10	3.00	3.10	3.00	3.10
Dicalcium phosphate	0.61	0.27	0.54	0.20	0.47	0.12	0.39	0.04
Limestone	0.97	0.97	0.96	0.89	0.93	0.81	0.90	0.85
Salt	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Vitamin mix[a]	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Trace mineral mix[b]	0.10	0.05	0.10	0.03	0.10	0.02	0.10	-
Phytase[c]	-	0.02	-	0.02	-	0.02	-	0.02
Antibiotic[d]	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Calculated composition								
ME, kcal/kg	3483	3487	3490	3494	3494	3501	3499	3508
CP, %	19.3	16.3	17.2	14.2	15.1	12.1	13.6	10.6
Lysine, %	1.05	1.03	0.90	0.88	0.75	0.73	0.65	0.63
True dig. Lys, %	0.92	0.92	0.79	0.79	0.65	0.65	0.56	0.56
True Thr:Lys	68	63	70	65	73	66	76	63
True Met:Lys	30	27	32	27	35	27	38	28
True Trp:Lys	22	18	22	18	22	17	22	15
Ca, %	0.60	0.50	0.56	0.44	0.52	0.40	0.48	0.36
P, %	0.50	0.40	0.46	0.36	0.43	0.33	0.40	0.30
Fe, mg/kg	225	132	213	101	199	69	188	39
Zn, mg/kg	137	79	136	59	134	39	132	19
Cu, mg/kg	18.8	11.9	17.9	9.1	16.9	6.3	16.3	3.9
Mn, mg/kg	51.9	31.4	49.4	24.3	46.8	17.3	44.5	10.6

Control: corn-soybean meal diet. LNE: 3% units reduced CP and 0.1% unit reduced P diet.

[a] Provided 6,607.9 IU/kg of vitamin A; 991.2 IU/kg of vitamin D, 26.4 IU/kg of vitamin E, 2.6 mg/kg of vitamin K, 33.0 mg/kg of Niacin, 6.0 mg/kg of Riboflavin, 19.8 mg/kg of Panthothenic Acid, and 25.8 µg/kg of vitamin B_{12}

[b] Provided 11.01 mg/kg of Cu, 110.13 mg/kg of Fe, 26.43 mg/kg of Mn, and 110.13 mg/kg of Zn

[c] Provided 40 mg of Tylosin per kilogram of diet.

Table VI.2. Effect of reduced dietary crude protein and phosphorus on pig growth performance and nutrient intake (Exp. 3)[a].

	Dietary treatment[b]			
Growth performance	Control	LNE	SE	P <
Initial wt, kg	28.0	28.0	0.01	0.33
Final wt, kg	118.3	117.0	1.24	0.60
Days to slaughter	110	110	0.00	
ADG, kg	0.836	0.844	0.01	0.23
ADFI, kg	2.253	2.204	0.01	0.14
F:G	2.70	2.61	0.01	0.18
Nutrient intake		g/d		
DM	1,925	1,879	32.8	0.43
N	53.4	45.0	0.60	0.01
P	9.78	7.38	0.13	0.01
Ca	15.0	11.6	0.20	0.01
K	17.2	13.8	0.28	0.01
Mg	3.16	2.74	0.05	0.02
Na	2.85	2.72	0.08	0.34
		mg/d		
Fe	45.2	27.9	0.58	0.01
Zn	25.3	12.8	0.78	0.01
Cu	4.01	2.00	0.11	0.01
Mn	12.1	5.8	0.37	0.01

[a]Least square means for 2 rooms (19 pigs per room) per treatment.
[b]Control: corn-soybean meal diet. LNE: 3% units reduced CP and 0.1% unit reduced P diet.

Table VI.3. Effect of reduced dietary crude protein and phosphorus on carcass characteristics (Exp.3) [a]

	Dietary treatment[b]			
	Control	LNE	SE	P <
Live wt, kg	116.6	116.0	0.40	0.50
Hot carcass wt, kg	88.5	87.7	0.38	0.50
10^{th} rib fat depth, cm	2.10	1.98	0.03	0.20
LMA, sq cm	46.9	44.8	0.69	0.43
Carcass yield, %	76.6	77.3	0.51	0.49
Fat-free lean, %	52.9	52.9	0.22	0.88
Metacarpal	175	165	10.00	0.62

[a]Least square means for 2 rooms (19 pigs per room) per treatment.
[b]Control: corn-soybean meal diet. LNE: 3% units reduced CP and 0.1% unit reduced P diet.

Table VI. 4. Initial body composition prediction equations (Exp 3)

Nutrient	Prediction equation for initial composition	R^2
Water	Water, lb = 0.5971 (initial Wt, lb) + 1.4681	0.99
CP	CP, lb = 0.212 (initial Wt, lb) - 0.6897	0.98
Ash	Ash, lb = 0.0258 (initial Wt, lb) + 0.1199	0.85
Fat	Fat, lb = 0.1608 (initial Wt, lb) - 0.9327	0.89
N	N, lb = 0.0339 (initial Wt, lb) - 0.1104	0.98
P	P, lb = 4.1863 (initial Wt, lb) + 34.329	0.85

N = 8

Table VI. 5. Initial and final body composition and nutrient accretion rate (Exp 3)[a]

	Dietary treatment[b]			
	Control	LNE	SE	P <
Estimated initial composition, kg				
Initial wt	27.94	27.89	0.02	0.33
Water	18.19	18.17	0.19	0.96
CP	5.25	5.24	0.07	0.96
Ash	0.84	0.84	0.01	0.95
Fat	5.44	5.43	0.05	0.96
N	0.84	0.84	0.01	0.96
P	0.15	0.15	1.37	0.96
Final composition, kg				
Final wt	116.6	116.0	0.40	0.50
Water	58.57	58.45	0.09	0.53
CP	20.01	19.54	0.57	0.66
Ash	2.93	2.77	0.05	0.25
Fat	30.15	30.67	0.16	0.26
N	3.37	3.29	0.12	0.71
P	0.437	0.457	0.01	0.41
Accretion rate, g/d				
Water	367.8	366.8	4.11	0.91
CP	134.6	130.5	4.16	0.61
Ash	18.99	17.55	0.31	0.19
Fat	225.4	230.6	2.79	0.41
N	23.08	22.36	0.91	0.68
P	2.60	2.79	0.07	0.33

[a]Least square means for 2 rooms (19 pigs per room) per treatment.
[b]Control: corn-soybean meal diet. LNE: 3% units reduced CP and 0.1% unit reduced P diet.

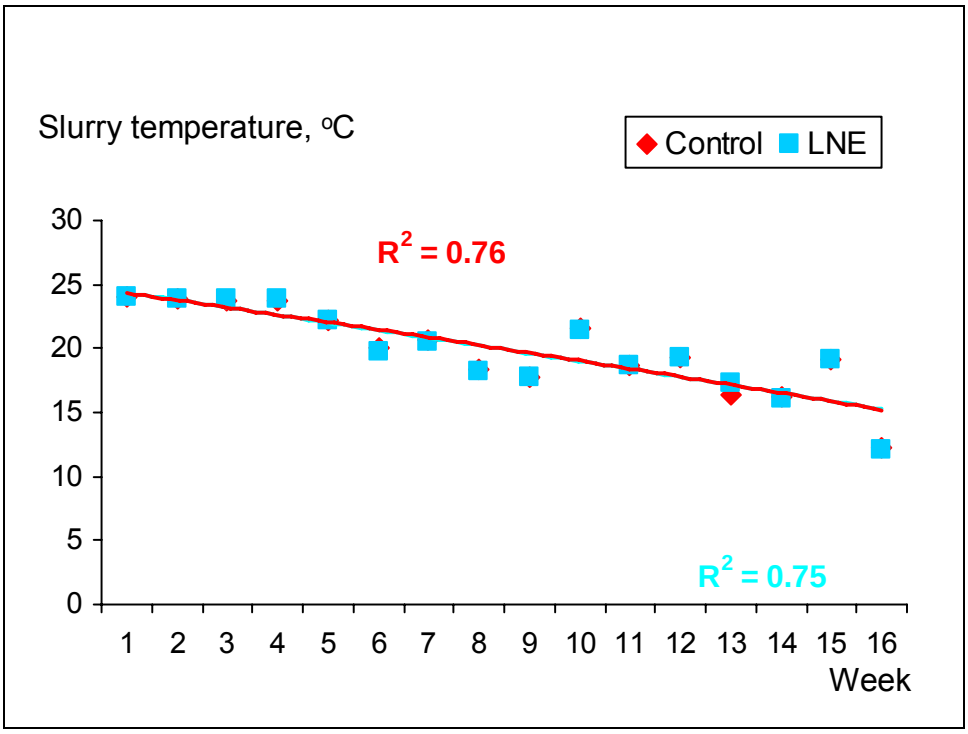


Figure VI.1. Slurry temperature plotted versus week for pigs fed control or LNE diet (Exp. 3). [a]Least square means for 2 rooms (19 pigs per room) per treatment.

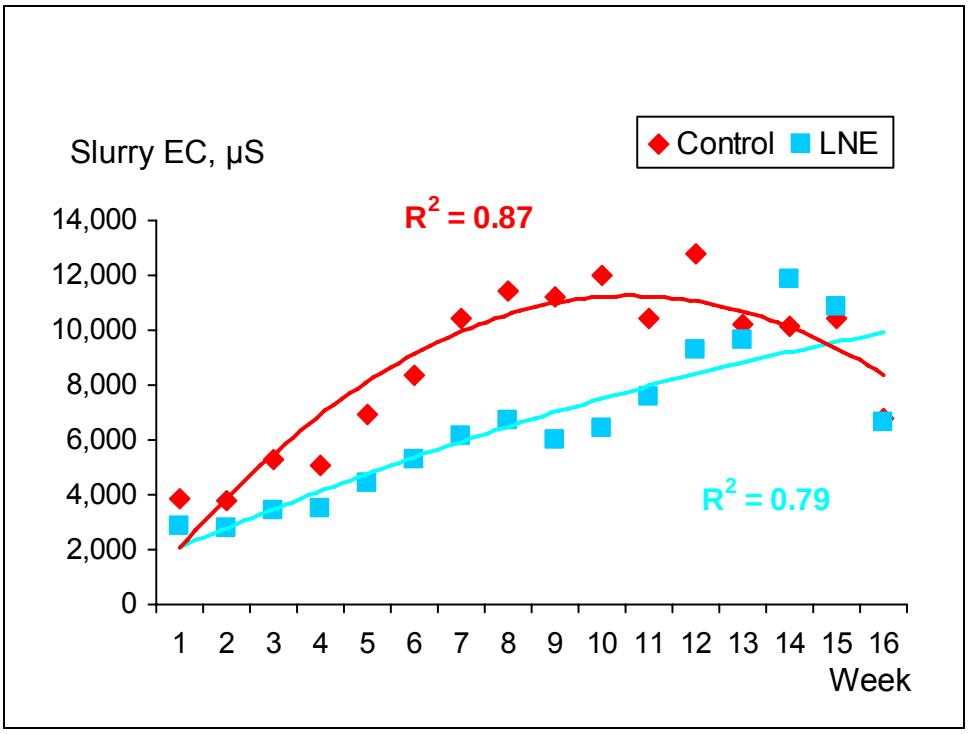


Figure VI.2. Slurry EC plotted versus week for pigs fed control or LNE diet (Exp. 3). [a]Least square means for 2 rooms (19 pigs per room) per treatment.

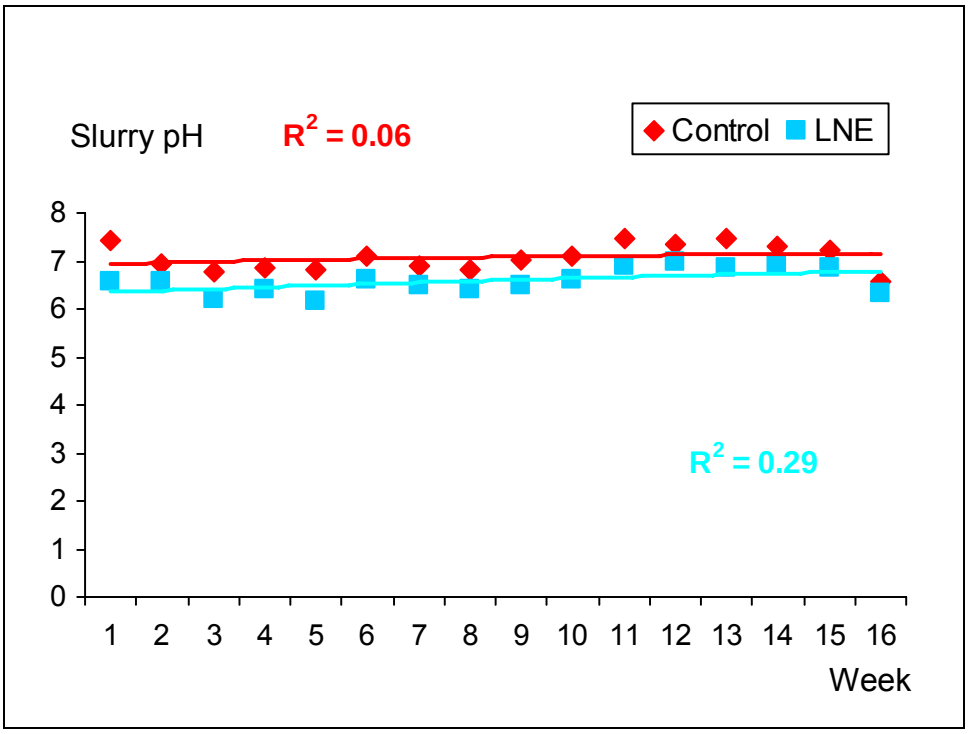


Figure VI.3. Slurry pH plotted versus week for pigs fed control or LNE diet (Exp. 3). [a]Least square means for 2 rooms (19 pigs per room) per treatment.

Table VI. 6. Effect of reduced dietary crude protein and phosphorus on slurry volume, temperature, EC, and pH (Exp. 3)[a].

	Dietary treatment[b]			
	Control	LNE	SE	PV <
Volume, L/pig/d	9.1	12.8	1.88	0.29
Temperature, ^{o}C	19.9	19.9	0.02	0.90
EC, mS	8.70	6.48	0.49	0.04
pH	7.07	6.59	0.07	0.09

[a]Least square means for 2 rooms (19 pigs per room) per treatment.
[b]Control: corn-soybean meal diet. LNE: 3% units reduced CP and 0.1% unit reduced P diet.

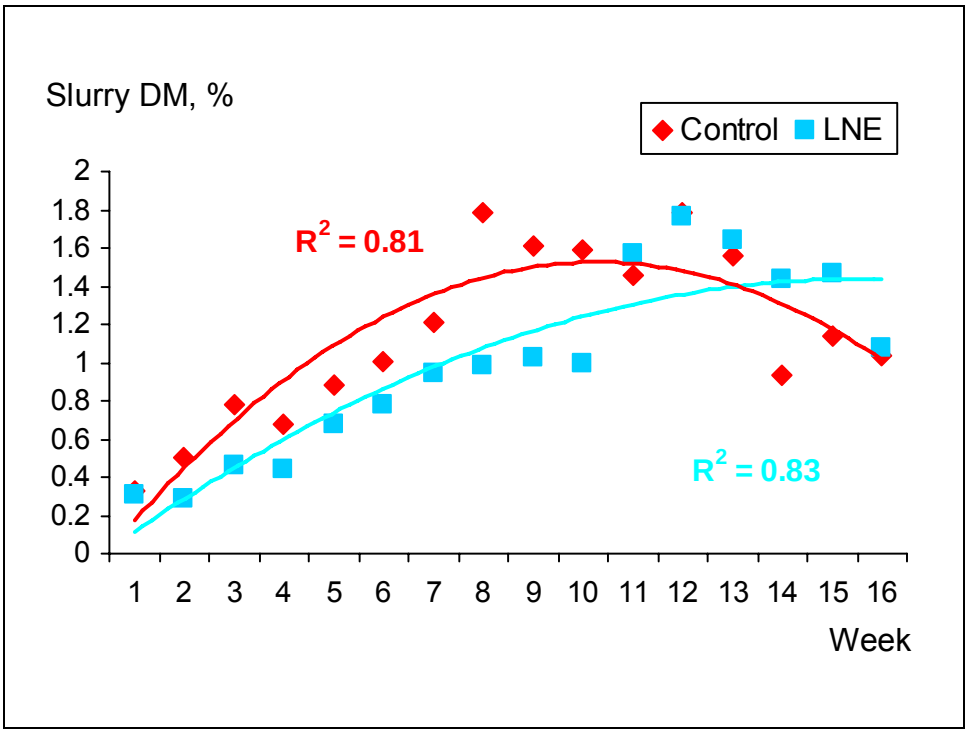


Figure VI.4. Slurry DM concentration plotted versus week for pigs fed control or LNE diet (Exp. 3). [a]Least square means for 2 rooms (19 pigs per room) per treatment.

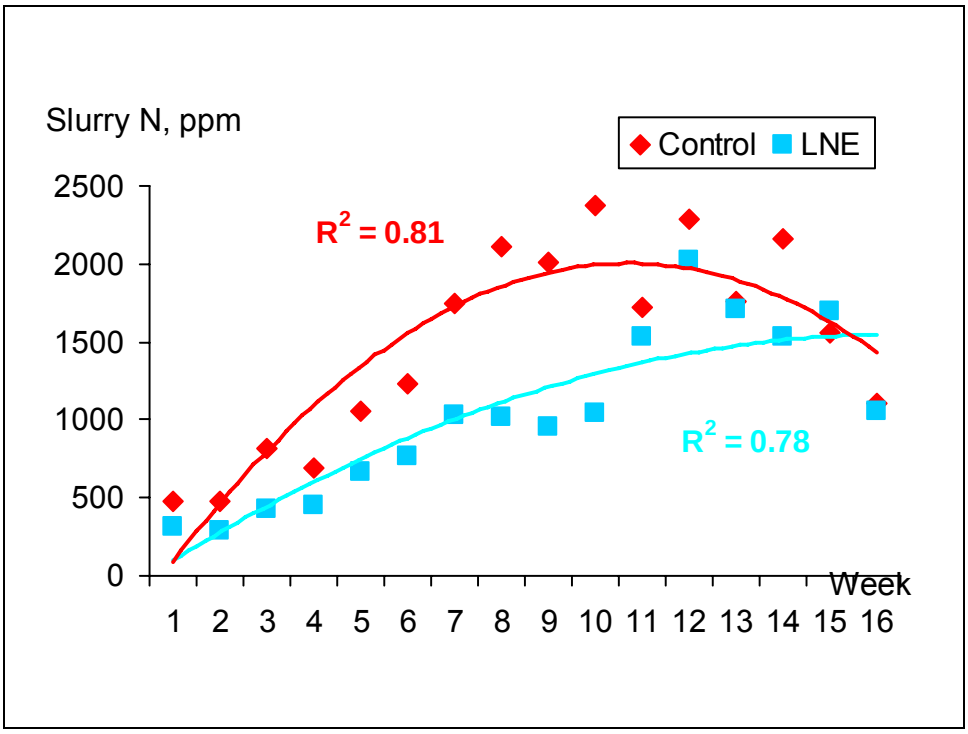


Figure VI.5. Slurry N concentration plotted versus week for pigs fed control or LNE diet (Exp. 3). [a]Least square means for 2 rooms (19 pigs per room) per treatment.

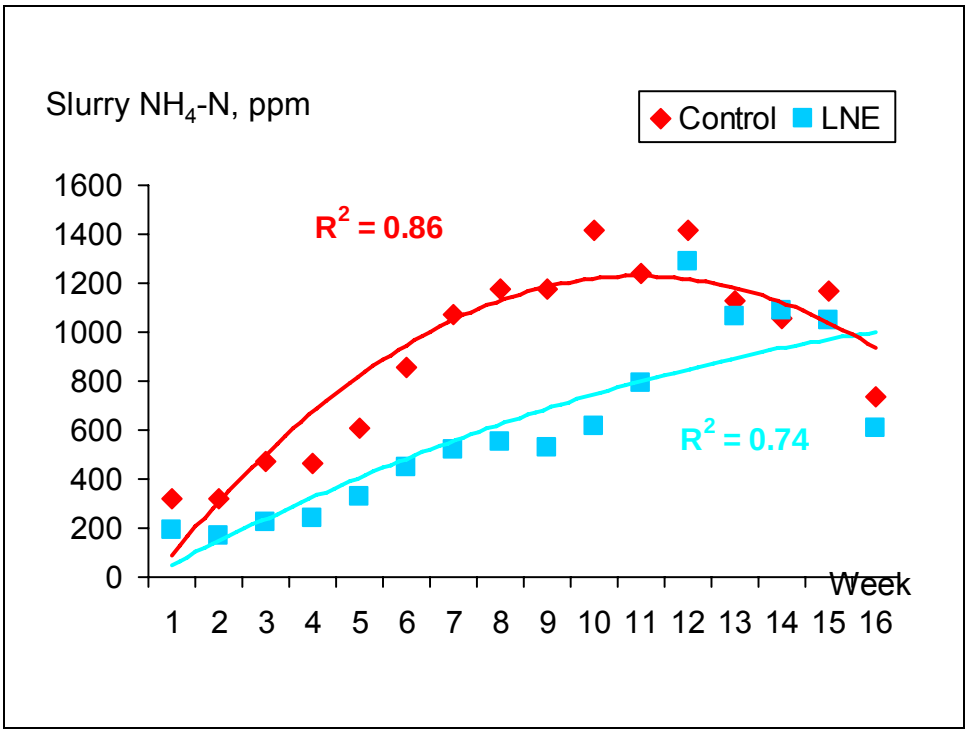


Figure VI.6. Slurry NH_4-N concentration plotted versus week for pigs fed control or LNE diet (Exp. 2). [a]Least square means for 2 rooms (19 pigs per room) per treatment.

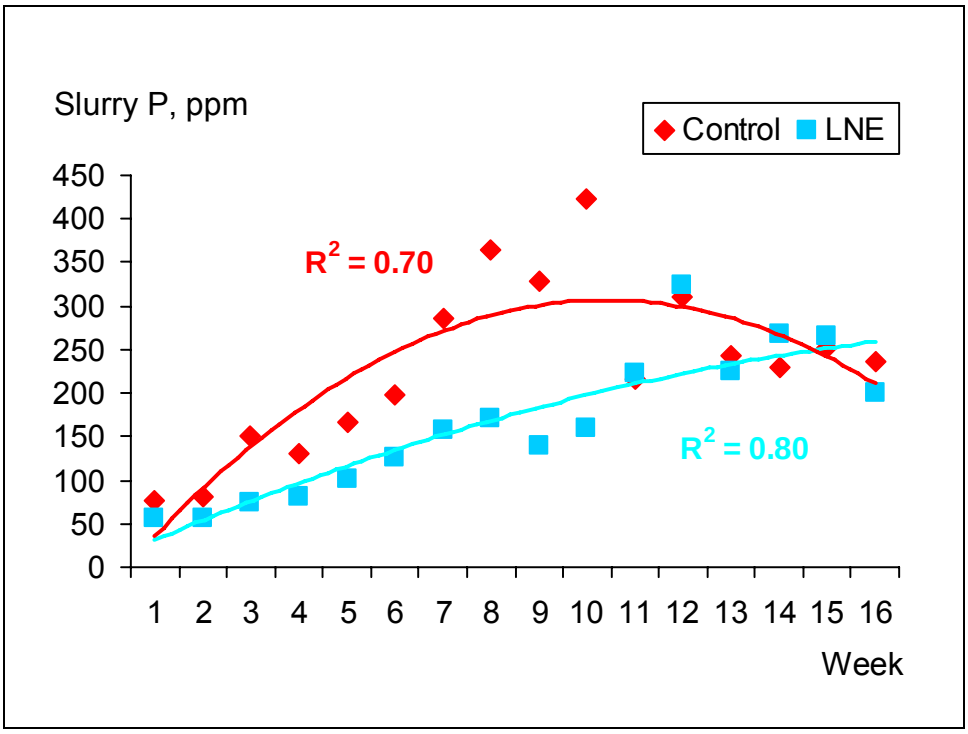


Figure VI.7. Slurry P concentration plotted versus week for pigs fed control or LNE diet (Exp. 3). [a]Least square means for 2 rooms (19 pigs per room) per treatment.

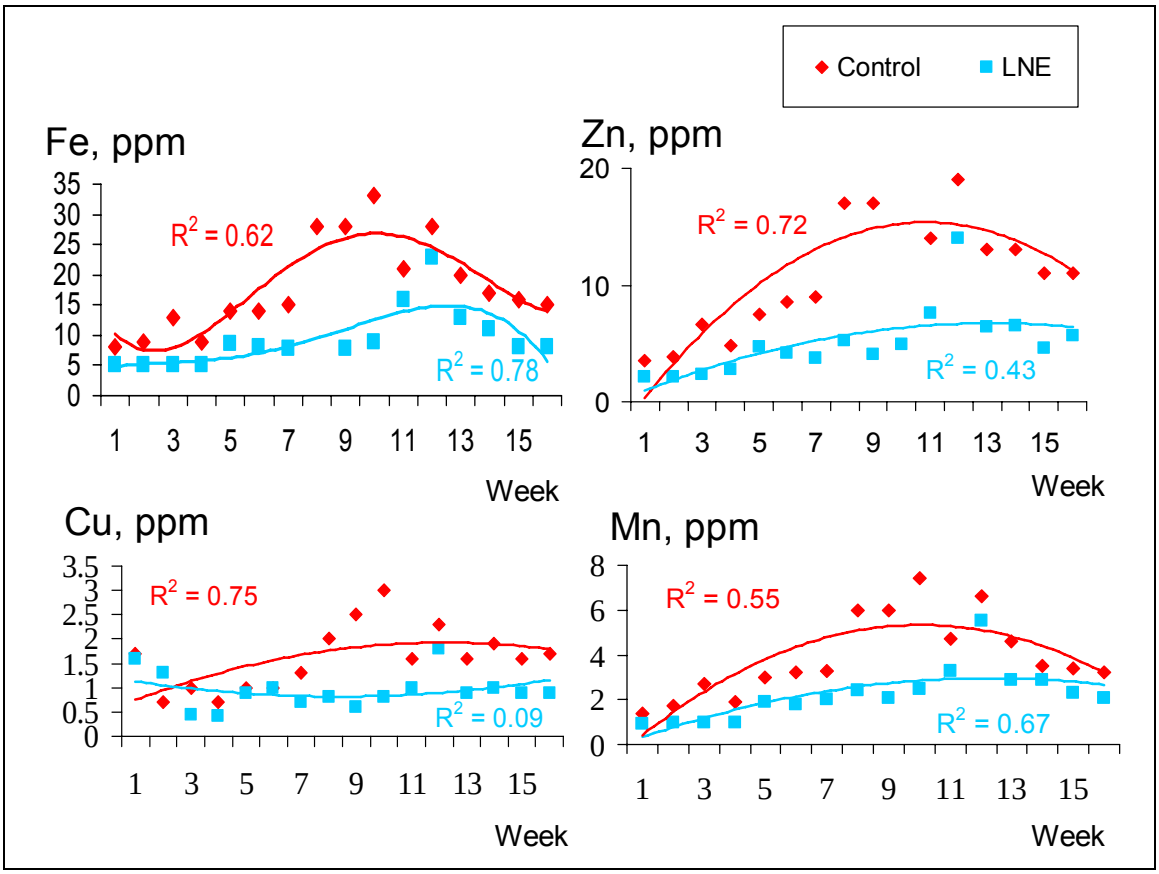


Figure VI.8. Slurry Fe, Zn, Cu and Mn concentration plotted versus week for pigs fed control or LNE diet (Exp. 3). [a]Least square means for 2 rooms (19 pigs per room) per treatment.

Table VI.7. Effect of reduced dietary crude protein and phosphorus on slurry nutrient concentration, DM basis (Exp. 3)[a].

	Dietary treatment[b]			
	Control	LNE	SE	P <
DM, %	1.21	1.04	0.01	0.05
	%, DM basis			
C	43.0	44.6	0.04	0.02
N	11.4	9.0	0.21	0.02
NH_4-N	6.99	5.02	0.16	0.01
P	2.11	1.57	0.06	0.02
WSP	1.88	1.44	0.06	0.04
Ca	2.71	2.32	0.05	0.03
K	5.37	4.73	0.17	0.12
Mg	1.05	1.07	0.02	0.63
Na	1.50	1.73	0.04	0.01
	ppm, DM basis			
Fe	155.1	94.4	0.41	0.01
Zn	92.9	47.7	0.31	0.01
Cu	13.4	9.57	0.04	0.03
Mn	33.0	21.3	0.08	0.01
C:N ratio	3.76	4.96	0.01	0.01
N:tP ratio	5.40	5.71	0.07	0.09
WSP:tP	0.89	0.91	0.04	0.71

[a]Least square means for 2 rooms (19 pigs per room) per treatment.
[b]Control: corn-soybean meal diet. LNE: 3% units reduced CP and 0.1% unit reduced P diet.

Table VI.8. Effect of reduced dietary crude protein and phosphorus on daily and cumulative nutrient excretion, 110 days (Exp. 3)[a].

	Dietary treatment[b]			
	Control	LNE	SE	P <
Daily excretion		g/pig		
DM	293	259	4.18	0.03
C	126	116	8.97	0.86
N	33.5	23.3	0.64	0.01
NH_4-N	20.5	13.0	0.27	0.01
P	6.20	4.09	0.15	0.01
Ca	7.95	5.94	0.12	0.01
K	15.8	12.2	0.47	0.01
Mg	3.08	2.74	0.03	0.01
Na	4.40	4.46	0.17	0.01
		mg/pig		
Fe	455	240	16.9	0.01
Zn	273	122	12.8	0.01
Cu	39.3	24.5	1.87	0.03
Mn	97.0	54.3	3.59	0.01
		as % of intake		
DM	15.2	13.8	0.36	0.11
N	62.7	51.9	1.93	0.06
P	63.4	55.4	2.55	0.16
Ca	53.1	51.2	1.48	0.47
K	91.9	88.7	3.95	0.62
Cumulative excretion		kg/pig		
DM, kg/pig	32.2	28.5	0.46	0.03
C, kg/pig	13.8	12.7	0.98	0.50
N, kg/pig	3.67	2.56	0.07	0.01
P, kg/pig	0.68	0.45	0.02	0.01

[a]Least square means for 2 rooms (19 pigs per room) per treatment.
[b]Control: corn-soybean meal diet. LNE: 3% units reduced CP and 0.1% unit reduced P diet.

Table VI.9. Air flow, ammonia and hydrogen sulfide emissions from finishing pigs fed a traditional corn-soybean meal diet or low nutrient excretion (110 days) (Exp. 3)[a].

	Dietary treatment[b]			
	Control	LNE	SE	P <
Air flow, m^3/min	46.1	45.7	1.22	0.88
NH_3, mg/m^3	0.863	0.418	0.02	0.04
NH_3, mg/min	29.8	12.8	0.51	0.03
NH_3, g/pig/d	2.32	1.02	0.02	0.02
H_2S, µg/m^3	7.36	8.65	0.66	0.39
H_2S, µg/min	240.1	262.7	9.24	0.47
H_2S, mg/pig/d	19.0	20.5	0.97	0.33

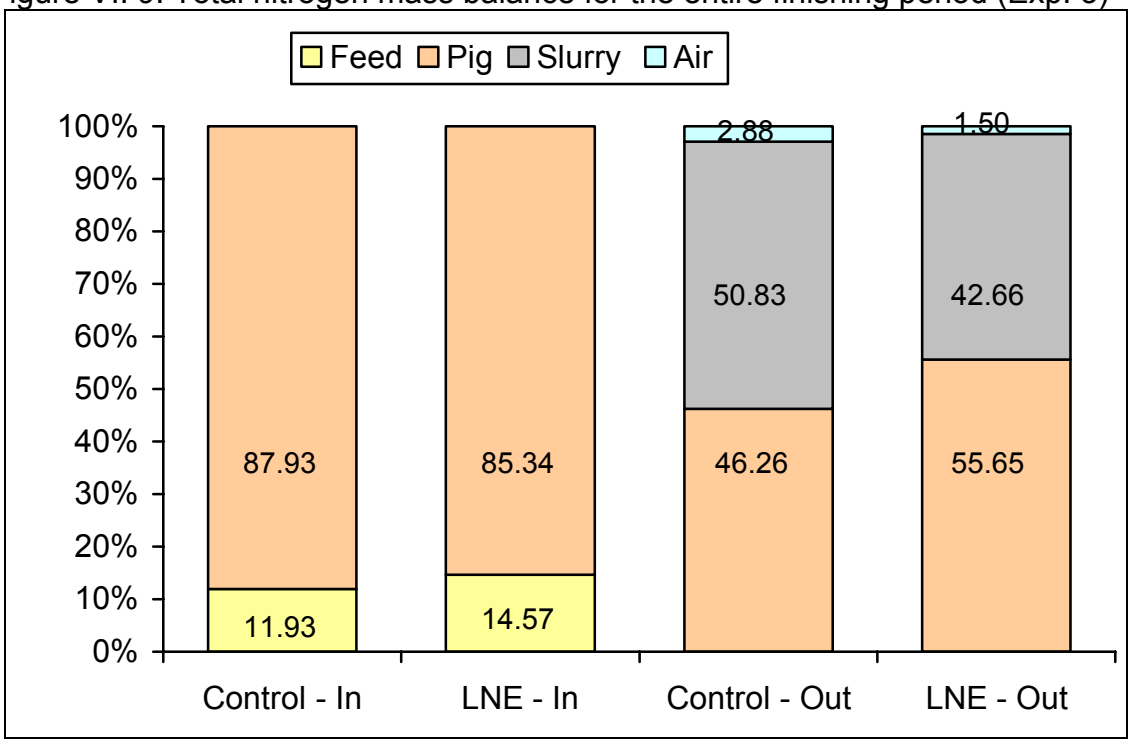
[a]Least square means for 2 rooms (19 pigs per room) per treatment.
[b]Control: corn-soybean meal diet. LNE: 3% units reduced CP and 0.1% unit reduced P diet.

Table VI.10. Estimated mass balance for N and P for the entire finishing period, 110 days (Exp. 3)[a]

	Dietary treatment[b]			
	Control	LNE	SE	P <
Total N entering, kg/pig	7.01	5.73	0.03	0.03
Pig initial N, kg/pig	0.837	0.835	0.01	0.30
Feed N, kg/pig	6.17	4.89	0.03	0.01
Total N exiting, kg/pig	7.22	5.93	0.02	0.02
Pig N, kg/pig	3.34	3.30	0.04	0.60
Slurry N, kg/pig	3.67	2.53	0.06	0.05
Ammonia N, kg/pig	0.208	0.089	0.01	0.03
N mass balance, kg/pig	-0.21	-0.20	0.01	0.50
Total P entering, kg/pig	1.207	0.945	0.01	0.03
Pig initial P, kg/pig	0.151	0.151	0.07	0.32
Feed P, kg/pig	1.056	0.793	0.07	0.03
Total P exiting, kg/pig	1.125	0.894	0.09	0.04
Pig P, kg/pig	0.445	0.450	0.03	0.40
Slurry P, kg/pig	0.680	0.444	0.07	0.03
P mass balance, kg/pig	0.083	0.051	0.02	0.05

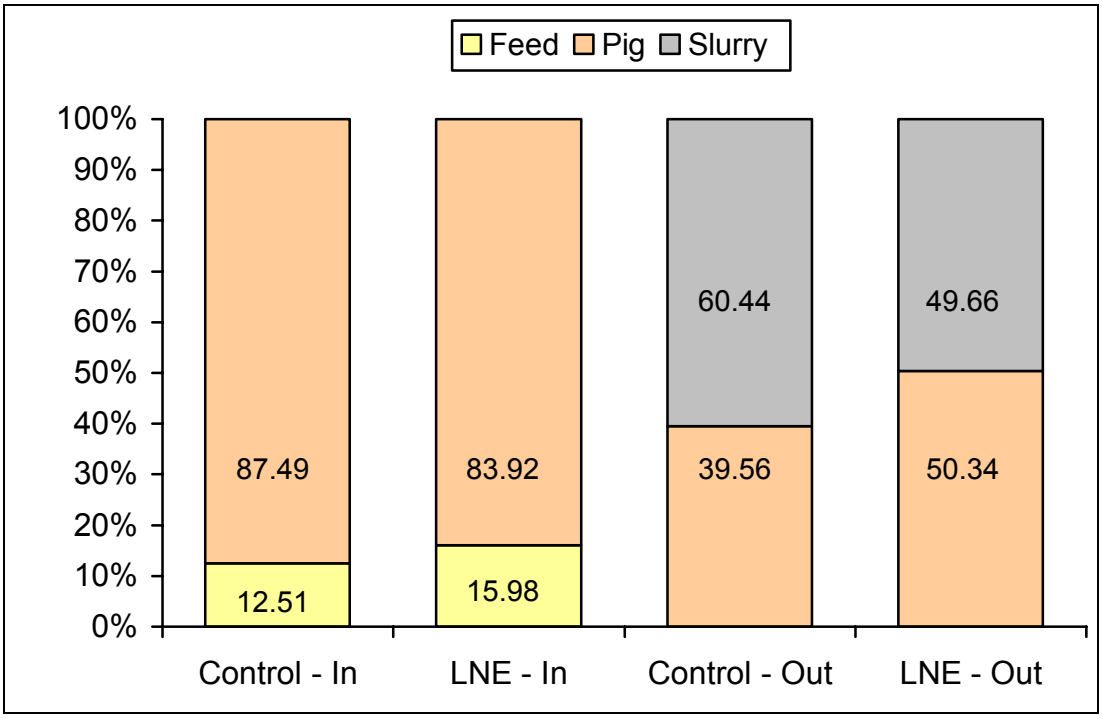
[a]Least square means for 2 rooms (19 pigs per room) per treatment.
[b]Control: corn-soybean meal diet. LNE: 3% units reduced CP and 0.1% unit reduced P diet.

Figure VI. 9. Total nitrogen mass balance for the entire finishing period (Exp. 3)[ab]



[a]Least square means for 2 rooms (19 pigs per room) per treatment.
[b]Control: corn-soybean meal diet. LNE: 3% units reduced CP and 0.1% unit reduced P diet.

Figure VI.10. Total phosphorus mass balance for the entire finishing period (Exp. 3)[ab]



[a]Least square means for 2 rooms (19 pigs per room) per treatment.
[b]Control: corn-soybean meal diet. LNE: 3% units reduced CP and 0.1% unit reduced P diet.

CHAPTER VII

DISCUSSION

Growth performance and nutrient intake

Initially all pigs had similar weight, and were fed to a target weight. The days to slaughter were not affected when dietary CP was reduced by 2 and 3% units, and P was reduced by 0.1% unit. Further reduction in dietary CP by 4% units, with the 0.1% unit reduction in P, increased the duration of the finishing period by 7 days. The increase in days to slaughter has been previously observed as a linear response as dietary crude protein concentration decreased from 18 to 10% CP (gilts with 40 kg initial W); although, there no statistical differences in growth traits were detected when the reduction in dietary protein was from 16 to 12% (Figueroa et al., 2002). Other studies support that the reduction in pig growth performance of pigs fed diets where CP has been reduced by 4% units or more is associated with limited supplies of valine, histidine, and/or non-essential amino acids (Figueroa et al., 2002, Figueroa et al., 2003). Also, it has been suggested that the reduction in dietary P by 0.1% unit may decrease ADG by 18% and feed efficiency by 3% (Harper et al., 1997). Therefore, it is possible that the differences in growth detected in this study could be associated with the reduced level of phosphorus in the diet with a limited supply of non-essential amino acids.

The reduction of dietary CP and P, in Experiments 1, 2 and 3, in addition to the reduction in dietary trace mineral supplementation, in Experiment 3, did not affect DM intake, ADG, ADFI, and F:G. Although in Experiment 3, when pigs were fed the LNE, ADG was numerically increased, in addition to a numeric decrease in ADFI and F:G ratio. The similarity in DM intake, ADG, ADFI, and F:G of pigs fed diets with reduced protein by less than 3% units has been widely supported (Tuitoek et al., 1997; Figueroa et al., 2002; Figueroa et al., 2003; Deng et al., 2007b). When a similar study was performed including sex as factor of study, the reduction in dietary CP resulted in increased feed intake of gilts, but not of barrows (Figueroa et al, 2004). However, it has been suggested that further reductions in dietary CP by 4% units or more may decrease ADG and increase the F:G ratio (Tuitoek et al., 1997; Gomez et al., 2002; Figueroa et al., 2002; Figueroa et al., 2003; Figueroa-Velazco et al., 2004; Deng et al., 2007a). Also, the numerical increased ADG, plus the numeral reduction in ADFI has been previously reported in growing gilts fed a diet with approximately 75% reduction in trace mineral supplementation (Creech et al., 2004).

Although, feed and DM intake were not affected by the reduction in dietary CP, N and trace minerals, the daily intake of N, P, Ca, K, Mg, Zn, and Fe tended to be reduced when the reduction in dietary CP was by 2% units, and the further reduction in dietary CP by 3 and 4% units reduced N, P, Ca, K, Mg, Zn, and Fe daily intake. The reduction in intake of the nutrients previously mentioned is explained through the reduction in those nutrients in the diet, without any increase in feed intake. As the reduction in dietary CP increases in the LNE diet,

the inclusion level of soybean meal in the LNE decrease, and with it the concentration of the nutrients provide by the soybean meal. In Experiments 1 and 2, daily Na, Cu, and Mn intake was similar for both dietary treatments, because the concentration of these nutrients in the LNE diet was similar to their concentration in the control diet. However, in Experiment 3, Fe, Cu, Zn and Mn daily intake was reduced when LNE was fed.

Carcass characteristics and bone breaking strength

In all the Experiments pigs were fed to a target weight. Therefore, live weight and hot carcass weight were not affected by diet. Reductions in dietary CP, P, and trace minerals in these Experiments did not affect backfat depth and carcass yield. However, LMA tended to be reduced, and fat-free lean was reduced when dietary CP was reduced by 4% units. Previous experiments have reported similar results, when pigs were fed a diet with a 4% units reduction in CP without reduction in ME (Kerr et al., 1995; Tuitoek et al., 1997; Le Bellego et al., 2001). Our results are in agreement with results from other studies which suggest that the reduction in dietary crude protein could have little effect on backfat depth and LMA (Kerr et al., 2003b; Figueroa-Velasco el at., 2004). However, in Experiment 2, the tendency to reduce LMA and increase backfat by feeding LNE have confounded the effects of the 4% unit reduction in dietary CP, with the effects of the 0.1% unit reduction in dietary P. Therefore, an effect of limited P availability, or an interaction effect between available P and limited amino acids can not be discharge. The reports concerning the impact of reduced CP diets on carcass

characteristics has been very variable, and the reasons are not very clear. The increase in backfat and the reduction of the LMA reported by Kerr et al. (1995) could be due to a limited sulfur amino acid supply in the reduced CP diet. It is possible, that the increase in backfat, and reduction in LMA that has been reported are associated with a limited amino acid supplementation in reduced CP diets (Kerr and Easter, 1995; Kerr et al., 1995; Tuitoek et al., 1997; Figueroa-Velasco et al., 2004). The reduction in LMA in addition to the increased fat deposition could be attributed to an increase in NE in the reduced CP diets (Kerr et al., 1995). It also has been suggested, that muscle and fat deposition could be sensitive to the N concentration in the diet (Kerr et al., 1995).

Bone strength was not affected by the reduction in dietary P by 0.1% unit when dietary CP was reduced by 2 and 3% units. However, metacarpal strength was numerically reduced in Experiment 2, where dietary P was also reduced by 0.1% unit but CP was further reduce by 4% units. Again, our results suggest that could be an interaction effect between dietary P and CP levels. Perhaps the numerical reduction in metacarpal strength in Experiment 2, a difference was not detected. Also in Experiment 2, metatarsal and the average of metacarpal and metatarsal strength were not affected by the reductions in dietary CP and P.

Body composition and nutrient accretion rate

Initial and final body composition and nutrient accretion rate was estimated only in Experiment 3. The estimated initial water, CP, ash, fat, and N content is close to previous reports using pigs with 21 to 37 kg of body weight (Ferrell and

Cornelius, 1984; Mahan and Shields, 1998; Lange et al., 2003). However, the previous reports available used pigs of different genotype ((HxY), Ferrell and Cornelius, 1984; [D(HxYxD)], Mahan and Shields, 1998). Our pigs initial body weight was 28 kg and were crossbreed [Dx(YxL)]. Additionally, these reports corresponded to empty body composition; in contrast our data was generated using whole body composition. Reductions in dietary CP, P and trace minerals during the finishing phase did not affect final whole body water, CP, ash, fat, N and P content. Also, accretion rates of water, CP, ash, fat, N and P were similar for both diets.

Slurry characteristics

In the three experiments, the volume of slurry produced per pig, and the slurry temperature were similar across all rooms. The similar slurry volume for both treatment groups is in agreement with a previous report (Canh et al., 1998). Although, in that study (Canh et al., 1998) the amount of water supply to the pig was fixed; therefore, is possible that with free access to water their results could be different. However, the results of the present study are in conflict with result from other study that supports that reduction in dietary protein reduces water intake, and urine volume, which results in similar reduction in slurry volume (Portejoie et al., 2004). A possible explanation for the difference detected in water intake Portejoie et al. (2004) is the reduction of water intake due to a reduction in feed intake of pigs fed the reduced protein diet. However, in our case neither feed intake nor water intake were affected by feeding the LNE diet.

The EC of slurry from pig fed a LNE with a 3 and 4% units reduction in dietary CP was reduced. The reduction in EC indicates decreased concentrations of salts in slurry. The observed reductions in EC in Experiments 2 and 3 can be associated with reduced concentration of Ca and Mg in the slurry from pigs fed LNE. Reductions in slurry salinity may also reduce the risk of soil salinization due to long term land application of swine slurry or effluent in cropping areas (Brady and Weil, 1999). Also, slurry pH tended to be reduced when dietary CP was reduced by 3 and 4% units. The reduction in slurry pH has been previously reported from a balance study where pigs were fed a diet with a reduction in CP of 4% units which resulted in a reduction of slurry pH by 1 unit (Canh et al., 1998). However, when the same diet was fed to pigs housed in a barn, the reduction in slurry pH decreased by 0.3 units (Canh et al., 1998).

The DM concentration of the slurry was not affected by the reduction in dietary CP and P in the LNE from Experiments 1 and 2. However, in Experiment 3, where, in addition to the reduction in dietary CP and P, trace mineral supplementation was sequentially reduced from phase 1 to phase 4, DM concentration in slurry was reduced by 12%. Additionally, C concentration in slurry was not affected by dietary manipulation in Experiments 1 and 2. Therefore, the reduction in slurry DM concentration may be mainly associated with reduction in slurry mineral concentration. The reduction in dietary CP by 2 to 4% units decreased slurry concentration of total N by 18 to 40%. In addition, the reduction in dietary CP by 3 and 4% units reduced ammonium N concentration in the slurry from pigs fed LNE by 28 and 56%, respectively.

These results are in agreement with previous reports in which the reduction in slurry N concentration was explained by the reduction of urinary N (Canh et al., 1998). It also has been reported that NH_4-N concentration in slurry is one of the main factors that influence slurry pH (Sommer and Husted, 1995). Therefore, the reduction in NH_4-N can be associated with the tendency to reduce slurry pH when pigs were fed LNE with 3 or 4% units reduction in CP.

The 0.1% unit reduction in dietary P in LNE reduced slurry P concentration, on a DM basis, by 23% (Experiments 1 and 2) with a further reduction by 26%, when phytase was added to the reduced P diet (Experiment 3). The reduction in P concentration in slurry is associated with the 24% reduction in P intake. Also in Experiment 2, slurry Ca concentration tended to be reduced when pigs were fed LNE, and in Experiment 3 was reduced by feeding LNE. However, it could be associated with variations in the ratio of soluble Ca to other minerals in luminal content.

In Experiment 2, slurry K concentration was also reduced when pigs were fed LNE and Mg concentration tended to be reduced. The reduction in K slurry concentration could be associated with the reduction in soybean meal inclusion in the LNE. Potassium concentration in soybean meal is approximately 2% (NRC, 1998). To reduce dietary CP by 4% unit in the LNE, soybean meal inclusion was reduced by 44 to 73%, in phase 1 to phase 3. Therefore, K concentration in LNE could be reduced by 1 to 1.5%. Also, the reduction in soy bean meal inclusion may be associated with the reduction in Mg concentration. Slurry Na concentration was increased when pigs were fed LNE diets where CP

was reduced by 3 and 4% units. The trace mineral concentration in slurry, Fe, Zn, Cu and Mn, was not affected by reduction of dietary CP and P in the LNE diets in Experiments 1 and 2. However, in Experiment 3, the LNE diet was reduced in CP, P and trace mineral concentration. The reduction in trace mineral concentration in the LNE reduced trace mineral concentration in slurry by approximately 38%.

In Experiment 1 and 2, the C:N ratio was numerically increased when pigs were fed LNE. The trend to increase the C:N ratio in slurry is associated with the reduction in N concentration in slurry. In Experiment 3, the slurry C:N ratio was reduced, due to a increase in C concentration in addition to a reduction in N in slurry. Any increase in the slurry C:N ratio is desirable from the environmental point of view. Even more important in systems were swine slurry is directly applied to cropping land. The C:N ratio in an stabilized soil ranges between 8:1 and 15:1 (Brady and Weil, 1999). The addition of organic mater with C:N ratio below 20 to the soil may result in release of N to the soil solution, and soluble N may exceed soil microorganism and plant uptake capacity (Brady and Weil, 1999).

In Experiment 3, feeding LNE tended to increase the slurry N:tP ratio, but the ratio of WSP:tP was not affect. It is very important that phytase inclusion in the LNE diet in Experiment 3 not only seams to improve P availability, reducing P concentration in slurry; it also reduced water soluble P concentration in slurry in a similar proportion (by 23%). These results are in agreement with a previous report which suggested that phytase addition to diets formulated with low phytate

soybean reduced total P and water soluble P in waste (Powers et al., 2006). The increase in water soluble P as fraction of the total P in waste was not observed in our experiment. Therefore, the effect of phytase addition on water soluble phosphorus in waste could be a function of total P to available P ratio in the feed.

Nutrient excretion

The nutrient concentration in the slurry was multiplied by the slurry volume and divided by the number of pigs to estimate nutrient excretion on a per pig basis. In Experiments 1 and 2, daily DM excretion was not affected by dietary manipulation in LNE. However, in Experiment 3, daily DM excretion was reduced by 12%. Recall that in Experiment 3 dietary trace mineral supplementation was reduced in the LNE, in addition to the reductions in CP and P. Daily carbon excretion was not affected by feeding LNE, in all 3 Experiments. Therefore, we can infer that the reduction in DM excretion detected in Experiment 3, when pigs were fed LNE, was may be due to a reduction in mineral excretion.

Nitrogen excretion was reduced by reduction of dietary CP in LNE (Figure VII.1). In Experiment 1, pigs fed LNE with a 2% units reduction in dietary CP excreted 21% less N than pigs fed the control diet. In Experiment 2, the reduction in CP was by 4% units, and decreased N excretion of pigs fed LNE by 41%. In Experiment 3, the 3% unit reduction in dietary CP decreased N excretion by 30% when pigs were fed LNE. Also, ammonium N in waste was reduced when dietary CP was reduced in LNE. In Experiment 1, the 2% unit

reduction in dietary CP reduced ammonium N concentration in waste by 26%. In Experiment 2, a further reduction in dietary CP by 4% units decreased ammonium N in waste by 56%. In Experiment 3, the 3% units reduction in dietary CP decreased ammonium in waste by 37%. Therefore it can be expected a reduction by 10% in daily N excretion and 13% in ammonium N in waste per each percentage unit reduction in dietary CP (Figure VII.1). Previous studies have reported a similar response (Kerr et al., 1995, Htoo et al., 2007). Other studies reported lower reductions in N excreted, such as 8% (Zervas and Zijlstra, 2002, Deng et al., 2007) and 6% for every 1% unit reduction in CP (Zervas and Zijlstra, 2002a). It is also important to note, that daily N excretion from pigs fed the control diet in all three experiments ranged from 32.3 to 34.7 g/pig (Figure VII.1).

In Experiments 1 and 2, the 0.1% unit reduction in dietary P reduced daily P excretion by 24% when pigs were fed LNE. The addition of phytase (500 FYT/kg) to the LNE, in Experiment 3, enhanced the reduction in daily P excretion to 35% (Figure VII.2). The reduction in daily P excretion by 31 to 35% in pigs fed a diet with a 0.1% unit reduction in P and addition of 500 FYT was previously reported (Kornegay and Harper, 1997; Liu et al., 1998). Note that comparing results from the three experiments, daily P excretion from pigs fed the control diets ranged from 6.2 to 6.8 g/pig (Figure VII.2).

In Experiments 1 and 2, mineral excretion was poorly affected by the diet. Daily K excretion was numerically reduced by feeding LNE, additionally in Experiment 2, daily Mn excretion was reduced when pigs were fed the

experimental diet. However, in Experiment 3, trace mineral supplementation was reduced in LNE. When pigs were fed LNE in Experiment 3, daily excretion of Ca, K, Mg, Fe, Zn, Cu, and Mn was reduced. Only daily Na excretion was increased with LNE. The overall macro-mineral excretion, with exception of Na, was reduced by 20% (Figure VII.3) and micro-mineral excretion by 46% (Figure VII. 4).

In all three Experiments, the excretion of all nutrients studied expressed as percentage of the intake was similar, with the exception of N excretion, which was numerically decreased when pigs were fed LNE. The reduction in N excretion as percent of intake was also observed by Zervas and Zijlstra (2002) and Deng et al (2007). In Experiment 1, cumulative N and P excretion were numerically reduced by feeding LNE. In Experiment 2, cumulative N and P excretion were numerically reduced by 1.36 and 0.14 kg/pig, respectively, in pigs fed LNE. Although, in Experiment 2, daily N and P excretion were statistically reduced for pigs fed the LNE, the increase of the finishing period by 7 days when pigs were fed LNE resulted in the loss of significance for the difference in cumulative excretion for N and P. However, from a practical point of view, the reduction of 1.36 kg of N, and 0.14 of P going to waste treatment, per finished pig, can be very attractive to swine producers. In Experiment 3, the reduction in daily and cumulative DM, N and P excretion when pigs were fed LNE were similar. Cumulative DM, N and P excretion were decreased by 12, 30, and 34%, respectively for the entire finishing period. In Experiments 1 and 2, the reduction in dietary CP and P levels in the diet had very little effect on the total amount of

minerals excreted over the entire growth-finishing period. However, in experiment 3, daily and cumulative mineral excretion was reduced in similar proportion. In Experiment 3, feeding LNE markedly decreased cumulative mineral excretion.

Air flow, ammonia and Hydrogen sulfide emissions

In Experiment 3, besides measuring nutrient excretion we were able to monitor air flow, ammonia and hydrogen sulfide emissions during the entire finishing period. Air flow was similar for all rooms. However, when pigs were fed LNE with a 3% units reduction in dietary CP ammonia emission was reduced by 56% (Figure VII.5), thus, each percentage unit reduction in dietary CP reduced ammonia emitted by 19%. Reduction of dietary CP has been previous reported as an effective strategy to reduce ammonia emission (Portejoie et al., 2004; Velthof et al., 2005; Panetta et al., 2006). Our results are in agreement with previous reports from laboratory studies; a 4% units reduction in dietary CP reduced ammonia emission by 54% (Velthof et al., 2005). Other laboratory study suggested that a 3% units reduction in dietary CP reduced ammonia emitted by 58% (Panetta et al., 2006). However, there was no comparable data from swine facilities with group fed pigs. Although, feeding LNE reduced ammonia emission, hydrogen sulfide emission was not affected by diet (Figure VII.5). This result is in agreement with a previous study that report that a reduction in dietary sulfate by 0.1% unit did not reduced hydrogen sulfide emission (Clark et al., 2005). However, when dietary sulfate was increased by 0.1% unit hydrogen sulfide emission increased (Clark et al., 2005).

Nitrogen and phosphorus mass balance from the finisher

In experiment 3, N and P mass balance for the entire finishing phase was estimated. The N and P mass balance estimation assumed that N and P entered the finisher via the pig and the feed, and exited the finisher via feed and waste. In this case waste was composed by slurry and emissions in exhaust air. The contribution of N and P from water and inlet air was insignificant, thus it was assumed to be zero. The partitioning of N and P entering the system via the pig and via the feed was modified by diet. When pigs were fed LNE the proportion of N entering the finisher via the feed was reduced by 3% units, and the partitioning shifted toward entering via pig. Therefore, the proportion of N entering via the pig was increased by 3% units. This was also true for P entering the finisher. Feeding LNE reduced the proportion of P entering the finisher via the feed by 3% units and increased the proportion entering via the pig by 3% units. Also the proportional distribution of N and P leaving the finisher via pig, slurry and air was modified by feeding LNE. Feeding LNE increased the proportion of N exiting the finisher as a market pig by 10% units, and reduced the proportion exiting via slurry and ammonia emitted by 8 and 1.4% units, respectively. Again, this was also true for P exiting the finisher. The proportion of P exiting the finisher via a finished pig increased by 10% units, at a time that P exiting the finisher via the slurry was reduced in similar proportion. Thus, LNE reduced total N and P exiting by 18 and 21%, respectively. The proportion of N and P entering the finisher that exited via the pigs increased from 47 to 58% for N and 37 to 48% for P for pigs fed LNE compared with those fed the control. The shift in proportional

distribution in the finisher N and P mass balance can be explained. The shift in N and P entering the finisher was due to the reduction in dietary N and P in LNE without changes in pig feed intake, pig initial composition and initial body weight. The shift in N and P exiting the finisher can be attributed to the reduction of N and P excretion, and ammonia emitted, with no change in finisher pig final composition and body weight. Additionally, it is important to note that the difference in total N entering the finisher and total N exiting the finisher was approximately 200 g, and the difference of total P entering with total P exiting approximately 67 g.

Summary

Bases in our results, the reduction in dietary CP by 2% units and P by 0.1% unit reduced daily and cumulative N excretion by 21% and the concentration of ammonium in waste by 29%. Additionally, it reduced daily and cumulative P excretion by 24%, without negative effects on pig growth performance, carcass characteristics, and bone strength.

The 4% units reduction in dietary CP and 0.1% unit in P numerically reduced daily and cumulative N excretion by 40 and 38%, respectively, and reduced ammonium concentration in waste by 56%, and daily and cumulative P excretion by 25 and 20%, respectively. However, it increased the duration of the finishing period by 7 days, tended to reduce the longissimus muscle area, and reduced carcass fat-free lean.

The reduction in dietary CP by 3% units, P by 0.1% unit, addition of phytase, and reduction in trace mineral supplementation to the diet, reduced daily and cumulative N excretion by 31%, ammonium in waste by 37%, ammonia emission by 56%, daily and cumulative P excretion by 35%, and daily and cumulative trace mineral excretion by 46%. Additionally, pig growth performance, carcass characteristics, and bone strength were not affected by the reduced nutrient diet.

In overall, it can be expected per each percentage unit reduction in dietary CP a reduction in daily N excretion by 10%, in ammonium in waste by 13%, and 18% in ammonia emission.

The reduction in dietary CP, P, and trace mineral in grower and finisher diets can markedly reduce N, P, and trace mineral excretion, and ammonia emission, without affecting pig growth performance, carcass traits, and bone strength.

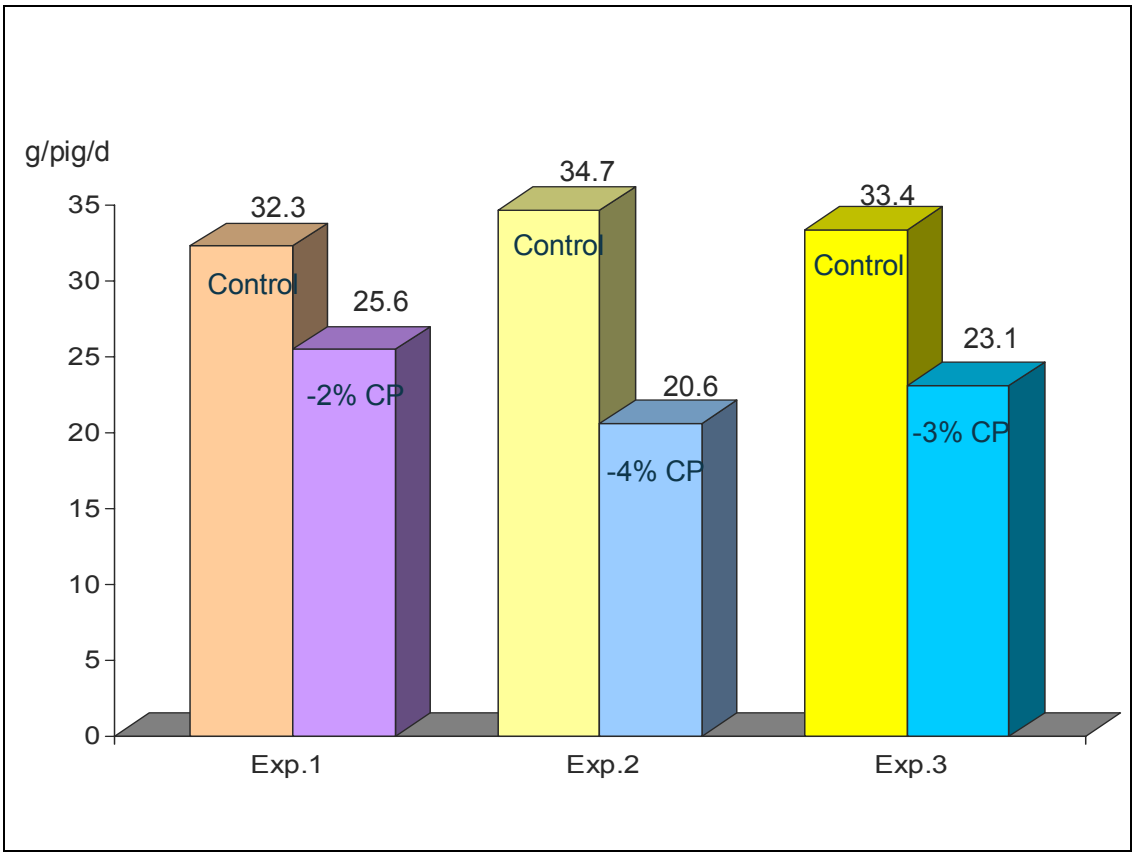


Figure VII.1. Comparison of results from the three Experiments for daily excretion of nitrogen
Control: corn-soybean meal diet. LNE: Low nutrient excretion diet.
Exp. 1: Experiment 1. Least square means for 2 rooms/treatment (12 pigs/room).
Exp. 2: Experiment 2. Least square means for 2 rooms/treatment (12 pigs/room).
Exp. 3: Experiment 3. Least square means for 2 rooms/treatment (19 pigs/room).

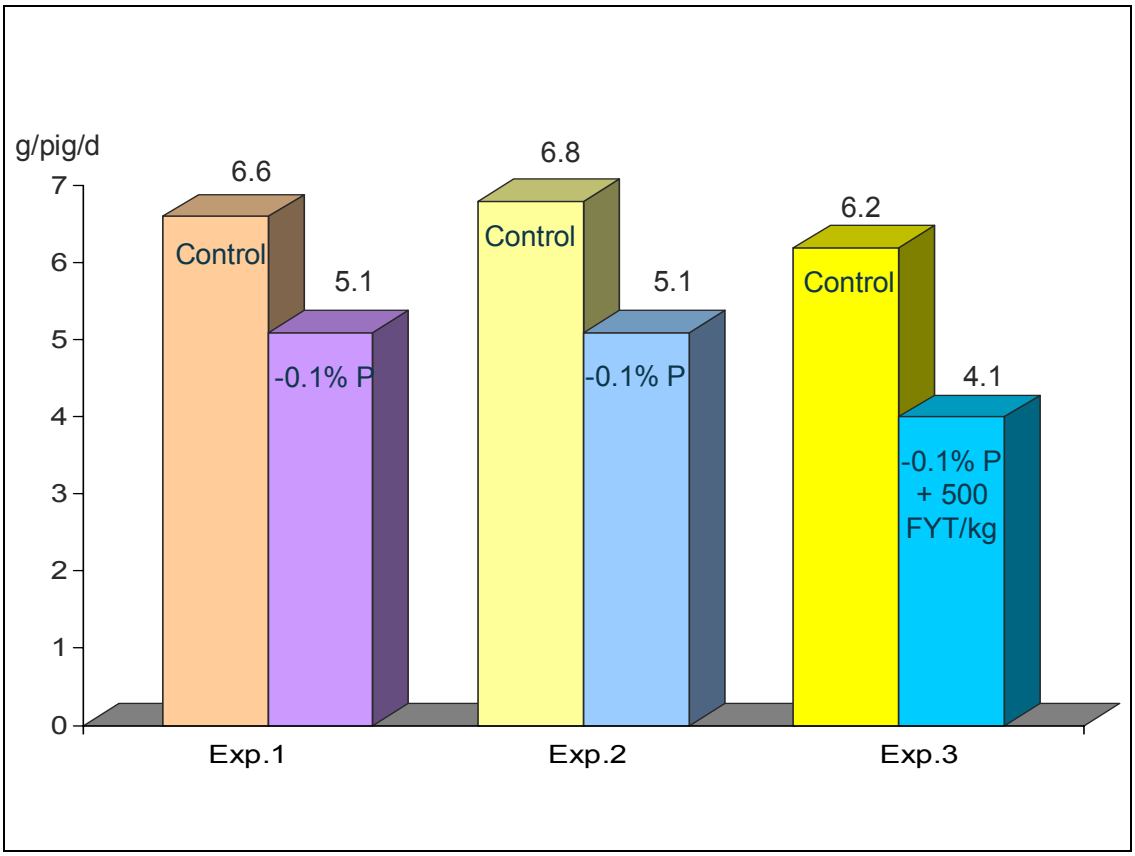


Figure VII.2. Comparison of results from the three Experiments for daily excretion of phosphorus
Control: corn-soybean meal diet. LNE: Low nutrient excretion diet.
Exp. 1: Experiment 1. Least square means for 2 rooms/treatment (12 pigs/room).
Exp. 2: Experiment 2. Least square means for 2 rooms/treatment (12 pigs/room).
Exp. 3: Experiment 3. Least square means for 2 rooms/treatment (19 pigs/room).

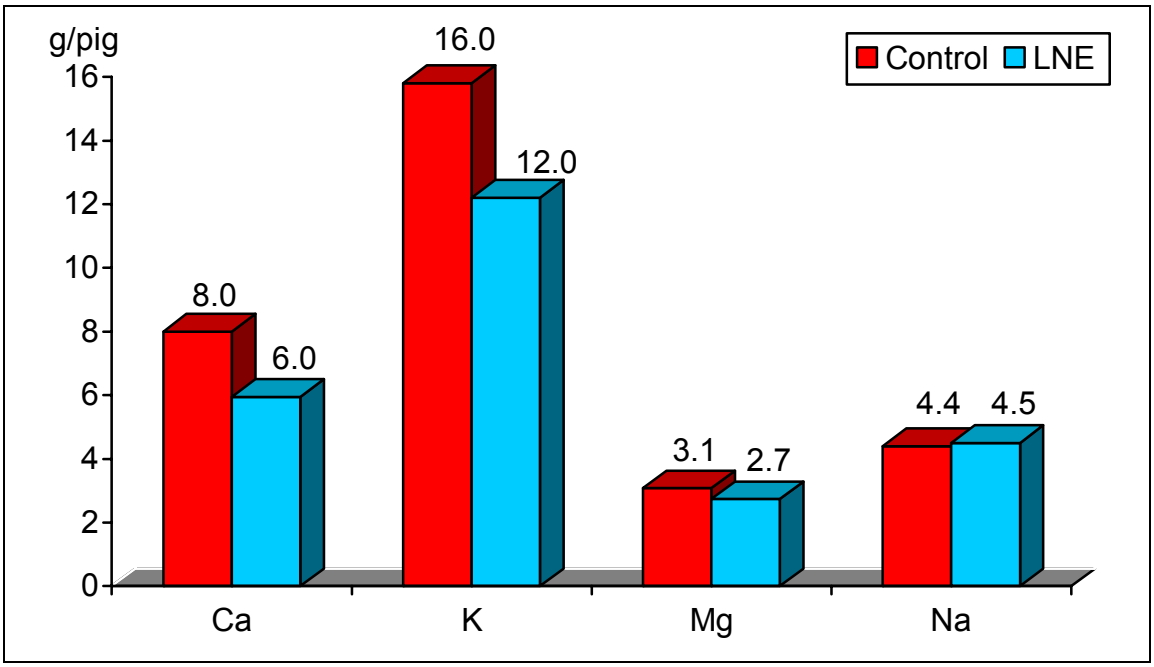


Figure VII.3. Macro-mineral daily excretion (Exp. 3)[a]
[a]Least square means for 2 rooms (19 pigs per room) per treatment.
Control: corn-soybean meal diet. LNE: 3% units reduced CP and 0.1% unit reduced P diet.

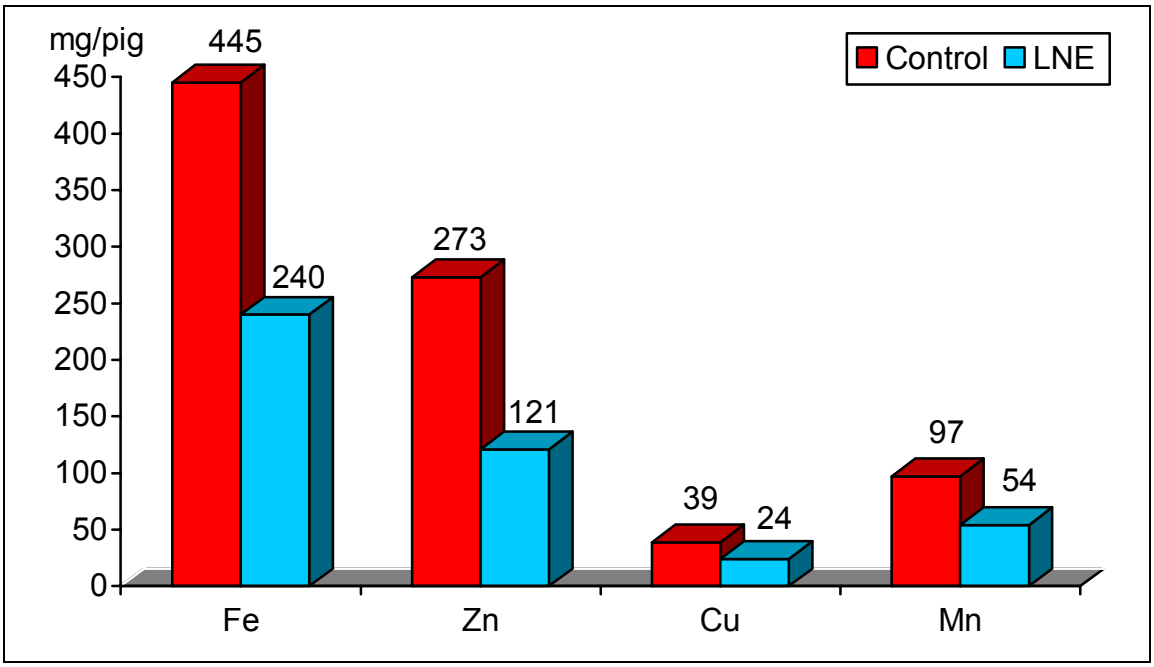


Figure VII.4. Micro-mineral daily excretion (Exp. 3)[a]
[a]Least square means for 2 rooms (19 pigs per room) per treatment.
Control: corn-soybean meal diet. LNE: 3% units reduced CP, 0.1% unit reduced P diet, with 500 FYT/kg, and reduced trace mineral supplementation.

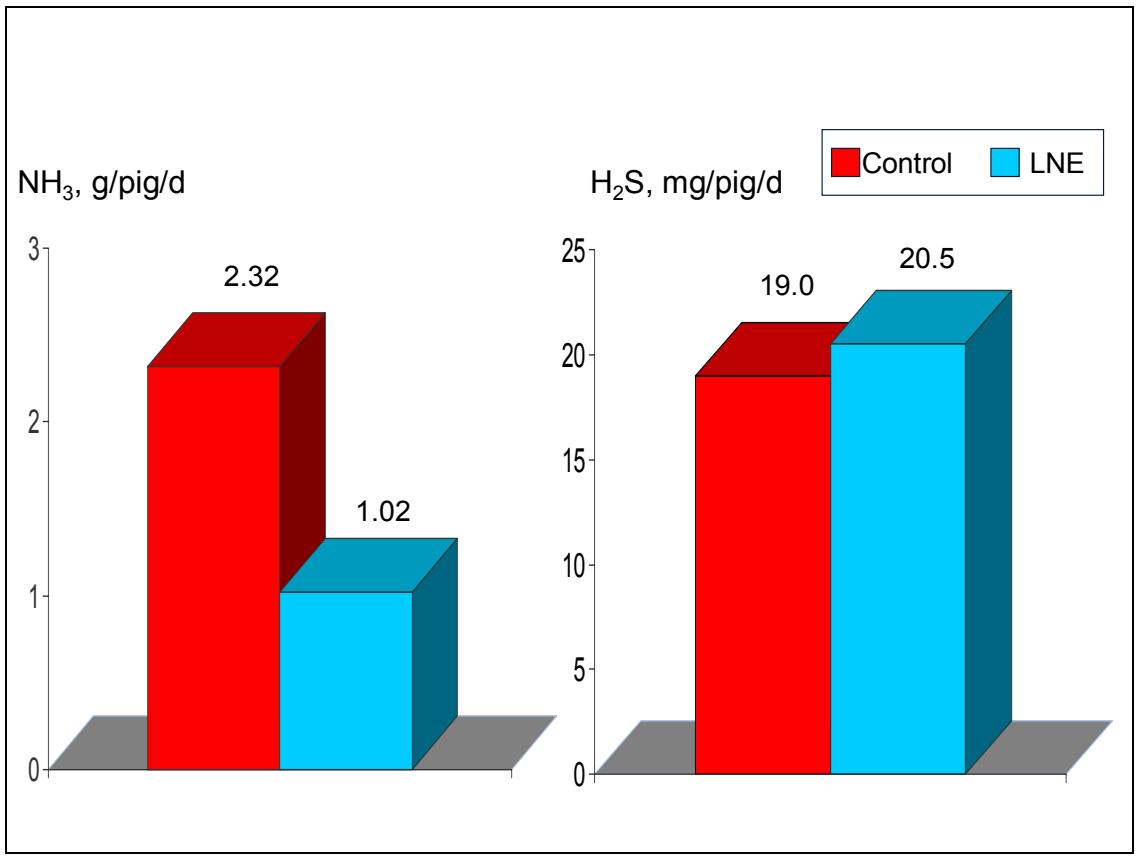


Figure VII.5. Daily ammonia and hydrogen sulfide emissions (Exp. 3)[a]
[a]Least square means for 2 rooms (19 pigs per room) per treatment.
Control: corn-soybean meal diet. LNE: 3% units reduced CP, 0.1% unit reduced P diet, with 500 FYT/kg, and reduced trace mineral supplementation.

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APPENDIX

Appendix Table 1

Pig means for days on test, initial and final weight, average daily gain, average daily feed intake, feed:gain ratio. Exp 1.

Room	Diet	Block	Days	IBW, kg	FBW, kg	ADG, kg	ADFI, kg	F:G
1	LNE	1	104	36.8	108.2	0.687	1.99	2.91
2	Control	1	97	36.7	109.1	0.747	2.15	2.88
3	LNE	2	111	32.6	108.0	0.718	2.01	2.80
4	Control	2	111	31.9	107.0	0.705	2.03	2.78

Control: traditional corn-soybean meal diet.
LNE: 2% units reduced CP and 0.1% unit reduced P diet.

Appendix Table 2

Analysis of variance for days on test, initial and final weight, average daily gain, average daily feed intake, feed:gain ratio. Exp 1.

		Mean square					
Source	df	Days	IBW, kg	FBW, kg	ADG, kg	ADFI, kg	F:G
Total	3						
Diet	1	12.25	0.60	0.01	553.7	0.008	0.001
Block	1	110. 25	96.53	6.66	28.9	0.003	0.011
Error	1	12. 25	0.43	4.33	1293.1	0.005	0.001
Control vs. LNE	1	12. 25	0.60	0.01	553.7	0.008	0.001
CV, %		3.31	0.86	0.87	5.04	3.42	0.18

Control: traditional corn-soybean meal diet.
LNE: 2% units reduced CP and 0.1% unit reduced P diet.

Appendix Table 3

Pig means for life body weight, hot carcass weight, and backfat depth. Exp 1.

					Fat depth, cm			
Room	Diet	Block	BWt, kg	HCW, kg	1st rib	10th rib	13th rib	Last lumbar
1	LNE	1	108.2	84.7	2.59	2.08	2.39	1.96
2	Control	1	113.1	88.2	3.02	2.11	2.29	1.96
3	LNE	2	112.3	86.6	2.77	2.06	2.16	2.03
4	Control	2	112.5	86.9	2.72	2.06	2.18	2.03

Control: traditional corn-soybean meal diet.
LNE: 2% units reduced CP and 0.1% unit reduced P diet.

Appendix Table 4

Analysis of variance for life body weight, hot carcass weight, and backfat depth. Exp 1.

		Mean square					
Source	df	LBW	HCW	1st rib	10th rib	13th rib	Last lumbar
Total	3						
Diet	1	31.58	18.40	0.006	0.0001	0.001	0.00
Block	1	14.82	0.42	0.001	0.0002	0.004	0.01
Error	1	25.71	12.04	0.009	0.0001	0.001	0.00
Control vs. LNE	1	31.58	18.40	0.006	0.0001	0.001	0.00
CV, %		2.07	1.82	8.70	0.61	2.82	0

Control: traditional corn-soybean meal diet.
LNE: 2% units reduced CP and 0.1% unit reduced P diet.

Appendix Table 5

Pig means for LMA, carcass yield and fat-free lean percentage. Exp 1.

Room	Diet	Block	LMA, cm	Carcass yield, %	Fat-free lean, %
1	LNE	1	37.35	78.25	50.79
2	Control	1	37.81	78.05	50.67
3	LNE	2	39.23	77.17	51.24
4	Control	2	40.32	77.25	51.54

Control: traditional corn-soybean meal diet.
LNE: 2% units reduced CP and 0.1% unit reduced P diet.

Appendix Table 6

Analysis of variance for LMA, carcass yield and fat-free lean percentage. Exp 1.

		Mean square		
Source	df	LMA, cm	Carcass yield, %	Fat-free lean, %
Total	3			
Diet	1	31.58	18.40	0.006
Block	1	14.82	0.42	0.001
Error	1	25.71	12.04	0.009
Control vs. LNE	1	31.58	18.40	0.006
CV, %		2.07	1.82	8.70

Control: traditional corn-soybean meal diet.
LNE: 2% units reduced CP and 0.1% unit reduced P diet.

Appendix Table 7

Pig means for metacarpal breaking strength. Exp 1.

Room	Diet	Block	Metacarpal breaking strength, kg
1	LNE	1	130.7
2	Control	1	159.6
3	LNE	2	151.0
4	Control	2	160.7

Control: traditional corn-soybean meal diet.
LNE: 2% units reduced CP and 0.1% unit reduced P diet.

Appendix Table 8

Analysis of variance for metacarpal breaking strength. Exp 1.

Source	df	Mean square, kg
Total	3	
Diet	1	373.7
Block	1	114.1
Error	1	92.5
Control vs. LNE	1	373.7
CV, %		6.39

Control: traditional corn-soybean meal diet.
LNE: 2% units reduced CP and 0.1% unit reduced P diet.

Appendix Table 9

Pig means for DM, C, N and P average daily intake for the entire finishing period. Exp 1.

			Average daily intake, g/pig			
Room	Diet	Block	DM	C	N	P
1	LNE	1	1,751	799.3	41.98	6.77
2	Control	1	1,896	888.0	53.43	9.39
3	LNE	2	1,773	810.4	42.88	6.90
4	Control	2	1,795	831.9	50.59	8.91

Control: traditional corn-soybean meal diet.
LNE: 2% units reduced CP and 0.1% unit reduced P diet.

Appendix Table 10

Analysis of variance for DM, C, N and P average daily intake for the entire finishing period. Exp 1.

		Mean square of intake, g/pig			
Source	df	DM	C	N	P
Total	3				
Diet	1	7039.2	3614.4	91.8	5.34
Block	1	1521.0	307.3	0.9	0.03
Error	1	3682.1	818.0	3.5	0.09
Control vs. LNE	1	7039.2	3614.4	91.8	5.34
CV, %		3.36	3.43	3.96	3.82

Control: traditional corn-soybean meal diet.
LNE: 2% units reduced CP and 0.1% unit reduced P diet.

Appendix Table 11

Pigs means for Ca, K, Mg, and Na average daily intake for the entire finishing period. Exp 1.

			Average daily intake, g/pig			
Room	Diet	Block	Ca	K	Mg	Na
1	LNE	1	8.85	11.85	2.33	2.36
2	Control	1	11.69	15.36	2.78	2.54
3	LNE	2	9.10	12.14	2.38	2.38
4	Control	2	11.05	14.57	2.63	2.43

Control: traditional corn-soybean meal diet.
LNE: 2% units reduced CP and 0.1% unit reduced P diet.

Appendix Table 12

Analysis of variance for Ca, K, Mg, and Na average daily intake for the entire finishing period. Exp 1.

		Mean square of average daily intake, g/pig			
Source	df	Ca	K	Mg	Na
Total	3				
Diet	1	5.73	8.80	0.119	0.013
Block	1	0.04	0.07	0.002	0.003
Error	1	0.20	0.29	0.010	0.004
Control vs. LNE	1	5.7288	8.8001	0.119	0.013
CV, %		4.36	4.00	3.87	2.72

Control: traditional corn-soybean meal diet.
LNE: 2% units reduced CP and 0.1% unit reduced P diet.

Appendix Table 13

Pigs means for Fe, Zn, Cu, and Mn average daily intake for the entire finishing period. Exp 1.

			Average daily intake, mg/pig			
Room	Diet	Block	Fe	Zn	Cu	Mn
1	LNE	1	345	273	30	78
2	Control	1	430	304	36	102
3	LNE	2	354	278	31	80
4	Control	2	433	288	34	97

Control: traditional corn-soybean meal diet.
LNE: 2% units reduced CP and 0.1% unit reduced P diet.

Appendix Table 14

Analysis of variance for Fe, Zn, Cu, and Mn average daily intake for the entire finishing period. Exp 1.

		Mean square of average daily intake, mg/pig			
Source	df	Fe	Zn	Cu	Mn
Total	3				
Diet	1	9.41	0.42	0.020	0.420
Block	1	0.08	0.03	0.001	0.002
Error	1	0.32	0.11	0.002	0.012
Control vs. LNE	1	9.41	0.42	0.020	0.420
CV, %		4.52	3.68	4.58	3.92

Control: traditional corn-soybean meal diet.
LNE: 2% units reduced CP and 0.1% unit reduced P diet.

Appendix Table 15

Slurry means for average volume, temperature, electrical conductivity, and pH for the entire finishing period. Exp 1.

Room	Diet	Block	Volume, L/pig	Temperature, °C	EC, µS	pH
1	LNE	1	11.99	22.40	3,506	7.04
2	Control	1	9.50	22.84	4,951	7.03
3	LNE	2	13.07	22.06	3,657	6.99
4	Control	2	12.46	22.13	4,216	7.04

Control: traditional corn-soybean meal diet.
LNE: 2% units reduced CP and 0.1% unit reduced P diet.

Appendix Table 16

Analysis of variance for average slurry volume, temperature, electrical conductivity, and pH for the entire finishing period. Exp 1.

		Mean square			
Source	df	Volume, L/pig	Temperature, °C	EC, µS	pH
Total	3				
Diet	1	2.40	0.07	1,003,212	0.0004
Block	1	4.08	0.28	85,576	0.0004
Error	1	0.88	0.03	196,519	0.0009
Control vs. LNE	1	2.40	0.07	1,003,212	0.0004
CV, %		8.00	0.83	10.86	0.43

Control: traditional corn-soybean meal diet.
LNE: 2% units reduced CP and 0.1% unit reduced P diet.

Appendix Table 17

Slurry concentration means for DM, C, N, NH_4-N, P and C:N ratio. Exp 1.

				Slurry concentration %, DM basis				
Room	Diet	Block	DM, %	C	N	NH4-N	P	C:N
1	LNE	1	1.84	43.2	8.3	4.1	1.8	6.8
2	Control	1	1.80	40.3	10.9	6.3	2.2	5.0
3	LNE	2	2.27	40.1	8.7	4.7	1.7	5.8
4	Control	2	1.89	37.4	9.8	5.8	2.1	4.8

Control: traditional corn-soybean meal diet.
LNE: 2% units reduced CP and 0.1% unit reduced P diet.

Appendix Table 18

Analysis of variance for slurry DM concentration and C:N ratio. Exp 1.

		Mean square of Slurry concentration	
Source	df	DM, %	C:N
Total	3		
Diet	1	0.044	1.95
Error	2	0.048	0.26
Control vs. LNE	1	0.044	1.95
CV, %		11.23	2.46

Control: traditional corn-soybean meal diet.
LNE: 2% units reduced CP and 0.1% unit reduced P diet.

Appendix Table 19

Analysis of variance for slurry C, N, NH_4-N, and P concentration. Exp 1.

		Mean square of Slurry concentration, % DM basis			
Source	df	C	N	NH4-N	P
Total	3				
Diet	1	8.21	3.29	2.62	0.173
Block	1	8.93	0.13	0.01	0.007
Error	1	0.01	0.56	0.27	0.002
Control vs. LNE	1	8.21	3.29	2.62	0.173
CV, %		0.23	7.93	10.02	2.26

Control: traditional corn-soybean meal diet.
LNE: 2% units reduced CP and 0.1% unit reduced P diet.

Appendix Table 20

Slurry concentration means for Ca, K, Mg, and Na for the entire finishing period. Exp 1.

			Slurry concentration, % DM basis			
Room	Diet	Block	Ca	K	Mg	Na
1	LNE	1	2.68	3.91	0.92	1.41
2	Control	1	2.93	5.13	1.02	1.30
3	LNE	2	2.67	4.18	0.92	1.40
4	Control	2	2.74	4.63	0.93	1.37

Control: traditional corn-soybean meal diet.
LNE: 2% units reduced CP and 0.1% unit reduced P diet.

Appendix Table 21

Analysis of variance for slurry concentration of Ca, K, Mg, and Na for the entire finishing period. Exp 1.

		Mean square of slurry concentration, % DM basis			
Source	df	Ca	K	Mg	Na
Total	3				
Diet	1	0.03	0.70	0.003	0.005
Block	1	0.01	0.01	0.002	0.001
Error	1	0.01	0.15	0.002	0.002
Control vs. LNE	1	0.03	0.70	0.003	0.005
CV, %		3.18	8.60	4.55	3.14

Control: traditional corn-soybean meal diet.
LNE: 2% units reduced CP and 0.1% unit reduced P diet.

Appendix Table 22

Slurry concentration means for Fe, Zn, Cu, and Mn for the entire finishing period. Exp 1.

			Slurry concentration, ppm DM basis			
Room	Diet	Block	Fe	Zn	Cu	Mn
1	LNE	1	14.05	10.92	1.82	3.24
2	Control	1	18.51	12.50	2.14	3.78
3	LNE	2	14.57	10.61	1.71	3.22
4	Control	2	18.00	11.65	1.96	3.56

Control: traditional corn-soybean meal diet.
LNE: 2% units reduced CP and 0.1% unit reduced P diet.

Appendix Table 23

Analysis of variance for slurry concentration of Fe, Zn, Cu, and Mn for the entire finishing period. Exp 1.

		Mean square of slurry concentration, ppm DM basis			
Source	df	Fe	Zn	Cu	Mn
Total	3				
Diet	1	155498.5	17199.3	821.2	1924.3
Block	1	0.1	3385.4	220.6	141.4
Error	1	2673.6	739.4	12.3	344.9
Control vs. LNE	1	155498.5	17199.3	821.2	1924.3
CV, %		3.18	2.38	1.84	2.88

Control: traditional corn-soybean meal diet.
LNE: 2% units reduced CP and 0.1% unit reduced P diet.

Appendix Table 24

Pig means for DM, C, N, NH_4-N, and P average daily excretion for the entire finishing period. Exp 1.

			Average daily excretion, g/pig				
Room	Diet	Block	DM	C	N	NH_4-N	P
1	LNE	1	288	122	24.4	12.3	5.08
2	Control	1	284	112	31.9	18.4	6.37
3	LNE	2	305	118	26.8	14.3	5.20
4	Control	2	322	119	32.7	19.2	6.90

Control: traditional corn-soybean meal diet.
LNE: 2% units reduced CP and 0.1% unit reduced P diet.

Appendix Table 25

Analysis of variance for DM, C, N, NH_4-N and P average daily excretion for the entire finishing period. Exp 1.

		Mean square of average daily excretion, g/pig				
Source	df	DM	C	N	NH_4-N	P
Total	3					
Diet	1	41.03	23.28	44.66	29.77	2.22
Error	2	431.27	13.50	1.63	1.12	0.07
Control vs. LNE	1	41.03	23.28	44.66	29.77	2.22
CV, %		6.93	3.12	4.42	6.60	4.60

Control: traditional corn-soybean meal diet.
LNE: 2% units reduced CP and 0.1% unit reduced P diet.

Appendix Table 26

Pig means for Ca, K, Mg, and Na average daily excretion for the entire finishing period. Exp 1.

			Average daily excretion, g/pig			
Room	Diet	Block	Ca	K	Mg	Na
1	LNE	1	7.62	11.49	2.67	4.10
2	Control	1	8.31	14.93	2.93	3.78
3	LNE	2	7.82	12.61	2.78	4.34
4	Control	2	8.90	15.45	3.04	4.61

Control: traditional corn-soybean meal diet.
LNE: 2% units reduced CP and 0.1% unit reduced P diet.

Appendix Table 27

Analysis of variance for Ca, K, Mg, and Na average daily excretion for the entire finishing period. Exp 1.

		Mean square of average daily excretion, g/pig			
Source	df	Ca	K	Mg	Na
Total	3				
Diet	1	0.79	9.82	0.07	0.01
Block	1	0.16	0.68	0.01	0.29
Error	1	0.04	0.09	0.01	0.09
Control vs. LNE	1	0.79	9.82	0.07	0.01
CV, %		2.43	2.20	0.02	6.97

Control: traditional corn-soybean meal diet.
LNE: 2% units reduced CP and 0.1% unit reduced P diet.

Appendix Table 28

Pig means for Fe, Zn, Cu, and Mn average daily excretion for the entire finishing period. Exp 1.

			Average daily excretion, g/pig/d			
Room	Diet	Block	Fe	Zn	Cu	Mn
1	LNE	1	400	317	51.82	93.64
2	Control	1	529	360	59.46	107.64
3	LNE	2	443	332	48.23	99.14
4	Control	2	602	395	62.56	118.93

Control: traditional corn-soybean meal diet.
LNE: 2% units reduced CP and 0.1% unit reduced P diet.

Appendix Table 29

Analysis of variance for Fe, Zn, Cu, and Mn average daily excretion for the entire finishing period. Exp 1.

		Mean square of average daily excretion, mg/pig			
Source	df	Fe	Zn	Cu	Mn
Total	3				
Diet	1	20863.6	2772.3	120.58	285.53
Block	1	3376.7	605.4	0.06	70.48
Error	1	225.7	103.5	11.18	8.38
Control vs. LNE	1	20863.6	2772.3	120.58	285.53
CV, %		3.04	2.90	6.02	2.76

Control: traditional corn-soybean meal diet.
LNE: 2% units reduced CP and 0.1% unit reduced P diet.

Appendix Table 30

Pig means for DM, C, N, and P excretion as percentage of the intake for the entire finishing period. Exp 1.

			Excretion as percentage of intake, %			
Room	Diet	Block	DM	C	N	P
1	LNE	1	16.46	15.26	58.10	75.08
2	Control	1	14.99	12.63	59.63	67.84
3	LNE	2	17.21	14.61	62.51	75.38
4	Control	2	17.93	14.08	64.64	77.37

Control: traditional corn-soybean meal diet.
LNE: 2% units reduced CP and 0.1% unit reduced P diet.

Appendix Table 31

Analysis of variance for DM, C, N, and P excretion as percentage of the intake for the entire finishing period. Exp 1.

		Mean square of excretion as percentage of intake, %			
Source	df	DM	C	N	P
Total	3				
Diet	1	0.14	2.49	3.37	6.88
Block	1	3.41	0.16	22.22	24.23
Error	1	1.21	1.11	0.09	21.31
Control vs. LNE	1	0.14	2.49	3.37	6.88
CV, %		6.61	7.45	0.50	6.25

Control: traditional corn-soybean meal diet.
LNE: 2% units reduced CP and 0.1% unit reduced P diet.

Appendix Table 32

Pig means for Ca, K, Mg, and Na excretion as percentage of the intake for the entire finishing period. Exp 1.

			Excretion as percentage of the intake, %			
Room	Diet	Block	Ca	K	Mg	Na
1	LNE	1	86.09	96.9	114.4	173.5
2	Control	1	71.09	97.2	105.6	148.8
3	LNE	2	85.88	103.9	116.7	182.6
4	Control	2	80.54	106.1	115.6	190.2

Control: traditional corn-soybean meal diet.
LNE: 2% units reduced CP and 0.1% unit reduced P diet.

Appendix Table 33

Analysis of variance for Ca, K, Mg, and Na excretion as percentage of the intake for the entire finishing period. Exp 1.

		Mean square of excretion as percentage of the intake, %			
Source	df	Ca	K	Mg	Na
Total	3				
Diet	1	103.6	1.40	24.51	73.16
Block	1	21.4	63.11	38.08	638.41
Error	1	23.3	0.92	14.95	261.11
Control vs. LNE	1	103.6	1.40	24.51	73.16
CV, %		5.97	0.95	3.42	9.30

Control: traditional corn-soybean meal diet.
LNE: 2% units reduced CP and 0.1% unit reduced P diet.

Appendix Table 34

Pig means for Fe, Zn, Cu, and Mn excretion as percentage of the intake for the entire finishing period. Exp 1.

			Excretion as percentage of the intake, %			
Room	Diet	Block	Fe	Zn	Cu	Mn
1	LNE	1	115.71	116.03	170.87	120.02
2	Control	1	115.08	118.41	165.82	105.45
3	LNE	2	125.04	119.23	157.15	124.43
4	Control	2	139.04	137.06	185.33	122.83

Control: traditional corn-soybean meal diet.
LNE: 2% units reduced CP and 0.1% unit reduced P diet.

Appendix Table 35

Analysis of variance for Fe, Zn, Cu, and Mn excretion as percentage of the intake for the entire finishing period. Exp 1.

		Mean square of excretion as percentage of the intake, %			
Source	df	Fe	Zn	Cu	Mn
Total	3				
Diet	1	44.71	102.13	133.79	65.36
Block	1	277.00	119.26	8.37	118.86
Error	1	53.49	59.76	276.24	42.07
Control vs. LNE	1	44.71	102.13	133.79	65.36
CV, %		5.91	6.30	9.79	5.49

Control: traditional corn-soybean meal diet.
LNE: 2% units reduced CP and 0.1% unit reduced P diet.

Appendix Table 36

Pig means for DM, C, N and P cumulative excretion for the entire finishing period. Exp 1.

			Cumulative excretion, kg/pig			
Room	Diet	Block	DM	C	N	P
1	LNE	1	29.98	12.68	2.54	0.53
2	Control	1	27.55	10.88	3.09	0.62
3	LNE	2	33.86	13.14	2.98	0.58
4	Control	2	35.75	13.16	3.63	0.77

Control: traditional corn-soybean meal diet.
LNE: 2% units reduced CP and 0.1% unit reduced P diet.

Appendix Table 37

Analysis of variance for DM, C, N and P cumulative excretion for the entire finishing period. Exp 1.

		Mean square of cumulative excretion, kg/pig			
Source	df	DM	C	N	P
Total	3				
Diet	1	2.81	0.14	0.51	0.03
Block	1	41.08	2.52	0.23	0.01
Error	1	2.81	0.19	0.01	0.01
Control vs. LNE	1	2.81	0.14	0.51	0.03
CV, %		0.43	3.45	3.51	2.53

Control: traditional corn-soybean meal diet.
LNE: 2% units reduced CP and 0.1% unit reduced P diet.

Appendix Table 38

Pig means for days on test, initial and final weight, average daily gain, average daily feed intake, feed:gain ratio. Exp 2.

Room	Diet	Block	Days	IBW, kg	FBW, kg	ADG, kg	ADFI, kg	F:G
1	Control	1	94	33.6	111.3	0.826	2.24	2.72
2	LNE	1	101	33.5	112.6	0.783	2.20	2.81
3	Control	2	116	28.9	108.5	0.704	2.08	2.96
4	LNE	2	122	26.9	104.9	0.639	1.99	3.13

Control: traditional corn-soybean meal diet.
LNE: 4% units reduced CP and 0.1% unit reduced P diet.

Appendix Table 39

Analysis of variance for days on test, initial and final weight, average daily gain, average daily feed intake, feed:gain ratio. Exp 2

		Mean square					
Source	df	Days	IBW, lb	FBW, lb	ADG, g	ADFI, kg	F:G
Total	3						
Diet	1		0.02	6.68	2896.6	0.004	0.02
Block	1		216.09	135.14	17824.9	0.034	0.08
Error	1		0.01	29.32	110.0	0.001	0.01
Control vs. LNE	1		0.02	6.68	2986.6	0.004	0.02
CV, %			0.18	2.25	1.42	1.17	1.21

Control: traditional corn-soybean meal diet.
LNE: 4% units reduced CP and 0.1% unit reduced P diet.

Appendix Table 40

Pig means for life body weight, hot carcass weight, and backfat depth. Exp 2.

					Fat depth, cm			
Room	Diet	Block	LBW, kg	HCW, kg	1st rib	10th rib	13th rib	Last lumbar
1	Control	1	111.3	88.6	3.63	2.69	2.67	2.26
2	LNE	1	112.6	90.1	2.95	2.82	2.35	2.24
3	Control	2	108.5	86.5	3.51	1.55	2.24	1.91
4	LNE	2	104.9	82.7	3.51	1.78	2.31	2.18

Control: traditional corn-soybean meal diet.
LNE: 4% units reduced CP and 0.1% unit reduced P diet.

Appendix Table 41

Analysis of variance for life body weight, hot carcass weight, and backfat depth. Exp 2.

		Mean square					
		lb		in			
Source	df	LBW	HCW	1st rib	10th rib	13th rib	Last lumbar
Total	3						
Diet	1	6.68	6.25	0.02	0.01	0.001	0.003
Block	1	135.14	108.58	0.01	0.19	0.014	0.006
Error	1	29.32	33.06	0.02	0.01	0.003	0.004
Control vs. LNE	1	6.68	6.25	0.02	0.01	0.001	0.003
CV, %		2.25	3.00	10.09	2.30	5.24	7.10

Control: traditional corn-soybean meal diet.
LNE: 4% units reduced CP and 0.1% unit reduced P diet.

Appendix Table 42

Pig means for LMA, carcass yield and fat-free lean percentage. Exp 2.

Room	Diet	Block	LMA, sq cm	Carcass yield, %	Fat-free lean, %
1	Control	1	44.97	79.62	49.71
2	LNE	1	38.65	79.94	47.62
3	Control	2	43.48	79.68	54.64
4	LNE	2	38.77	78.89	52.73

Control: traditional corn-soybean meal diet.
LNE: 4% units reduced CP and 0.1% unit reduced P diet.

Appendix Table 43

Analysis of variance for LMA, carcass yield and fat-free lean percentage. Exp 2.

		Mean square		
Source	df	LMA, sq in	Carcass yield, %	Fat-free lean, %
Total	3			
Diet	1	0.73	0.06	4.00
Block	1	0.01	0.24	25.20
Error	1	0.02	0.31	0.01
Control vs. LNE	1	0.73	0.06	4.00
CV, %		1.95	0.70	0.18

Control: traditional corn-soybean meal diet.
LNE: 4% units reduced CP and 0.1% unit reduced P diet.

Appendix Table 44

Pig means for metacarpal, metatarsal, and metacarpal-metatarsal bone breaking strength. Exp 2.

			Bone breaking strength, kg		
Room	Diet	Block	Metacarpal	Metatarsal	Metacarpal-metatarsal
1	Control	1	154.3	136.8	145.4
2	LNE	1	136.1	118.9	127.6
3	Control	2	139.9	124.8	135.1
4	LNE	2	137.4	122.5	132.6

Control: traditional corn-soybean meal diet.
LNE: 4% units reduced CP and 0.1% unit reduced P diet.

Appendix Table 45

Analysis of variance for metacarpal, metatarsal, and metacarpal-metatarsal bone breaking strength. Exp 2.

		Mean square, kg		
Source	df	Metacarpal	Metatarsal	Metacarpal-metatarsal
Total	3			
Diet	1	234.4	102.1	102.3
Block	1	2.4	17.9	7.1
Error	1	8.5	61.1	59.2
Control vs. LNE	1	234.4	102.1	102.3
CV, %		2.02	6.22	5.69

Control: traditional corn-soybean meal diet.
LNE: 4% units reduced CP and 0.1% unit reduced P diet.

Appendix Table 46

Pig means for DM, C, N and P average daily intake for the entire finishing period. Exp 2.

			Average daily intake, g/pig			
Room	Diet	Block	DM	C	N	P
1	Control	1	1,968	901	54.9	9.68
2	LNE	1	1,924	892	40.1	7.42
3	Control	2	1,831	807	50.6	8.95
4	LNE	2	1,742	868	36.0	6.79

Control: traditional corn-soybean meal diet.
LNE: 4% units reduced CP and 0.1% unit reduced P diet.

Appendix Table 47

Analysis of variance for DM, C, N and P average daily intake for the entire finishing period. Exp 2.

		Mean square of intake, g/pig			
Source	df	DM	C	N	P
Total	3				
Diet	1	4,413.6	688.8	216.1	4.88
Block	1	25576.0	3446.3	17.1	0.46
Error	1	514.6	1253.5	0.01	0.01
Control vs. LNE	1	4,413.6	688.8	216.1	4.88
CV, %		1.22	4.09	0.20	0.61

Control: traditional corn-soybean meal diet.
LNE: 4% units reduced CP and 0.1% unit reduced P diet.

Appendix Table 48

Pig means for Ca, K, Mg, and Na average daily intake for the entire finishing period. Exp 2.

			Average daily intake, g/pig			
Room	Diet	Block	Ca	K	Mg	Na
1	Control	1	12.4	16.3	2.92	2.67
2	LNE	1	10.0	13.3	2.61	2.59
3	Control	2	11.6	15.1	2.72	2.47
4	LNE	2	8.72	11.9	2.53	2.39

Control: traditional corn-soybean meal diet.
LNE: 4% units reduced CP and 0.1% unit reduced P diet.

Appendix Table 49

Analysis of variance for Ca, K, Mg, and Na average daily intake for the entire finishing period. Exp 2.

		Mean square of average daily intake, g/pig			
Source	df	Ca	K	Mg	Na
Total	3				
Diet	1	7.02	9.43	0.06	0.01
Block	1	1.10	1.56	0.02	0.04
Error	1	0.06	0.02	0.01	0.00
Control vs. LNE	1	7.02	9.43	0.06	0.01
CV, %		2.25	1.00	0.96	0

Control: traditional corn-soybean meal diet.
LNE: 2% units reduced CP and 0.1% unit reduced P diet.

Appendix Table 50

Pig means for Fe, Zn, Cu, and Mn average daily intake for the entire finishing period. Exp 2.

			Average daily intake, mg/pig			
Room	Diet	Block	Fe	Zn	Cu	Mn
1	Control	1	488	327	40	107
2	LNE	1	361	284	38	94
3	Control	2	456	305	37	100
4	LNE	2	333	261	28	76

Control: traditional corn-soybean meal diet.
LNE: 4% units reduced CP and 0.1% unit reduced P diet.

Appendix Table 51

Analysis of variance for Fe, Zn, Cu, and Mn average daily intake for the entire finishing period. Exp 2.

		Mean square of average daily intake, g/pig			
Source	df	Fe	Zn	Cu	Mn
Total	3				
Diet	1	0.016	0.002	0.00003	0.0003
Block	1	0.001	0.001	0.00004	0.0001
Error	1	0.000	0.000	0.00001	0.0001
Control vs. LNE	1	0.016	0.002	0.00003	0.0003
CV, %		0.49	0.17	9.79	5.83

Control: traditional corn-soybean meal diet.
LNE: 4% units reduced CP and 0.1% unit reduced P diet.

Appendix Table 52

Slurry means for average volume, temperature, electrical conductivity, and pH for the entire finishing period. Exp 2.

Room	Diet	Block	Volume, L/pig	Temperature, °C	EC, mS	pH
1	Control	1	8.9	17.2	5.17	7.13
2	LNE	1	8.9	17.1	3.43	6.42
3	Control	2	10.1	17.9	4.45	6.90
4	LNE	2	13.7	17.5	2.58	6.01

Control: traditional corn-soybean meal diet.
LNE: 4% units reduced CP and 0.1% unit reduced P diet.

Appendix Table 53

Analysis of variance for average slurry volume, temperature, electrical conductivity, and pH for the entire finishing period. Exp 2.

		Mean square			
Source	df	Volume, L/pig	Temperature, °C	EC, µS	pH
Total	3				
Diet	1	3.13	0.07	3.26	0.64
Block	1	8.70	0.31	0.62	0.10
Error	1	3.10	0.03	0.01	0.01
Control vs. LNE	1	3.13	0.07	3.26	0.64
CV, %		16.91	0.92	1.66	1.36

Control: traditional corn-soybean meal diet.
LNE: 4% units reduced CP and 0.1% unit reduced P diet.

Appendix Table 54

Slurry concentration means for DM, C, N, P and C:N ratio. Exp 2.

				Slurry concentration %, DM basis			
Room	Diet	Block	DM, %	C	N	P	C:N
1	Control	1	0.62	53.7	13.0	2.54	4.1
2	LNE	1	0.59	48.7	8.2	1.96	6.0
3	Control	2	0.54	55.5	12.3	2.40	4.5
4	LNE	2	0.46	56.3	7.1	1.84	8.0

Control: traditional corn-soybean meal diet.
LNE: 4% units reduced CP and 0.1% unit reduced P diet.

Appendix Table 55

Analysis of variance for slurry DM, C, N, P concentration and C:N ratio. Exp 2.

		Mean square of Slurry concentration				
Source	df	DM, %	C	N	P	C:N
Total	3					
Diet	1	0.003	4.6	25.54	0.33	7.01
Block	1	0.011	21.8	0.80	0.02	1.40
Error	1	0.001	8.4	0.04	0.01	0.65
Control vs. LNE	1	0.003	4.6	25.54	0.33	7.01
CV, %		4.23	5.41	1.88	0.57	14.25

Control: traditional corn-soybean meal diet.
LNE: 4% units reduced CP and 0.1% unit reduced P diet.

Appendix Table 56

Slurry concentration means for Ca, K, Mg, and Na for the entire finishing period. Exp 2.

			Slurry concentration, % DM basis			
Room	Diet	Block	Ca	K	Mg	Na
1	Control	1	2.82	5.72	1.29	2.04
2	LNE	1	2.76	4.19	1.18	2.27
3	Control	2	3.01	5.81	1.28	2.28
4	LNE	2	2.91	3.73	1.14	2.49

Control: traditional corn-soybean meal diet.
LNE: 4% units reduced CP and 0.1% unit reduced P diet.

Appendix Table 57

Analysis of variance for slurry concentration of Ca, K, Mg, and Na for the entire finishing period. Exp 2.

		Mean square of slurry concentration, % DM basis			
Source	df	Ca	K	Mg	Na
Total	3				
Diet	1	0.007	3.25	0.015	0.05
Block	1	0.029	0.03	0.001	0.05
Error	1	0.001	0.08	0.001	0.01
Control vs. LNE	1	0.007	3.25	0.015	0.05
CV, %		0.73	5.75	1.02	0.57

Control: traditional corn-soybean meal diet.
LNE: 4% units reduced CP and 0.1% unit reduced P diet.

Appendix Table 58

Slurry concentration means for Fe, Zn, Cu, and Mn for the entire finishing period. Exp 2.

			Slurry concentration, ppm DM basis			
Room	Diet	Block	Fe	Zn	Cu	Mn
1	Control	1	165	106	16	38
2	LNE	1	142	91	13	33
3	Control	2	160	101	15	36
4	LNE	2	173	96	14	32

Control: traditional corn-soybean meal diet.
LNE: 4% units reduced CP and 0.1% unit reduced P diet.

Appendix Table 59

Analysis of variance for slurry concentration of Fe, Zn, Cu, and Mn for the entire finishing period. Exp 2.

		Mean square of slurry concentration, % DM basis			
Source	df	Fe	Zn	Cu	Mn
Total	3				
Diet	1	0.0001	0.0001	0.00	0.001
Block	1	0.0002	0.0000	0.00	0.001
Error	1	0.0003	0.0001	0.00	0.001
Control vs. LNE	1	0.0001	0.0001	0.00	0.001
CV, %		11.25	5.08	0.80	1.44

Control: traditional corn-soybean meal diet.
LNE: 4% units reduced CP and 0.1% unit reduced P diet.

Appendix Table 60

Pig means for DM, N, NH_4-N, and P average daily excretion for the entire finishing period. Exp 2.

			Average daily excretion, g/pig			
Room	Diet	Block	DM	N	NH_4-N	P
1	Control	1	292	38.0	25.4	7.42
2	LNE	1	297	24.2	13.1	5.81
3	Control	2	256	31.5	20.9	6.13
4	LNE	2	242	17.1	7.5	4.44

Control: traditional corn-soybean meal diet.
LNE: 4% units reduced CP and 0.1% unit reduced P diet.

Appendix Table 61

Analysis of variance for DM, N, NH_4-N and P average daily excretion for the entire finishing period. Exp 2.

		Mean square of average daily excretion, g/pig			
Source	df	DM	N	NH_4-N	P
Total	3				
Diet	1	20.9	198.7	165.1	2.72
Block	1	2045.8	45.9	25.4	1.77
Error	1	92.0	0.1	0.3	0.01
Control vs. LNE	1	20.9	198.7	165.1	2.72
CV, %		3.53	1.17	3.36	0.67

Control: traditional corn-soybean meal diet.
LNE: 4% units reduced CP and 0.1% unit reduced P diet.

Appendix Table 62

Pig means for Ca, K, Mg, and Na average daily excretion for the entire finishing period. Exp 2.

			Average daily excretion, g/pig			
Room	Diet	Block	Ca	K	Mg	Na
1	Control	1	8.23	16.7	3.8	5.9
2	LNE	1	8.18	12.4	3.5	6.7
3	Control	2	7.71	14.9	3.3	5.9
4	LNE	2	7.03	9.0	2.8	6.0

Control: traditional corn-soybean meal diet.
LNE: 4% units reduced CP and 0.1% unit reduced P diet.

Appendix Table 63

Analysis of variance for Ca, K, Mg, and Na average daily excretion for the entire finishing period. Exp 2.

		Mean square of average daily excretion, g/pig			
Source	df	Ca	K	Mg	Na
Total	3				
Diet	1	0.13	25.4	0.15	0.24
Block	1	0.69	6.8	0.38	0.16
Error	1	0.10	0.7	0.02	0.10
Control vs. LNE	1	0.13	25.4	0.15	0.24
CV, %		4.06	6.13	3.71	5.04

Control: traditional corn-soybean meal diet.
LNE: 4% units reduced CP and 0.1% unit reduced P diet.

Appendix Table 64

Pig means for Fe, Zn, Cu, and Mn average daily excretion for the entire finishing period. Exp 2.

			Average daily excretion, g/pig			
Room	Diet	Block	Fe	Zn	Cu	Mn
1	Control	1	480	310	47.9	111
2	LNE	1	421	269	39.4	97
3	Control	2	410	260	39.4	92
4	LNE	2	417	232	35.0	78

Control: traditional corn-soybean meal diet.
LNE: 4% units reduced CP and 0.1% unit reduced P diet.

Appendix Table 65

Analysis of variance for Fe, Zn, Cu, and Mn average daily excretion for the entire finishing period. Exp 2.

		Mean square of average daily excretion, mg/pig			
Source	df	Fe	Zn	Cu	Mn
Total	3				
Diet	1	683	1,181	41.5	203.6
Block	1	1,377	1,874	41.8	360.7
Error	1	1,140	47	4.2	0.1
Control vs. LNE	1	683	1,181	41.5	203.6
CV, %		7.82	2.57	5.08	0.35

Control: traditional corn-soybean meal diet.
LNE: 4% units reduced CP and 0.1% unit reduced P diet.

Appendix Table 66

Pig means for DM, C, N and P excretion as percentage of the intake for the entire finishing period. Exp 2.

			Excretion as percentage of intake, %			
Room	Diet	Block	DM	C	N	P
1	Control	1	14.8	17.4	69.2	76.6
2	LNE	1	15.4	16.2	60.4	78.3
3	Control	2	14.0	17.0	62.2	68.5
4	LNE	2	13.9	16.9	47.4	65.5

Control: traditional corn-soybean meal diet.
LNE: 4% units reduced CP and 0.1% unit reduced P diet.

Appendix Table 67

Analysis of variance for DM, C, N, and P excretion as percentage of the intake for the entire finishing period. Exp 2.

		Mean square of excretion as percentage of intake, %			
Source	df	DM	C	N	P
Total	3				
Diet	1	0.06	0.45	139.8	0.4
Block	1	1.40	0.02	98.9	109.9
Error	1	0.12	0.28	8.9	5.5
Control vs. LNE	1	0.06	0.45	139.8	0.4
CV, %		2.40	3.15	4.98	3.24

Control: traditional corn-soybean meal diet.
LNE: 4% units reduced CP and 0.1% unit reduced P diet.

Appendix Table 68

Pig means for Ca, K, Mg, and Na excretion as percentage of the intake for the entire finishing period. Exp 2.

			Excretion as percentage of the intake, %			
Room	Diet	Block	Ca	K	Mg	Na
1	Control	1	66.4	97.8	120	262
2	LNE	1	87.1	105.8	139	285
3	Control	2	66.6	93.2	112	276
4	LNE	2	82.3	82.3	121	284

Control: traditional corn-soybean meal diet.
LNE: 4% units reduced CP and 0.1% unit reduced P diet.

Appendix Table 69

Analysis of variance for Ca, K, Mg, and Na excretion as percentage of the intake for the entire finishing period. Exp 2.

		Mean square of excretion as percentage of the intake, %			
Source	df	Ca	K	Mg	Na
Total	3				
Diet	1	330.2	0.5	196.6	234.7
Block	1	5.1	177.6	176.7	43.5
Error	1	6.4	75.7	22.8	51.2
Control vs. LNE	1	330.2	0.5	196.6	234.7
CV, %		3.35	9.14	3.88	2.59

Control: traditional corn-soybean meal diet.
LNE: 4% units reduced CP and 0.1% unit reduced P diet.

Appendix Table 70

Pig means for Fe, Zn, Cu, and Mn excretion as percentage of the intake for the entire finishing period. Exp 2.

			Excretion as percentage of the intake, %			
Room	Diet	Block	Fe	Zn	Cu	Mn
1	Control	1	99	95	120	104
2	LNE	1	117	95	103	103
3	Control	2	90	85	106	92
4	LNE	2	125	89	126	102

Control: traditional corn-soybean meal diet.
LNE: 4% units reduced CP and 0.1% unit reduced P diet.

Appendix Table 71

Analysis of variance for Fe, Zn, Cu, and Mn excretion as percentage of the intake for the entire finishing period. Exp 2.

		Mean square of excretion as percentage of the intake, %			
Source	df	Fe	Zn	Cu	Mn
Total	3				
Diet	1	713.64	3.49	3.57	22.4
Block	1	0.01	59.26	19.48	37.5
Error	1	76.30	4.37	359.67	33.1
Control vs. LNE	1	713.64	3.49	3.57	22.4
CV, %		8.12	2.30	16.67	5.75

Control: traditional corn-soybean meal diet.
LNE: 4% units reduced CP and 0.1% unit reduced P diet.

Appendix Table 72

Pig means for DM, C, N and P cumulative excretion for the entire finishing period. Exp 2.

			Cumulative excretion, kg/pig		
Room	Diet	Block	DM	N	P
1	Control	1	27.4	3.57	0.70
2	LNE	1	30.0	2.44	0.59
3	Control	2	29.7	3.66	0.71
4	LNE	2	29.5	2.08	0.54

Control: traditional corn-soybean meal diet.
LNE: 4% units reduced CP and 0.1% unit reduced P diet.

Appendix Table 73

Analysis of variance for DM, C, N and P cumulative excretion for the entire finishing period. Exp 2.

		Mean square of cumulative excretion, kg/pig		
Source	df	DM	N	P
Total	3			
Diet	1	1.39	1.84	0.02
Block	1	0.83	0.02	0.01
Error	1	1.88	0.05	0.01
Control vs. LNE	1	1.39	1.84	0.02
CV, %		4.70	7.66	4.72

Control: traditional corn-soybean meal diet.
LNE: 4% units reduced CP and 0.1% unit reduced P diet.

Appendix Table 74

Pig means for days on test, initial and final weight, average daily gain, average daily feed intake, feed:gain ratio. Exp 3.

Room	Diet	Block	Days	IBW, lb	FBW, lb	ADG, g	ADFI, g	F:G
1	Control	1	110	65.65	261.84	845	2,235	2.64
2	LNE	1	110	65.69	268.47	834	2,295	2.75
3	Control	2	110	57.35	252.97	843	2,172	2.58
4	LNE	2	110	57.50	251.89	838	2,211	2.64

Control: corn-soybean meal diet.
LNE: 3% units reduced CP and 0.1% unit reduced P diet.

Appendix Table 75

Analysis of variance for days on test, initial and final weight, average daily gain, average daily feed intake, feed:gain ratio. Exp 3

		Mean square					
Source	df	Days	IBW, lb	FBW, lb	ADG, g	ADFI, g	F:G
Total	3						
Diet	1	0	0.01	7.70	69.81	2,397	0.01
Block	1	0	67.98	161.93	0.39	5,375	0.01
Error	1	0	0.01	14.86	9.46	117	0.01
Control vs. LNE	1	0	0.001	7.70	69.81	2,396	0.01
CV, %		0	0.09	1.49	0.37	0.49	0.94

Control: corn-soybean meal diet.
LNE: 3% units reduced CP and 0.1% unit reduced P diet.

Appendix Table 76

Pig means for DM, N and P average daily intake for the entire finishing period. Exp 3

			Average daily intake, g/pig		
Room	Diet	Block	DM	N	P
1	LNE	1	1,906	45.4	7.46
2	Control	1	1,964	54.1	9.95
3	LNE	2	1,853	44.5	7.30
4	Control	2	1,887	52.7	9.61

Control: traditional corn-soybean meal diet.
LNE: 3% units reduced CP and 0.1% unit reduced P diet.

Appendix Table 77

Analysis of variance for DM, N and P average daily intake for the entire finishing period. Exp 3

		Mean square of intake, g/pig		
Source	df	DM	N	P
Total	3			
Diet	1	2,106	71.7	5.76
Error	2	2,157	0.7	8.58
Control vs. LNE	1	2,106	71.7	5.76
CV, %		2.44	1.73	2.19

Control: traditional corn-soybean meal diet.
LNE: 3% units reduced CP and 0.1% unit reduced P diet.

Appendix Table 78

Pigs means for Ca, K, Mg, and Na average daily intake for the entire finishing period. Exp 3

			Average daily intake, g/pig			
Room	Diet	Block	Ca	K	Mg	Na
1	LNE	1	11.5	13.7	2.7	2.7
2	Control	1	15.3	17.5	3.2	2.7
3	LNE	2	11.6	13.9	2.7	2.7
4	Control	2	14.7	16.8	3.1	3.0

Control: traditional corn-soybean meal diet.
LNE: 3% units reduced CP and 0.1% unit reduced P diet.

Appendix Table 79

Analysis of variance for Ca, K, Mg, and Na average daily intake for the entire finishing period. Exp 3.

		Mean square of average daily intake, g/pig			
Source	df	Ca	K	Mg	Na
Total	3				
Diet	1	11.52	11.27	0.18	0.02
Error	2	0.08	0.15	0.01	0.01
Control vs. LNE	1	11.52	11.27	0.18	0.02
CV, %		0.99	0.97	0.96	3.18

Control: traditional corn-soybean meal diet.
LNE: 3% units reduced CP and 0.1% unit reduced P diet.

Appendix Table 80

Pigs means for Fe, Zn, Cu, and Mn average daily intake for the entire finishing period. Exp 3

			Average daily intake, mg/pig			
Room	Diet	Block	Fe	Zn	Cu	Mn
1	LNE	1	27.47	13.50	1.90	5.61
2	Control	1	45.82	24.50	3.89	11.61
3	LNE	2	28.41	12.01	2.10	5.98
4	Control	2	44.47	26.16	4.13	12.59

Control: traditional corn-soybean meal diet.
LNE: 3% units reduced CP and 0.1% unit reduced P diet.

Appendix Table 81

Analysis of variance for Fe, Zn, Cu, and Mn average daily intake for the entire finishing period. Exp 3.

		Mean square of average daily intake, mg/pig			
Source	df	Fe	Zn	Cu	Mn
Total	3				
Diet	1	296.1	158.1	4.04	39.8
Error	2	0.7	1.2	0.02	0.3
Control vs. LNE	1	296.1	158.1	4.04	39.8
CV, %		2.25	5.82	5.32	5.84

Control: traditional corn-soybean meal diet.
LNE: 3% units reduced CP and 0.1% unit reduced P diet.

Appendix Table 82

Pig means for life body weight, hot carcass weight, and backfat depth. Exp 3.

Room	Diet	Block	LBW, lb	HCW, lb	Fat depth 10th rib, cm
1	LNE	1	255	195	0.77
2	Control	1	259	198	0.80
3	LNE	2	244	190	0.79
4	Control	2	250	191	0.85

Control: corn-soybean meal diet.
LNE: 3% units reduced CP and 0.1% unit reduced P diet.

Appendix Table 83

Analysis of variance for life body weight, hot carcass weight, and backfat depth. Exp 3

		Mean square		
Source	df	LBW, lb	HCW, lb	Fat depth 10th rib, in
Total	3			
Diet	1	21.8	3.4	0.002
Block	1	98.3	28.5	0.001
Error	1	0.6	1.2	0.002
Control vs. LNE	1	21.8	3.4	0.001
CV, %		0.29	0.56	0.94

Control: corn-soybean meal diet.
LNE: 3% units reduced CP and 0.1% unit reduced P diet.

Appendix Table 84

Pig means for LMA, carcass yield and fat-free lean percentage. Exp 3.

Room	Diet	Block	LMA, sq in	Carcass yield, %	Fat-free lean, %
1	LNE	1	7.05	76.52	53.16
2	Control	1	7.12	76.49	52.79
3	LNE	2	6.83	78.12	52.68
4	Control	2	7.43	76.65	52.93

Control: corn-soybean meal diet.
LNE: 3% units reduced CP and 0.1% unit reduced P diet.

Appendix Table 85

Analysis of variance for LMA, carcass yield and fat-free lean percentage. Exp 3.

		Mean square		
Source	df	LMA, sq in	Carcass yield, %	Fat-free lean, %
Total	3			
Diet	1	0.11	0.56	0.01
Block	1	0.01	0.77	0.03
Error	1	0.07	0.51	0.10
Control vs. LNE	1	0.11	0.56	0.01
CV, %		3.72	0.94	0.59

Control: corn-soybean meal diet.
LNE: 3% units reduced CP and 0.1% unit reduced P diet.

Appendix Table 86

Pig means for metacarpal breaking strength. Exp 3

Room	Diet	Block	Metacarpal breaking strength, kg
1	LNE	1	174.5
2	Control	1	169.9
3	LNE	2	156.3
4	Control	2	180.0

Control: traditional corn-soybean meal diet.
LNE:3% units reduced CP and 0.1% unit reduced P diet.

Appendix Table 87

Analysis of variance for metacarpal breaking strength. Exp 3.

Source	df	Mean square
Total	3	
Diet	1	90.63
Block	1	16.56
Error	1	2000.22
Control vs. LNE	1	90.63
CV, %		8.32

Control: traditional corn-soybean meal diet.
LNE: 3% units reduced CP and 0.1% unit reduced P diet.

Appendix Table 88

Pigs means for initial body composition. Exp 3

Room	Diet	Block	Water, kg	CP, kg	Ash, kg	Fat, kg	N, kg	P, g
1	LNE	1	19.6	5.75	0.90	5.82	0.92	161.6
2	Control	1	19.3	5.66	0.89	5.75	0.90	159.7
3	LNE	2	16.8	4.73	0.78	5.05	0.76	141.5
4	Control	2	17.1	4.84	0.79	5.13	0.77	143.6

Control: traditional corn-soybean meal diet.
LNE: 3% units reduced CP and 0.1% unit reduced P diet.

Appendix Table 89

Analysis of variance for initial body composition. Exp 3.

		Mean square					
Source	df	Water	CP	Ash	Fat	N	P
Total	3						
Diet	1	0.01	0.01	0.001	0.01	0.01	0.01
Block	1	6.64	083	0.012	0.48	0.02	326.77
Error	1	0.07	0.01	0.001	0.01	0.01	3.76
Control vs. LNE	1	0.01	0.01	0.001	0.01	0.01	0.01
CV, %	3	1.52	1.87	1.42	1.37	1.91	1.28

Control: traditional corn-soybean meal diet.
LNE: 3% units reduced CP and 0.1% unit reduced P diet.

Appendix Table 90

Pigs means for final body composition. Exp 3

			Average daily intake, mg/pig					
Room	Diet	Block	Water, kg	CP, kg	Ash, kg	Fat, kg	N, kg	P, g
1	LNE	1	59.8	20.9	2.91	32.27	3.57	481.3
2	Control	1	60.1	20.6	3.00	31.96	3.48	445.8
3	LNE	2	57.1	18.2	2.63	29.08	3.01	432.7
4	Control	2	57.1	19.4	2.85	28.33	3.27	427.6

Control: traditional corn-soybean meal diet.
LNE: 3% units reduced CP and 0.1% unit reduced P diet.

Appendix Table 91

Analysis of variance for final body composition. Exp 3.

		Mean square					
Source	df	Water	CP	Ash	Fat	N	P
Total	3						
Diet	1	0.01	0.22	0.03	0.28	0.01	411
Block	1	8.35	3.88	0.05	11.63	0.15	1117
Error	1	0.02	0.65	0.01	0.05	0.03	231
Control vs. LNE	1	0.01	0.22	0.03	0.28	0.01	411
CV, %	3	0.22	4.08	2.28	0.74	0.84	3.40

Control: traditional corn-soybean meal diet.
LNE: 3% units reduced CP and 0.1% unit reduced P diet.

Appendix Table 92

Pigs means for water, CP, ash, fat, N and P accretion rate. Exp 3

			g/pig/d					
Room	Diet	Block	Water	CP	Ash	Fat	N	P
1	LNE	1	365	138	18.2	241	24.1	2.90
2	Control	1	372	136	19.2	240	23.5	2.62
3	LNE	2	368	122	16.9	220	20.6	2.67
4	Control	2	363	132	18.7	211	22.6	2.59

Control: traditional corn-soybean meal diet.
LNE: 3% units reduced CP and 0.1% unit reduced P diet.

Appendix Table 93

Analysis of variance for water, CP, ash, fat, N and P accretion rate. Exp 3.

		Mean square					
Source	df	Water	CP	Ash	Fat	N	P
Total	3						
Diet	1	0.76	16.75	2.05	27.32	0.51	0.03
Block	1	7.57	95.57	0.86	617.08	4.70	0.01
Error	1	33.72	34.54	0.19	15.60	1.67	0.01
Control vs. LNE	1	0.76	16.75	2.05	27.32	0.51	0.01
CV, %	3	1.58	4.43	2.39	1.73	5.69	3.85

Control: traditional corn-soybean meal diet.
LNE: 3% units reduced CP and 0.1% unit reduced P diet.

Appendix Table 94

Pig means for DM, C, N and P average daily excretion for the entire finishing period. Exp 3.

			Average daily excretion, g/pig				
Room	Diet	Block	DM	C	N	NH_4-N	P
1	LNE	1	264	109	23.0	13.2	3.97
2	Control	1	289	115	32.6	20.9	6.03
3	LNE	2	255	122	23.6	12.9	4.21
4	Control	2	297	137	24.3	20.1	6.37

Control: traditional corn-soybean meal diet.
LNE: 3% units reduced CP and 0.1% unit reduced P diet.

Appendix Table 95

Analysis of variance for DM, C, N, NH_4-N and P average daily excretion for the entire finishing period. Exp 3.

		Mean square of average daily excretion, g/pig				
Source	df	DM	C	N	NH_4-N	P
Total	3					
Diet	1	1126	105	102.4	55.85	4.45
Error	2	34	160	0.8	0.15	0.04
Control vs. LNE	1	1126	105	102.4	55.85	4.45
CV, %		2.13	10.49	3.21	2.30	0.98

Control: traditional corn-soybean meal diet.
LNE: 3% units reduced CP and 0.1% unit reduced P diet.

Appendix Table 96

Pig means for Ca, K, Mg, and Na average daily excretion for the entire finishing period. Exp 3.

			Average daily excretion, g/pig			
Room	Diet	Block	Ca	K	Mg	Na
1	LNE	1	5.97	11.99	2.74	4.70
2	Control	1	7.79	15.13	3.04	4.42
3	LNE	2	5.92	12.50	2.75	4.23
4	Control	2	8.11	16.36	3.11	4.38

Control: traditional corn-soybean meal diet.
LNE: 3% units reduced CP and 0.1% unit reduced P diet.

Appendix Table 97

Analysis of variance for Ca, K, Mg, and Na average daily excretion for the entire finishing period. Exp 3.

		Mean square of average daily excretion, g/pig			
Source	df	Ca	K	Mg	Na
Total	3				
Diet	1	4.04	12.28	0.11	0.01
Error	2	0.03	0.44	0.01	0.06
Control vs. LNE	1	4.04	12.28	0.11	0.01
CV, %		2.33	4.75	1.33	5.37

Control: traditional corn-soybean meal diet.
LNE: 3% units reduced CP and 0.1% unit reduced P diet.

Appendix Table 98

Pig means for Fe, Zn, Cu, and Mn average daily excretion for the entire finishing period. Exp 3.

			Average daily excretion, m/pig			
Room	Diet	Block	Fe	Zn	Cu	Mn
1	LNE	1	246	131	26.8	56.2
2	Control	1	432	257	37.9	92.2
3	LNE	2	234	113	22.2	52.6
4	Control	2	478	289	40.7	101.7

Control: traditional corn-soybean meal diet.
LNE: 3% units reduced CP and 0.1% unit reduced P diet.

Appendix Table 99

Analysis of variance for Fe, Zn, Cu, and Mn average daily excretion for the entire finishing period. Exp3.

		Mean square of average daily excretion, mg/pig			
Source	df	Fe	Zn	Cu	Mn
Total	3				
Diet	1	46357	22857	219	1813
Error	1	348	197	7	25
Control vs. LNE	1	46357	22857	219	1813
CV, %		6.85	9.19	8.30	6.72

Control: traditional corn-soybean meal diet.
LNE: 3% units reduced CP and 0.1% unit reduced P diet.

Appendix Table 100

Pig means for DM, N, NH_4-N, and P average daily excretion for the entire finishing period. Exp 3.

			Average daily excretion, g/pig			
Room	Diet	Block	DM	N	NH_4-N	P
1	LNE	1	264	23.0	13.2	3.97
2	Control	1	289	32.6	20.9	6.03
3	LNE	2	255	23.6	12.9	4.21
4	Control	2	297	34.3	20.1	6.37

Control: traditional corn-soybean meal diet.
LNE: 3% units reduced CP and 0.1% unit reduced P diet.

Appendix Table 101

Analysis of variance for DM, N, NH_4-N and P average daily excretion for the entire finishing period. Exp 3.

		Mean square of average daily excretion, g/pig			
Source	df	DM	N	NH_4-N	P
Total	3				
Diet	1	1126.0	102.4	55.85	4.44
Error	2	34.9	0.8	0.15	0.04
Control vs. LNE	1	1126.0	102.4	55.85	4.44
CV, %		2.14	3.21	2.29	4.05

Control: traditional corn-soybean meal diet.
LNE: 3% units reduced CP and 0.1% unit reduced P diet.

Appendix Table 102

Pig means for air flow and ammonia emission for the entire finishing period. Exp 3.

Room	Diet	Block	Air flow m^3/min	NH_3 Emission mg/ m^3	mg/min	g/pig/d
1	LNE	1	771	0.34	10.17	814
2	Control	1	748	0.81	27.87	2148
3	LNE	2	755	0.50	15.43	1223
4	Control	2	789	0.92	31.70	2489

Control: traditional corn-soybean meal diet.
LNE: 3% units reduced CP and 0.1% unit reduced P diet.

Appendix Table 103

Analysis of variance for Pig means for air flow and ammonia emission for the entire finishing period. Exp 3.

		Mean square of			
		Air flow	NH_3 Emission		
Source	df	m^3/min	mg/ m^3	mg/min	g/pig/d
Total	3				
Diet	1	29.76	0.20	288.48	1691060
Block	1	130.95	0.02	20.68	140634
Error	1	831.38	0.01	0.52	1126
Control vs. LNE	1	29.76	0.20	288.48	1691060
CV, %		3.77	3.82	3.39	2.01

Control: traditional corn-soybean meal diet.
LNE: 3% units reduced CP and 0.1% unit reduced P diet.

Appendix

Determination of P content in feed and slurry samples using the quinolinium molydophosphate method (AOAC, 1998). Phosphorus concentration was determined in all feed and slurry samples. Acid cleaned, dry, quartz, 120 ml beakers were used. For feed analysis, approximately, 2.5 g of feed were weighed into thebeaker. For slurry analysis, an aliquot of 5 ml was transferred to the weighed and tarred clean beaker; and the weight of the 5 ml of slurry was recorded (ranged from 5 to 6 g). After weighing the sample, the procedure for determination of P content was similar for feed or slurry samples. Samples were ashed during 4 h at 550^{o}C. Samples were allowed to cool down, and 40 ml of a 25% v/v HCl solution were added. Followed, solution was placed over a hot plate set at 500^{o}C and brought to a boil. After cooling, the digested ash solution was transferred to a 250 ml volumetric flask. The matrix solution was diluted to volume with distilled-deionized water and mixed thoroughly. An aliquot of 50 ml of the diluted sample solution was transferred to a clean, 250 ml Erlenmeyer flask, and 25 ml of distilled-deionized water were added. This solution was brought to a boil and 50 ml of Quimociac reagent (appendix, table) added very slowly. Phosphorus contented in the sample was precipitated with the addition of the Quimociac reagent, the solution was brought to a boil, removed from the hot plate, and allowed to cool down. After cooling, the solution was filtered into a weighed, dry, gooch filter crucible with a glass fiber prefilter (Millipore Serie AP40, 0.5 to 0.6 mm of thickness, 247 to 456 sec/ 100 ml of flowrate, distributed y Fisher Scientific, Cincinnati, OH). The Erlenmeyer was

carefully rinsed with distilled-deionized water to ensure that no precipitated was leaf attached to the flask. The gooch crucible with prefilter and P precipitate were placed in the oven for at least 8 hours at 100 ^{o}C. After cooling down, the crucible with precipitate was accurate weighed, and it weight used to calculate content of P in the sample expressed as percent. The following formula was used:

%P = ((Wt of P precipitate, g x 250 ml)/50 ml) x ((0.013997 x 100)/sample Wt, g)

Appendix table 104

Preparation of Quimociac reagent and suggested aliquot of sample matrix solution, and Quimociac reagent to use based on anticipated P concentration in the sample.

Step y step Quimociac reagent preparation (2 litters):

1. Place a liter Erlenmeyer flask on a magnetic stirrer and insert a 1” Teflon covered bar magnet.
2. Add 300 ml distilled deionized water.
3. Add 127.6 g dihydrate citric acid (or 107.8 g of anhydrous citric acid, or 117.9g monohydrate citric acid) while stirring.
4. Add 170 ml concentrated nitric acid to the citric acid solution and allow cooling.
5. In a 1 liter Erlenmeyer flask, dissolve 140 g sodium molydate in 300 ml distilled deionized water with a magnet stirrer and stir bar.
6. Slowly add the molydate solution to the citric-nitric solution with stirring.
7. In a 250 ml Erlenmeyer flask, add 10 ml synthetic quinoline to a mixture of 200 ml of distilled deionized water and 70 ml concentrated nitric acid.
8. Slowly add the quinoline solution to the molydate- citric-nitric acid mixture, mix well, and let stand for 24 hours.
9. Filter y siphon into a 2 liter Erlenmeyer filtering flask. Use a large Büchner-type filtering funnel and No. P8 filter paper (Fisher scientific, Cincinnati, Oh).
10. Transfer filtered solution to a 2-liter volumetric flask.
11. Add 560 ml C. P. acetone.
12. Dilute to 2 liters with distilled deionized water and thoroughly mix.
13. Store in a polyethylene bottle with a lid.

based on anticipated P concentration in the sample is suggested the following aliquots of sample matrix solution, and Quimociac reagent:

Anticipated sample P content, %	Aliquot of sample matrix solution, ml	Aliquot of Quimociac reagent, ml
0-4	50	50
4-6	25	50
6-15	10	50
15-30	10	100

VITA

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Candidate for the Degree of

Doctor of Philosophy

Thesis: MASS BALANCE OF NUTRIENTS FOR THE SWINE FINISHING PHASE: EFFECTS OF DIETARY MANIPULATION ON NUTRIENT RETENTION, NUTRIENT EXCRETION, AND GASEOUS EMISSIONS

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Title of Study: MASS BALANCE OF NUTRIENTS FOR THE SWINE FINISHING PHASE: EFFECTS OF DIETARY MANIPULATION ON NUTRIENT RETENTION, NUTRIENT EXCRETION, AND GASEOUS EMISSIONS

Pages in Study: 264 Candidate for the Degree of Doctor of Philosophy

Major Field: Animal Nutrition

Scope and Method of Study: A total of 3 experiments were conducted to evaluate the effects of reducing dietary CP, P, and trace minerals on DM, N, P and mineral excretion, and ammonia and hydrogen sulfide emissions during the finishing period. The control was a fortified corn-soybean meal-based diet. The experimental diet was a low nutrient excretion (LNE) diet similar to the control with the exceptions that CP (2% units in Experiment 1, 4% units in Experiment 2, and 3% units in Experiment 3) and P (0.1% units in the 3 experiments) were reduced, phytase added (Experiment 3), and trace minerals sequentially reduced (Experiment 3).

Findings and Conclusions: The LNE diet with 2% units reduction in CP reduced daily N and P excretion by 20% and 24%, respectively, and tended to reduce cumulative N and P excretion in a similar proportion. However, feeding LNE with 2% units reduction in CP had little effect on daily and total mineral excretion during the finishing period. When CP was further reduced by 4% units, daily N and P excretion was reduced by 40 and 25%, respectively, and cumulative N and P excreted for the entire period by 1.36 and 0.14 kg/finished pig, respectively, during a 112-day finishing period. When CP was reduced by 3% units, P by 0.1% unit, phytase added, and trace mineral inclusion reduced, nutrient excretion and ammonia emission was markedly decreased during the finishing period. The proportion of N and P entering the finisher that exited via the pigs increased from 47 to 58% for N and 37 to 48% for P for pigs fed LNE compared with those fed the control. These results suggest that reductions in dietary CP, P and trace minerals in growing-finishing diets markedly decreased DM, N, P and mineral excretion, and ammonia emission, without affecting pig growth performance or fat-free lean gain. Therefore, dietary manipulation is an effective strategy to reduce nutrient excretion and ammonia emissions simultaneously.

ADVISER'S APPROVAL: Scott Carter